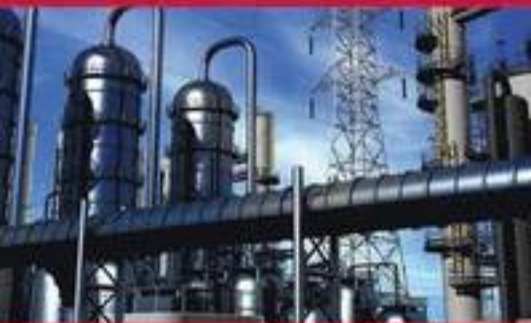


# Process Engineering and Industrial Management



Edited by Jean-Pierre Dal Pont

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Edited by  
Jean-Pierre Dal Pont

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## Foreword

Process engineering, the science and art of effectively transforming feedstock materials into commercial products, was born in the 19th Century. Its origins can be found further back in the course of history: fermentations, distillations, macerations, and extractions enabled our remote ancestors to enjoy edible, potable, and pharmaceutically active substances, as mining, grinding, mixing, and smelting produced metals to be worked up into useful products – swords as well as ploughs. But it was only with the quantitative description of chemical science in the 19th Century that the engineering of processes could be put on a rigorous basis. The great chemist, Antoine Lavoisier had shown the way when he formulated the law of conservation of mass in 1789. The subsequent development of thermodynamics initiated by Lazare Carnot and continued by Clausius, Kelvin, Gibbs, and others, gave us the framework for designing efficient processes. As a result, by 1900 the world's production of basic chemicals like sulphuric acid was measured in millions of tonnes, and a vast range of new products, from dyestuffs to aspirin became available to the general public.

And so our profession has continued to develop, with the new science and technology enabling new processes to make new products, and new requirements stimulating new discoveries and more innovation. In parallel, *process engineering* itself has developed its own methods, theorems, terminology, and literature, organising and recording the advances made and applied.

The role of the industrial company in the history of process engineering is an honourable one, and we can be proud of the way in which the products we make have contributed to the health, welfare, and quality of life of the world's population. We have, it is true, suffered some terrible accidents, and we have been slow, in some cases very slow, to recognise the effects of our activities on the environment. But we can also be proud of the contribution of process engineers in introducing better approaches to industrial safety and environmental protection. "Systems thinking" with its imperative to look at the whole problem – the complete lifecycle, the entire

supply chain, the integrated plant – is a grand discipline for dealing with complex issues far beyond the limits of the chemical and process industries.

There are many texts dealing with the technologies of our profession, from reactor engineering to process control, but there are surprisingly few which deal with process engineering in the context of an industrial company, as this book does. That context is really important, as Industry has a vital role in solving the problems of excessive reliance on fossil fuels, meeting the challenge of sustainable development, exploiting the opportunities provided by the revolutions in biotechnology and information technology, and harnessing the power of change and innovation – the big issues of our time.

The authors have combined to write an authoritative account of process engineering and the business company, based on their extensive practical experience. It is a *tour de force*. I commend it to students, teachers, and practitioners alike. Read on!

Richard DARTON  
President, European Federation of Chemical Engineering  
OBE (Order of the British Empire)

## Foreword

This book *Process Engineering and Industrial Management*, that Jean-Pierre Dal Pont has coordinated and to which he has widely contributed, is undoubtedly one of those books that an honest industrial man must read.

It is in fact the result of the experience of more than 30 years that Jean-Pierre Dal Pont has devoted to industry, in Europe, USA, and Asia Pacific.

For over a century, the industrial company has been the source of almost all the innovations that make our day-to-day life. It has been able to implement the process engineering technologies widely exhibited in this book, organize, and create new businesses beyond its original boundaries.

Currently, it is still the industrial company to which we must turn to face the challenges of the century: to fight hunger, to constantly improve people's health, to solve energy challenges, to protect the environment, and so on.

Now, the depletion of fossil resources (oil, gas, metals, etc.) compels us to imagine and implement radically new solutions.

The techniques of process engineering in this book by Jean-Pierre Dal Pont, as well as those relating to the project management, to the analysis of life cycle, or to TQM are those which are now used in industry and which enable our factories to remain competitive.

The book also questions the condition of the plant in the future, how it needs to be flexible, ever more environmentally friendly, and integrated into society to contribute to harmonious development.



This manufacturing plant will implement microtechnologies and intensified processes using more and more new techniques for modelization, simulation, and communication.

The book is a source of information and reflection for the students, engineering students, and professionals who have to study, develop the processes, build, and operate industrial tools. It will promote dialog among people in charge of marketing, human relations, finance, and technicians of process engineering whether they are from academia or industry.

The future of our society depends on the necessary *reorganization* of industry. It is a tribute to this book, that it contributes to the understanding of it.

Jean PELIN  
Executive Director of Chemical Industries Association

## Introduction

# Process Engineering and Industrial Management: Industrial Projects and Management of Change

This book is a collection of the experiences of professionals from the academic and industrial worlds.

The book aims to explain what a company is, demonstrate its mechanisms and organization, and explain the processes that are at the root of its evolution. Its purpose is to depict the importance of process engineering in companies, whose mission is the transformation of matter and energy, and to define its contribution to the evolution of society.

This book is intended for students, to assist them in their research projects. By providing the basis for process development in the laboratory, and engineering techniques, it will serve professionals who design production tools, make them work, and improve them.

Lifecycle analysis, process assessment methods, progress techniques and the basics of risk management complement the range of essential tools for the engineer, who was considered to be the honorable man of the 19th Century, and is anxious to assert his role in society.

This book is not meant to be a project management guide or a book dedicated to business strategy for students in business schools.

---

Introduction written by Jean-Pierre DAL PONT.

It is above all a general book, a book of reflection in which the reader can benefit from the basic knowledge scattered across multiple works.

It rests on two essential pillars: process engineering and the company.

The concept of process engineering followed the concept of chemical engineering which originated in the United States during the early 20th Century when the oil industry was in the development stage. It accompanied the extraordinary growth of the chemical industry, in particular, during and after World War II. This concept, developed by the late Jacques Villermaux, Professor at the ENSIC (National School of Chemical Industries, Nancy, France), was based on the fact that chemical engineering techniques can be applied to all process industries, that is to say all industries that can transform matter and energy; pharmaceuticals, biotechnology, paper, cement, the environment, energy, metallurgy, cosmetics industries, and so on.

It received its consecration at the first congress held in Nancy, France in 1987. The GFGP (French Group of Process Engineering) was founded in 1988, and in 1997 became the SFGP (French Process Engineering Society), a learned society whose mission is to promote process engineering.

Manufacturing industry deals with the production of “discrete” goods with defined outlines (automobiles, electronic appliances, construction industry, etc.). Many chemical products of all kind are used in the processes of this industrial sector.

A European car uses 130–190 kg of plastics, silicones, paints (5 kg), oils (4 kg), and glass (90–140 kg).

Process and manufacturing industries have much in common whether it is management, strategic approach, how projects are led, concept of sustainable development, risk management, and so on.

The industrial company, as we presently know it, was shaped during the 18th Century. As early as 1712, blacksmith Thomas Newcomen’s atmospheric steam-engine enabled the use of mines by pumping out water that flooded them frequently. During the 19th Century, the Industrial Revolution expanded rapidly in Britain due to the industrial use of steam.

France, Germany, and the United States followed suit from the mid-19th Century.

Players in the Industrial Revolution raised their capital to move from inventions toward innovations, of which the railways are perhaps the best illustration. They invested by taking risks to create the most diverse machines which enabled them to create wealth. These enormous changes wreaked total havoc on predominantly rural

societies as well as on the environment. In Britain, the first industrialized country, it was not until the late 19th Century that the average individual started enjoying the benefits of industrialization.

Extraordinary characters who were active between the 19th and 20th Centuries, such as Edison, Ford, Fayol, Taylor, to name but a few, invented the basics of company management which are still in use today.

The company that we are focusing on is essentially the industrial company which can be distinguished from service companies by the fact they use an industrial tool. That distinguishes them from service companies.

To take an example: an industrial company will use its know-how in process engineering to transform fossil resources and biomass into all sorts of chemicals, pharmaceuticals, transportation means, power generators, and so on, to offer society an increasing number of goods and services that are essential for human well-being.

The company today is still a source of wealth and well-being but may also be a source of harm to both humans and the environment. The company must take itself to task.

It is faced with a situation that is unprecedented in the history of mankind, and subjected to considerable changes. The company, through its innovations, causes societal change at a rate never seen before.

Let us cite some of the most critical challenges faced by our societies:

– the depletion of raw fossil materials with increasing costs due to their location in inhospitable areas or politically unstable countries: oil, copper, lithium, rare earth minerals, and so on;

– developed countries had become accustomed to abundant energy at a low price, which in addition to comfort, which gave us a sense of unprecedented freedom where mobility is the most visible consequence. Those days are gone!

– water scarcity. Water is life! A billion people do not have a sufficient quantity and quality of water. This water imbalance has led to water borne diseases especially in young children, and this may become a source of conflict if planned efforts are not implemented worldwide! 500 million people live in the Brahmaputra basin. Tibet is the water tower of Asia! The White Nile and Blue Nile pass through 10 countries! The Turkish project, called Anatolia of the South-East, includes 22 dams; giving Turkey control of the Tigris and the Euphrates!

– global warming is subject to controversy, but its effects are already manifesting themselves! Examples of global warming include melting glaciers, melting ice packs, vegetation change, rising sea levels, and so on;

– population growth is putting an increasingly strong pressure on the environment and is accentuating a significant discrepancy in wealth between countries. The aging of the population in some of the developed countries such as Japan, Germany, and Italy is another source of imbalance whose effects are already being felt.

The current economic crisis which originated with the bankruptcy of Lehman Brothers in September 2008 took the world by surprise. It highlighted the complexity and opacity of the banking systems.

Presently, trust has not been restored. The industrialized world hopes that only growth can create wealth and jobs. This requires consumption leading to a loss of raw materials, and increased adverse human impact on the environment. Has not the world returned to a paradoxical, even inconsistent, economic and industrial process?

Globalization has jostled the balance arising from the Europeanization of the world following the conquests of the Portuguese in the 15th and 16th Centuries which was then followed by Spanish, British, French, and German imperialism. Currently, China has emerged as the banker of the United States and the workshop of the world. What a change!

The company, faced with increasingly demanding customers in a world under media scrutiny, where everything goes faster and where competition, especially under the impact of emerging countries, is intensifying, should review its strategy in a timely manner. This strategy can be simply defined by answering the following questions:

- in which markets should we remain, which should we expand, or abandon?
- which technologies should be used, which means of production and distribution should be implemented?

Answers to these questions result in a strategic plan for the company. This plan underpins a portfolio of research projects, investments, and disinvestments of structural changes.

Its implementation requires knowledge of company operations, project management, and the industrialization process. These areas implement process engineering and the engineering of which it is a component.

The company must ensure the smooth running of operations that frees up the profit essential to its survival, and also manage the change resulting from its strategic vision.

Change management is implementing processes that rely on hard techniques and the most advanced social and human sciences; part of the book is devoted to this.

The societies of industrialized countries are based on science and technology.

The IT revolution is not over; the petaflops computer has arrived! Along with a society based on IT, a new forward-looking concept can now be added: a society based on knowledge.

The employee, to face this changing world, will be forced to undergo training throughout his lifetime.

*Knowledge management* has been made necessary because of the abundance and fragmentation of knowledge generated by the increasing complexity, the proliferation of technology, and by the mobility of required or subjected individuals.

The concept of sustainable development is not the latest media concept in fashion. The company is aware that our present behavior will affect the lives of future generations.

The development of new products and services must be considered. There arises a question about the future, it is the question of what we want to produce: where and how we want to produce it? These questions require the company to reconsider its research, industrialization, production, and distribution processes in a spirit of continuous improvement and innovation.

The reconciliation of the company, customer, and its suppliers will continue. It will also be closer to society and the communities where it operates. In a transparent company, “citizen” is not an empty word. The company will always be judged based on its profit, but this will not be the only criteria.

Man is more than ever at the center of the mechanism! A position he should have never left!

We increasingly ask the question about “circular” economies based on the rational use of raw materials, where their recycling is made easier by launching “green” eco-designed products on to the market.

Will it be otherwise?

A new industry needs to be invented with new processes and new “sustainable” equipment.

This would be a new industrial revolution! Chemistry and process engineering are essential for its deployment! “Chemistry is our future”, said Thomas Alva Edison ... That was a century ago!

The future today is tomorrow!

**Note to reader**

The chapters can be read separately and are grouped into three parts:

– *the company today*: brief history, description of its structure, and mode of operation;

– *process development and industrialization*: methods to incorporate the laboratory research into an industrial tool to meet current expectations;

– *the need to adapt the company for the future*: this last part aims to explore the methods necessary for organizations to define, develop, and improve competitive industrial tools.

## Acknowledgments

This book is the result of a long process that started 40 years ago, when my late master, Pierre Le Goff, Professor ENSIC, asked me to return to school for a conference on distillation; he thought that I could bring out the views of a person from the industry!

This liking for contact with the academic research and teaching, and students and much more, process engineering, has never left me.

I am grateful to Jean-Claude Charpentier, whose successful career and dynamism is well known for supporting me from the beginning in this “parallel career” only interrupted by 6 years of expatriation to the United States and 5 years to Asia Pacific and which extends within the SFGP (French Process Engineering Society).

Jacques Villermaux, who vanished too soon and was the founder of GFGE (French Process Engineering Society), which later became SFGP, internationally recognized visionary, encouraged me, on my return from the United States in 1989 to do an industrial, managerial conferences, rather than technical ones.

The aim of this book is to juxtapose the academic point of view, cautiously left to teachers–researchers, and the industrial point of view that I acquired after 7 years of technical research, 10 years in manufacturing, and then working as an industrial manager in the United States, France, and Asia.

I want to thank the following school principals and their deputies for having opened the doors of their schools and for having advised me in my brief but strong interventions with students:

– Michel Roques, founder and director of the ENSGSI of Pau;



– Alain Storck, Michel Dirand, Michael Matlosz, successive directors of the ENSIC;

– Thérèse Gibert and George Santini of ESCOM;

– Renaud Gicquel, Jérôme Gosset, Alain Gaunand, Didier Mayer, director of Energy and Process Engineering department from the Ecole des Mines de Paris and Alain Gaunand. I owe a special thanks to Jérôme Gosset, who gave me a course on the management of change while completing my course on project management.

I extend my warmest thanks to Mr. Louis Faton, CEO of Faton publishers specialized in journals and books of art and history and magazines for young people, which allowed me to reproduce some of my eight articles published by Clartés<sup>1</sup> publishers.

I would also like to thank the Encyclopedia “Techniques de l’Ingénieur”, which allowed me to reproduce a few excerpts from my article AG 10 and figures from the article AG 3,300 of M.C. Charrier “Implementing Projects in an Engineering Company”. Readers will find in this Encyclopedia many references to articles published in these editions, a genuine anthology of sciences for the engineer.

I express my gratitude to Michel Royer, friend and former colleague without whom this work could not have been completed, for his contribution to certain chapters, the patient work of compilation of my articles and lectures and bibliography searches and assistance for layout of documents.

This book would not have achieved its goal without the contribution of the co-authors who have provided their scientific components.

Dr. Richard Darton and Jean Pelin, UIC Executive Director, gave me confidence and prefaced the book: in this work I express my gratitude for the honor they have given me.

I also thank Sophie Jullian for supporting the IFP Énergies Nouvelles; Yves Roule, who encouraged me use his expertise in engineering; Jacques Breysse, Philippe Tanguy, and Didier Caudron for their advice; and Jack Legrand, who encouraged me and recommended me to the publisher.

Alexandra Pere-Gigante and Genevieve Roques have helped me in completing this manuscript. My warm thanks to them.

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<sup>1</sup> These items are only available at the Bibliothèque Nationale de France.

As I have already pointed out, this book is not the work of a specialist but is intended as a book of introduction, thought and, if I may, of passion, striving to provide sources of solutions to the problems that raise questions and concerns in current society.

I owe this passion to all those with whom I have spent my professional life: I thank and dedicate this work to them.

Jean-Pierre DAL PONT

PART 1

## The Company as of Today

## Chapter 1

# The Industrial Company: its Purpose, History, Context, and its Tomorrow?

The industrial company, as we know it, dates back almost 100 years. However, the understanding of technical issues, the customer–supplier relationship, and the place of the individual within the company have changed dramatically. At the beginning of this century, the consideration of sustainable development, depletion of fossil materials, and climate change require new approaches where innovation plays a decisive role.

Existing enterprises in liberal countries, or even countries that claim to represent socialist systems such as China, have very common characteristics due to their structure, mode of organization, and operation; these enterprises are based on capitalism that can be defined as a system “based on individual investments to produce marketable goods” [APP 10].

This is the type of company that we will be discussing.

The 18th Century witnessed the birth of the entrepreneur who risked his capital in the hope of achieving profit.

One cannot separate the company from its historical, social, economic, and environmental contexts. It is necessary to go back several centuries to understand the company today; its beginning was slow when compared to the rapid changes that have affected us relentlessly since the beginning of this century.

*A flashback* to the past will help us to throw light on the future.

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Chapter written by Jean-Pierre DAL PONT.

### 1.1. Purpose, structure, typology

The purpose of the industrial company is to satisfy customers by selling them products coming from manufacturing tools, sometimes with services required for their use: after-sale customer service, technical support, possible reclamation after the use of by-products generated by the process if they are chemical products.

In the manufacturing (automotive, electrical equipment, audio visual, etc.) industry, the recycling of all or a part of equipment takes the form of a genuine *fully fledged industry*, due to the depletion of certain raw materials such as copper, rare earth elements and due to their cost, which keeps on increasing.

It is the existence of manufacturing means that distinguishes the industrial company from service corporations, such as banks, insurance companies, food service companies, and so on. The borderline between these two concepts is not clear cut. The kitchens of a food service company make up an industrial tool, thereby requiring maintenance and energy; this tool can be the source of environmental damage (smells, smoke, waste) which must be controlled using chemical processes.

The industrial company makes increasing use of subcontracting for executing non-strategic tasks, that is tasks which are not a part of the enterprise's business. If security, cleaning, catering, and so on, can be rightly classified under this category, it is questionable whether the outsourcing of maintenance, instrumentation, inspection, utility production and sometimes, the complete manufacturing of the finished product is safe. There could be loss of control of know-how and project management.

The products marketed by the company originate from its research and development services and engineering and design departments or have been acquired from third-parties via patent or license purchases. The know-how and knowledge accumulated over the years are thus one of the essential characteristics in this type of organization.

At the initial stage of the company, there are generally one or more individuals who are willing to start out – the entrepreneur(s) – with reasons as diverse as the desire to buy their independence, sometimes by alienating themselves, to earn money and notoriety, to develop themselves, and so on.

The company is a *human venture*.

Industrial enterprises are vastly diverse. Can we compare General Motors, a skilled tradesman working alone or with a partner, an IT multinational, a pharmaceutical company or a building firm with 20 employees? What these enterprises have in common is the act of implementing financial, human, and intellectual means. The intellectual means recovered by the implemented technologies differentiate them from the original input.

**1.1.1. The four pillars of the company**

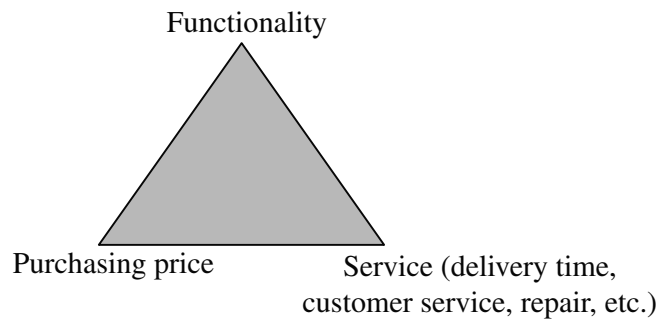
Any company is supported by four pillars: economic, financial, human, and legal.

**1.1.1.1. The economic pillar: the product/market relationship**

The concept of product/market relationship is currently the very basis of the economic concept.

The product is what the company offers on determined markets (automotive, electrical goods, audiovisual, construction, etc.) where it will face competition.

What the customer wants (Figure 1.1) is a product that meets his requirements, this is its *functionality*.

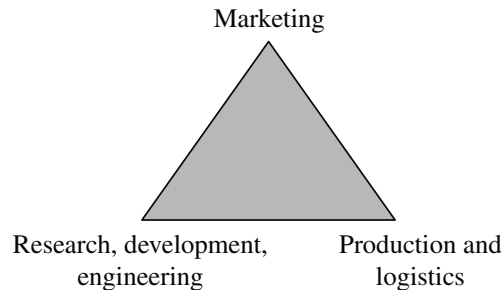


**Figure 1.1.** *The product seen by the customer*

The primary function of an automobile is, but not limited to, transportation. The customer also wants to spend as little as possible while being served quickly and assured of support from the supplier (after-sale customer service, repair, etc.).

Success at the company level (Figure 1.2) is based on another tripod:

- marketing that aims to analyze the markets in order to identify the customer’s requirements;
- research and development (R&D) in charge of designing the product and the engineering (engineering and design department), which must define the industrial tool and have it built;
- production and logistics, whose mission is the creation of the product and making it available to the customer, in other words, the distribution.



**Figure 1.2.** *The product seen by the company*

A wobbly *tripod* is a source of failures and disappointments. A product may be excellent, perfectly respond to demand, but if the plant that manufactures it is unreliable (breakdowns, repeated strikes, etc.), then the customer is tempted to look for another source of supply.

#### 1.1.1.2. *The financial pillar*

Right from its creation, the company has required stable resources. This cash requirement is covered by the capital, which is provided by the entrepreneur and his associates, if any, and by loans taken mostly from the banks. This is the liability of the company.

The entrepreneur takes a risk that he shares with his shareholders.

He, therefore, has a *duty to achieve a given result (profit)* to pay for the capital loaned.

The company is the permanent seat of exchanges:

– *expenses*, caused by the production and distribution; and

– *revenues* generated by sales. The company must have money at all times: this is the treasury. The initial economic difficulties faced by an company are always at the treasury level. The inability to pay implies the suspension of payment.

#### 1.1.1.3. *The human pillar*

Employees are considered the first asset of the company. They are the individuals who run the company and make it evolve; they dedicate the largest part of their everyday life to it, often carrying with them a sense of pride.

The company provides a social status: it is a source of development, satisfaction but sometimes also of imbalance, frustration, alienation, and even illness. Work

forms an integral part of life; to assert this, all we have to do is listen to what the unemployed have to say. All enterprises state that their greatest capital is human capital, but how many of them practise what they preach? Stress, various occupational illnesses, suicides, and acts of violence are dreadful indicators of deep problems.

#### 1.1.1.4. *The legal pillar*

The legal form of the company defines the hierarchy within the company and the relationships with third-parties.

The company has the obligation to accept the laws of the countries where it operates, be it only for the quality of the products that it sells there, which must respect some rules and adhere to certain codes. In capitalist economy countries, there are several types of companies: partnerships, joint stock companies, cooperative enterprises, and so on.

Most companies are *corporations*, whereas the individual is a *physical person*. Owing to this corporation status, the company has the right to have capital, to sign contracts, buy, sell, use, and so on.

### 1.1.2. *Typology of enterprises*

Enterprises can be classified according to several criteria. Besides the legal form that we have just described, enterprises are most often characterized by their size and the nature of their job stream.

#### 1.1.2.1. *The size of the company*

This is the most important and most accessible criterion. It gives the company its power, its local, national, and international impact, and its ability to influence its field of activity.

The size of the company can be measured by the amount of capital, turnover, and by the number of employees.

French regulation distinguishes 4 categories of enterprises based on their size:

- small office/home office (SOHO) with less than 10 employees;
- small and medium-sized enterprises (SME) with 10–249 employees;
- mid-sized enterprises with 250–4,999 employees;
- large enterprises, which employ more than 5,000 employees.



#### 1.1.2.2. *The enterprise's business*

Enterprises, excluding non-financial or insurance companies can be industrial, commercial, agricultural, or service providers.

The company can belong either to the private sector or to the public sector (as with national energy or transport suppliers such as the Private – DOW Chemicals and the Public – NASA). The major technological breakthrough in information technology, especially with the Internet, and the significant interest in genetics have led to the creation of start-up companies. This is the domain of “venture” capital: the shareholder expects significant returns, given the nature of innovative products ... which need to be invented.

### **1.2. A centennial history**

One cannot separate the history of today's company from the historical context of the last 6 centuries. The extraordinary exploration of the planet by men goes hand in hand, over time, with increasing technological discoveries.

The resulting innovations impacted on companies on a permanent basis.

The Age of Enlightenment brought about a revolution of ideas and the reconsideration of age old social systems.

The discovery of unprecedented mineral wealth (gold, silver), the use of unknown crops in Europe (sugarcane, cotton), not to mention silk, spices and furs, transformed companies. This influenced events by endowing some of the nations with powers that were not possessed by conquered countries; supremacy of transportation, where sea transport was practically the only viable mode of travel till the mid-19th Century, supremacy of weapons (rifle against bow, rapid-fire gun against primitive gun).

We must also take into consideration the importance of the quality of administrative and organizational systems and of the management that enables the efficient use of technical and human resources. It remains perplexing that England (excluding Scotland and Wales), populated by only 5–6 million people in the 18th Century, was able to conquer a country like India with 40 times as many people.

#### **1.2.1. *The Europeanization of the planet***

Man, since time immemorial, has continued to migrate, to go further, driven by a desire for material and the quest for knowledge, or pushed by the need to move to escape famines, enemies, and disasters. Every human group has always tried to enslave its neighbors, to enforce its laws or its ideology on them: the missionaries have always accompanied the warriors.

Globalization as we observe it today has transformed the world into a single stage. In fact, globalization commenced in the late 15th Century with the discovery of America by Christopher Columbus, who landed in the Caribbean in 1492. Subsequently, the Portuguese, Spanish, French, English, and Dutch competed for vast territories.

The conquerors of these countries were able to control the Americas, Africa, and Australia; they imposed the culture and language of their native country, for better or worse; they exchanged goods, precious metals, techniques, animals, plants, and so on, as well as diseases with devastating effects. From the Pre-Columbian populations estimated at 90–110 million inhabitants, only 10% would survive the invaders [APP 10].

It is interesting to note that massive wealth acquired far away had very little impact on the lifestyle of some of the colonizing countries. The Spanish *hidalgos* despised trade, while a French nobleman derogated himself by being involved in trade.

Japan and China remain as special cases; we will analyze them later.

It is from the mid-18th Century that the great discovered territories experienced unprecedented growth, along with expansion of Europeanization. This standardization of the planet proceeded hand-in-hand with the Industrial Revolution and population growth.

Thirty million Europeans emigrated between 1880 and 1914, mainly to the United States, which accommodated the underprivileged and persecuted looking for a world of freedom and opportunity. The colonies provided opportunities to those who were not put off by exile and remoteness.

The need for manpower resulted in slavery. Brazil imported 4 million Africans over 3 centuries to cultivate sugar cane [APP 10]. The Caribbean soon followed suit.

The invention of the *Cotton gin* (*gin*, diminutive for *engine*) in 1793 by Ely Whitney [DOD 84] facilitated the separation of seeds from the staple fibers of American cotton. This simple invention allowed intensive production of cotton in the southern colonies. This resulted in the prosperity of plantation owners and the development of slavery, in turn leading to the American Civil War from 1861 to 1865.

The two world wars, a sad appanage of the first half of the 20th Century, saw a significant disruption of the global order. The beginning of the 21st Century sees globalization in full swing. Blue jeans, Coca-Cola<sup>®</sup> and other soft drinks have taken hold of the planet. The suit and tie is worn by businessmen from Tokyo to New York. There are no more borders to information and exchange of goods. The American model of consumption imposes itself universally, but for how long?

### **1.2.2. Evolution of the company over time**

In Table 1.1, we have tried to represent the evolution of the Western company from the 19th Century to the present day. They are of course the “state-of-the-art” enterprises of their time. We can note that, even in countries just as developed as France, we find Taylorist enterprises. What about developing countries?

We can define 4 periods which lie between the 19th Century and the end of the 20th Century. Each period corresponds to a vision of the company, which is sometimes strongly influenced by political-economic theories such as capitalism or the various forms of communism, and the weight of great historical events.

The employee is managed very differently in terms of hiring, training, salary, job security, safety, working conditions, and also in terms of hierarchy. He will maintain highly variable relationships with his superiors depending on the time and the type of company where he works.

Breakthroughs in technology (cars, plastics, aviation, information technology, nuclear industry, etc.) will create new industries, new professions, influence the lifestyle of the citizen, and completely change his behavior and way of thinking. The old technologies will disappear; this forms the basis of Schumpeterism (see Box 1.5).

The Industrial Revolution of the 19th Century has rationalized the concentration of men, machines, and capital and given rise to the entrepreneur and the “captain of industry”. The foreman is the keeper of knowledge; and has total control over the worker. There are no engineers as yet.

### **1.2.3. The Industrial Revolution in England**

The term “The Industrial Revolution in England” refers to the transformation of the essentially agricultural and artisan society of the 19th Century into a society that drew most of its wealth from industry based on mining, river, sea and land transport, and of course, on trade. The development of railway transport represented a revolution in itself.

Everyone agrees to the fact that this revolution based on the steam engine was born in England and that it gradually spread to France and Germany. The United States, by virtue of its size, its extreme wealth, the quality of its manpower provided to entrepreneurs through immigration and its liberal system, overtook Europe in the late 19th Century. The 20th Century was undoubtedly “American”, but what will the 21st Century be?

Chinese, perhaps?

Period	Highlights	The company as an organization	The individual in the company	Socio-political environment	Breakthroughs New management methods
19th Century	Industrial Revolution  Colonization	Manufacturing: emergence of the company replacing craftmanship  Huge concentration of capital, machinery, men  The factory	Foremen and laborers  Birth of the engineer	Capitalism  American Civil War–1st Industrial War (1861–1865)  Marxism	Steam engine Mines, steel industry Cotton in the U.S. Chemical industry (dyes, explosives) Electricity
Late 19th Century early 20th Century (1937)	Productivity revolution	The company is a closed system Profit maximization F. W. Taylor ( <i>Scientific Management</i> , 1909). Taylorism: study of tasks H. Fayol ( <i>Industrial and General administration</i> , 1916)	Strong hierarchy, unity of command Work broken down into specialized tasks Scientific management Control, centralization, organization by departments	World War I (1914–1918) The Popular Front (France) (1936) Fascism The New Deal (USA) Marxism-Leninism	Assembly line (Ford) Petroleum Applied Research (Thomas Edison) Volkswagen Socio-technological giants (TVA project in Tennessee)

**Table 1.1.** *Brief overview on the evolution of the company and its environment (the Western world and Japan)*

Period	Highlights	The company as an organization	The individual in the company	Socio-political environment	Breakthroughs New management methods
1937–1960	Study of the psychology and behaviour of employees (Hawthorne Plant) Behaviorism	Fayolism: definition of functions H. Ford, Fordism: assembly lines (1913) (assembly-line work)  The company is considered to be an open system Beginning of decentralization Objective-based management	Motivation by money  Man is no longer considered to be 100% rational Money is no longer the only motivation Birth of communication	World War II (1939–1945) Production economy The Glorious 30 years in France: 1945–1973	Sulfamids, penicillin Nylon Nuclear energy (Hiroshima, 1945) Computers United States: – Value Analysis (1942); – project-based management (1960); – strategic management (1960).

**Table 1.1.** (continued) Brief overview on the evolution of the company and its environment (the Western world and Japan)

<p>1960–2000</p>	<p>IT Revolution Consultants (management breakthroughs)</p>	<p>Matrix management Supply Chain (customer-supplier reconciliation) Computers invade the company Internationalization Computer engineering Telecommuting Product/market relationship Product Life Cycle Re-engineering</p>	<p><i>Beginning of period</i> The individual is considered to be preponderant, it is mollycoddled Continuing education Expatriation Need for adaptation and flexibility <i>End of period</i> Unsecured job (employability) Loss of references</p>	<p>R. Carson, <i>Silent Spring</i> (1962) Market economy Globalization Free trade against protectionism Global competition Rich countries against poor countries 1973: first oil crisis Industrial disasters: Seveso-Bhopal ... 1989: fall of communism Management by finance Customer is king</p>	<p>Tarnishing the image of chemistry Genetic engineering Space Exploration Electronics, Internet Quality (TQM) Process Analysis Pension funds lead the world Company concentration (by sectors)</p>
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**Table 1.1.** (continued) *Brief overview on the evolution of the company and its environment (the Western world and Japan)*

Period	Highlights	The company as an organization	The individual in the company	Socio-political environment	Breakthroughs New management methods
21st Century	<p>Knowledge management</p> <p>New production concepts</p> <p>Companies based on knowledge</p>	<p>Matrix management</p> <p>Customer-supplier partnership</p> <p>Subcontracting, distribution</p> <p>Company-society relationship:</p> <ul style="list-style-type: none"> <li>– corporate citizen</li> <li>– redefinition of work</li> <li>– Consideration of the concept of sustainable development</li> </ul>	<p>Need for reconsideration (adaptation)</p> <p>Loss of reference (loss of fidelity to the company)</p> <p>The company turned over to financial power</p> <p>Participation in the company (stock options)</p>	<p>Unpredictable world</p> <p>Technological revolutions every 10 years</p> <p>Sustainable development</p> <p>Product safety</p> <p>Emerging countries: China</p> <p>Poor countries against rich countries</p> <p>The employee capitalizes</p> <p>Media hype</p>	<p>Genetics (hopes and concerns)</p> <p>GMO</p> <p>Digital Revolution</p> <p>Continues</p>

**Table 1.1.1.** (continued) *Brief overview on the evolution of the company and its environment (the Western world and Japan)*

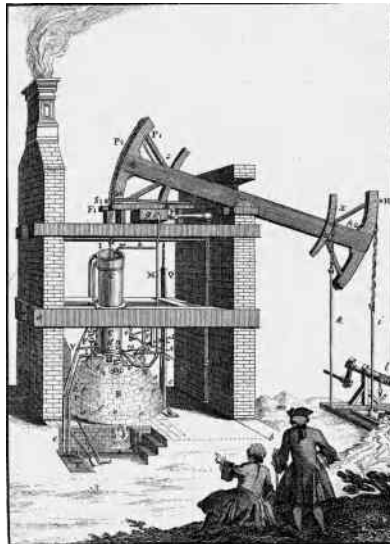
Japan entered the scene in the late 19th Century and cornered a vast empire in Asia; at the height of its ambitions defeating the Russian fleet at the Battle of Tsushima in 1905 and conquering what is now Taiwan, Korea, and a part of China. Having been defeated in 1945, Japan, reduced to its historic space, launched itself in to the commercial conquest of the world, which we will come back to later.

The origins of the Industrial Revolution are complicated. Joyce Appleby: [APP 10] questions the fact that this revolution started in England whereas it could have started in France, Germany, or China. These three countries in fact had intelligentsia of the highest order and a certain political stability, along with coal and iron in abundance.

It was actually the combination of a number of elements that enabled England to lead an unprecedented transformation during the first half of the 19th Century; this transformation began with the 18th Century and continued for two centuries. It should be noted that only at the end of the period, that is at the end of the 19th Century, could the British people ... finally enjoy the benefits of the machine age. The factors that enabled England to make a mark for itself include, but are not limited to:

– *innovations*, in large numbers, which entrepreneurs industrialized and perfected for decades to conduct “business” as we would say today: it is impossible to list all of them!

As early as 1712, the Newcomen pump enabled us to extract the water that flooded mines (Figure 1.3).



**Figure 1.3.** *Newcomen pump*



Thomas Newcomen (1663–1729), a blacksmith by profession, is considered to be “the Father of the Industrial Revolution”. The pump that bears his name was the first “steam engine” to use steam power economically. Steam is injected into the cylinder where the steam lifts a piston. Cold water which is injected into the cylinder condenses the steam, thus creating a vacuum. Under the effect of atmospheric pressure, the piston goes down. The movement of the piston is transmitted to a reciprocating pump by means of a balancing beam. Many coal mines rendered unusable due to flooding were saved from bankruptcy. The first pump was installed in 1712. When Newcomen died, 100 pumps were in use. This technology prevailed for 50 years and was then modernized by James Watt (1736–1819). In 1763, he created a real steam engine by installing, amongst other things, a condenser that was separated from the piston (patent of 1769). The success of his partnership with Matthew Boulton (1728–1809) for the sales of machines, resulting from his inventive talent, is legendary. Boulton, who had a keen marketing sense, enabled Watt to devote himself to his works by freeing him of trade and financial concerns [BIL 96].

The Stephensons invented steam traction and railways. The textile industry was the first industry in the 19th Century: the steam engine enabled the mechanization of this industry.

#### 1.2.3.1. *Intellectual openness, entrepreneurship and protection of discoveries*

Thinkers reflect on the governance of society, on human nature, on the production of wealth, and on the value of work. Among them, Adam Smith (1723–1790) is considered to be the founder of modern economics. His book in 1776, *Inquiry into the Nature and Causes of the Wealth of Nations*, established theories in relation to work, wages, prices, and taxes. He advocated free trade and non-interventionism of the state in economic affairs; he was opposed to corporations.

More than a century before Taylor, he advocated work specialization in order to increase productivity; his hairpin example is well known.

Inventions have been protected by patents since 1624 [APP 10], thus paying back the efforts and investments of the inventors.

#### 1.2.3.2. *An efficient banking system*

The Bank of England, founded in 1694 [APP 10], emerged as the most important institution in Europe in the 18th Century. We can recollect that the first modern bank was founded in 1609 by the Dutch and that Bonaparte founded the Banque de France in 1800.

The effectiveness of the English system prompted Napoleon to call England a nation of shopkeepers!

### 1.2.3.3. *The development of agriculture, political stability, population growth*

At the beginning of the 17th Century [APP 10], 80% of the population worked on the land. England had 5–6 million people and 1 million horses. Advances in agriculture were very significant and the specter of famine disappeared. The population of England doubled between 1780 and 1830.

In the mid-19th Century, only 40% of the population was working on the land. This percentage is at 3% today. The end of the Napoleonic Wars brought about stability in the country and an unprecedented development of the colonial empire, a natural outlet for manufactured goods, and an important source of raw materials.

### 1.2.4. *Taylorism, Fordism, Fayolism*

In the late 19th and early 20th Century, Frederick Taylor and Henri Fayol (see Boxes 1.1 and 1.2) provided the traditional company with the form that we know today.

Taylorism [POU 98], still unduly criticized a century after its birth, probably due to the lack of knowledge of the industrial life of its detractors, has revolutionized the life of the factory.

Taylor invented the analysis of the actions needed to accomplish a task: this forms the basis of scientific management.

Translated into modern language, Taylor wanted to:

- *improve plant productivity* by asking the worker for an “honest day’s work”. But the timing, the visible tip of the iceberg, was unwelcome. The worker felt like a robot;

- *improve the manufacturing processes* (Taylor was the world’s leading specialist in machining), know the costs (Taylor was an accountant) by the introduction of what was to become analytical accounting;

- *reconcile workers and employers* by efficiently distributing the profit generated by better management, but the worker is paid for piece work;

- *select and train workers (best man to fit a job)*;

- divide labor between those who design it and those who perform it: drive out empiricism; birth of the modern engineer, engineering and design departments, planning department, and scheduling.

The foreman is restricted to the supervision of laborers.

Henry Ford [LAC 87] adopted Taylorism to the letter (see below). He invented the assembly line in 1913 for the assembly of magnetos which reduced the time required for their production from 15 to 5 minutes.

Detroit emerged as the kingdom of timing, division of labor, cutting waste, and the continuous study of the manufacturing process. Previously, each car was handmade by skilled workers. The division into basic assembly line tasks, which are simple to perform, makes manufacturing by unskilled workers possible. We can recollect Charlie Chaplin's *Modern Times*.

The production increased from 160,000 to 320,000 cars from 1912 to 1914 with the same strength of 14,000 workers.

However, Henry Ford, by reducing the manufacturing costs and hence the selling price, enabled the average American to buy a car; he even received congratulatory letters from "public enemies no. 1" (Dillinger, Bonnie and Clyde) for whom the car was an essential "work tool". Ford's technology revolutionized the *American way of life* for the better and perhaps for the worse.

Fifteen million Model Ts were produced between 1908 (the year of launch) and 1927, when the Model "A" replaced the Model "T". In 1919, half of the cars in American were Model Ts.

Ford also invented vertical integration; he produced steel for manufacturing his automobiles and had his own distribution network. In 1917, the "Rouge" plant was the largest factory in the world: 1,600 m long and 2,500 m wide.

Louis Renault met Taylor and Ford during a trip to the United States in 1911. He wanted to introduce their methods in France.

However, the ill-prepared application of the "Taylor system" resulted in major strikes, including the 44 day strike in 1913. Renault generalized timing after dismissing the union leaders.

Fayolism refers to the management of the company, whereas Taylorism refers to the factory.

Fayolism classifies the set of operations in the company into six main functions: technical, commercial, financial, accounting, administrative, and safety.

H. Fayol defined 14 principles of management from which we will quote:

- the division of labor into specialized tasks;
- the unity of command: the employee has only one manager;
- promotion of the best employees.

Fayol can be considered as the founder of modern management. Administration means anticipating, organizing, and controlling.



F.W. Taylor was born near Philadelphia, to a very wealthy Quaker family. He passed the entrance test at Harvard, gave up his studies and became a simple worker in a small pump plant and then joined a steel plant, the Midvale Steel Co., where he worked for 12 years. He became a foreman and then a mechanical engineer by taking correspondence courses. He also held the post of accountant before finishing as chief engineer. Taylor became a specialist in metal working, with many patents, which made him rich and famous. He established himself as a consulting engineer in 1893.

Taylor invented the job analysis technique, whose most obvious manifestation is the timing of tasks. His book, *The Principles of Scientific Management* (1911), applies Taylorism and forms the basis of scientific management.

He had many supporters: Henry Ford, Louis Renault, Lenin, and so on.

**Box 1.1.** *Frederick Winslow Taylor (1856–1915)*

### **1.2.5. The advent of research**

The scientific discoveries of the late 19th and early 20th Centuries had a significant impact on enterprises.

The entrepreneur carried out research to create business. In modern-day terms, he wanted to innovate. Innovation means creating new products, new applications, whereas invention is limited to the acquisition of new knowledge.



H. Fayol, a French Engineer, graduated from the School of Mines of Saint-Etienne (France). He was the director of the Commentry mine for 30 years. He became the CEO of the Company “Société de Commentry, Fourchambault, Decazeville”, a post from which he retired at the age of 77. Fayol laid the foundations of “administrative theory”. His major work, *Administration industrielle et générale*, was published in 1916. He is considered to be one of the pioneers of management.

**Box 1.2.** *Henri Fayol (1841–1925)*

Non other than T.A. Edison better symbolizes the integration of research into the company. *Start-ups*, already mentioned, can be considered as a system pushed to the extreme: one that speculates on innovations ... potential innovations.

*No company today can do without research.*

#### **1.2.6. *The individual in the company***

Everything we have just discussed primarily relates to two periods ending around 1937. Until then, the company was a closed system, where man was considered to be completely rational. The salary must be sufficient to meet his needs. “Work and keep quiet” one might say.

Starting from the 1930s, the rise in the level of education, standard of living, access to more information, the growing maturity of the working masses (to use Marxist-Leninist terms) changed this Taylorian perception of the labor world.

A significant number of schools try to understand the behavior of the individual in the company. Elton Mayo (1880–1949) is regarded as the founder of the Human

Relations movement and work sociology. The Ecole de Mayo, whose influence was significant around 1940, gave rise to *behaviorism*.



H. Ford, the son of a farmer, was the pioneer of the American automotive industry. An eccentric and visionary, he invented the standardization of major parts and assembly line work in his plants at Detroit. He fervently adopted Taylorism: everything was timed. Assembly line work was used for the first time in 1913 to manufacture magnetos. Applied to the manufacture of the famous Model “T”, it reduced the assembly time from 13 hours to one and a half hours. The Model “T” was the first car available to the average American.

**Box 1.3.** *Henry Ford (1863–1947) [LAC 87]*

Frederick Herzberg, a Professor of psychology, studied the motivations of men at work. Douglas McGregor proposed theories X and Y. According to theory X, man is lazy by nature, whereas theory Y states that he can be motivated if appropriate motivating elements can be found. Psychologists and social psychologists entered the company after the war.

Labor laws became increasingly concerned about protecting the employee. Advances in medicine, reduction of working hours, respect for rest periods, consideration of occupational hazards, the study of risk related to products, and ergonomic studies were some of the many benefits offered to workers in developed countries.

No other country in the world is more “consuming” than the United States, which was considered to be the “master of the world” after World War II. The end of hostilities halted the military–industrial system resulting from the unprecedented

transformation of the industry in peacetime, especially in the automotive industry, to manufacture airplanes, tanks, and the most diverse means of transportation. The number of men and women in the armed forces would reduce from 12 million to no more than 1 and a half million in peacetime. Consumption broke all records: cars, refrigerators, televisions, and single-family houses were offered on credit to a population looking for comfort.



T.A. Edison, a news vendor (train boy) at the age of 12, deaf and self-taught, Edison was the author of 1,093 patents. An inventor of the phonograph and the incandescent lamp, among other things, he established companies for manufacturing and distributing electricity. His inventions helped America to transform from an agricultural country into an industrial country. Visitors can visit his house and laboratory in West Orange, New Jersey. His friend Henry Ford relocated his first laboratory from Menlo Park (New Jersey), where he invented the incandescent lamp, to Greenfield Village, the first American theme park opened in 1929 near Detroit.

**Box 1.4.** *Thomas Alva Edison (1847–1931) [PRE 89, ISR 98, JOS 92]*

After World War II, France experienced exceptional growth: France copied the United States.

This is the period of *The Glorious Thirty*, the 30 years that ended with the first oil crisis in 1973.

There was a gradual change from a manufacturing economy to a free market economy. The customer found everything he desired; the situation was thus far from shortage.



J. Schumpeter, Austrian Finance Minister in 1919, did not prove himself to be a very shrewd banker. He left for the United States in 1935 where he taught at Harvard.

The book *Capitalism, Socialism, and Democracy*, published in 1942, is one of his most remarkable works. He invented the term *creative destruction*, a process by which new technologies, new products, and new manufacturing and distribution methods throw out the old and force companies to adapt themselves if they want to survive.

Innovation is not only a source of progress but also a crisis factor responsible for economic cycles; an expansion phase is followed by a recession phase.

Like Karl Marx, Schumpeter believed in the fall of capitalism in evolved societies. However, he thought that this would be the best economic system, provided it was implemented by entrepreneurs who took risks.

**Box 1.5. Joseph A. Schumpeter (1883–1950) [SCH 75]**

Advertising incited him to consume. Globalization amplified the phenomenon of competition. A job is no longer guaranteed. The loyalty that bound the employee to his company vanishes slowly. The best people sell themselves to the highest bidder. The company tries to retain them by employee stock ownership plans and partnerships. The company has become an open system.

During this period, the pace of innovation quickened. The last decades of the 20th Century were marked by the IT revolution of which the Internet is a part. This revolution is similar to that of the printing revolution in the 15th Century, which still continues today: its effects have not yet been assessed. *The period of certainties is over.*



The conquest of space had an unexpected consequence. The photograph of the Earth taken from space showed us that our living space is finite. The concept of company and notion of work are being challenged; resources, including petroleum, are limited. The purpose of the company and work are being challenged.

The energy problem began to increase sharply. Use of nuclear energy for peaceful purposes appeared to be an interesting solution in addition to renewable energy sources (hydropower, wind, solar, biomass, tidal, etc.).

### **1.3. New challenges imposed by globalization and sustainable development**

The dawn of the 21st Century brings with it challenges that are unprecedented in the history of mankind. Population growth, the inevitable exhaustion of fossil resources (petroleum, copper, lithium), climatic disturbances, climate change, and disparities in living standards generate fear and questions.

The rich industrialized countries have mostly adopted the same capitalist system, born with the industrial revolution.

#### **1.3.1. Globalization**

The company is now faced with the globalization of economies and competition which keeps on growing. There are practically no barriers to trade and communication. In this context, enterprises are forced to define their strategies at a global level. The various financial crises that punctuated the global economy over the last 10 years continue to threaten the global stock markets.

The Asian countries, which represent half of all humanity, market quality products, although they have not completely monopolized entire markets such as the audiovisual or the motorcycle industry. Next to an aging but still powerful Japan, the *four dragons* (South Korea, Singapore, Taiwan, and in China) have risen to an international level. China with over 1.3 billion people “has woken up from a slumber” and transformed completely.

*“Globalization of the economy implies the globalization of responsibility”* (Kofi Annan, former Secretary General of the UN).

The concept of sustainable development changes the enterprise’s mission: it places man at the center of the system; this is a new vision. The industrial company or the service company, whether private or public, is thus obliged to implement a governance to cope with the abovementioned notions.

The UNDP (United Nations Development Programme) simply defines governance as – the exercise of economic, political, and administrative authority. It requires: “participation, transparency, and accountability”. To further simplify this, we can say that governance is the organization of decision-making processes, either at the government level or at the company level. There can be no governance without a value system!

#### 1.3.1.1. *Communication*

Extraordinary improvement of communication and its deployment are undoubtedly the key factor of a system of belonging to the same planet. The Internet, mobile phone, and fax enable individuals who have never seen each other and, in most cases, have little chance of meeting each other, to connect almost instantaneously.

Television brings the world within reach of the poorest; it shows him landscapes that he has never seen and undoubtedly will never see, and gives him the impression of a global village. CNN, Cable News Network, right from its foundation in 1980, has given live reports of events around the world.

#### 1.3.1.2. *Transportation, space exploration*

The development of aviation, which is just a century old, gave birth to mass tourism. One “does China” after visiting Machu Pichu in Peru. Tourism, which is manna from heaven for poor countries, “desecrates” the sites that were the very soul of the visited country; it leaves behind waste and exacerbates the desires of the underprivileged. The vision of the Earth by satellite gives a sense of finiteness and containment to “Earthlings”. Nothing escapes the space objects and “terrestrial” cameras which constantly monitor us.

#### 1.3.1.3. *The internationalization of goods and cash flows*

Globalization leads to the commoditization of consumer goods; we buy the latest Japanese or Korean audiovisual product in New York. China has emerged as the global workshop; it knows how to exploit its manpower that costs about one-tenth of what it costs in developed countries to launch industries demanding personnel, such as the textile, electronics and plastics industries, and manufacturing industries in general.

*The globalization of trade leads to economic globalization.*

#### 1.3.1.4. *The new geopolitical order*

The planet has almost nothing left to be discovered: there is practically no virgin land. Now, under the surveillance of satellites, it is “watched” constantly by the superpowers and nothing can obstruct the Internet.

There is practically no conquest of one country by another; the conquest of Kuwait by Iraq in 2001 was cut short. Countries are no longer colonized by other countries ... at least openly. The colonial wars are over! Other subtler forms of war including terrorism and religious intolerance have replaced them.

#### 1.3.1.5. *The conquest of today is the conquest of markets*

One billion people consume 80% of the planet's resources; 1 billion of the "damned" endanger its future through deforestation, land overuse, water pollution, and generation of greenhouse gases, especially CO<sub>2</sub> by burning carbon fuels. Do we need to emphasize that these poor people are at the origin of a population explosion that puts their future at risk and drives them to a wild emigration that is feared and rejected by most of the developed countries?

Another division is economic by nature: North America, Europe, and Asia-Pacific, mainly China, represent the existing forces and the forces in the making. Scientific progress and technological revolutions are changing our way of life more and more quickly each day and widening the gap that separates the developed countries from the rest of the world, and why not say it openly, the United States from the rest of the world! What we have just mentioned is the cause of fears that are becoming more and more intense.

#### 1.3.1.6. *Fears*

##### 1.3.1.6.1. Fear ahead of progress

It seems to be clear that, since the 1970s, technological progress has led to changes that society cannot take in and understand. This holds true for GMOs (genetically modified organisms), genetic engineering, and nanotechnologies. Some would want to stop every progress, even though progress has always existed undoubtedly, we would be surprised to meet our grandmother *Lucy* (*Australopithecus afarensis*) at a street corner.

##### 1.3.1.6.2. Fear of the nuclear industry

In 1945, the United States alone had the knowledge and means to manufacture the atomic bomb. Currently, the atomic bomb is within reach of any country that wants to develop it. The fear of the bomb is coupled with the fear of nuclear power plants; the Chernobyl disaster 20 years ago is in everyone's memory and what about Japan's cataclysm in March 2011? The fear of contamination by radioactive materials and terrorist attacks using "dirty" bombs is also prevalent. The collapse of Russia and the waste that has resulted from it, leaves us to weigh suspicions that the accidents involving nuclear submarines will not disappear.

1.3.1.6.3. Fear related to the internationalization of enterprises, technological transfers

From 1970, large enterprises have tried to become global and leave their native country. China is a major target. They have sometimes relocated their production to countries with cheap labor. The developed countries are flooded with Asian products at prices that defy competition.

1.3.1.6.4. Fear of job loss

The feeling that setting up enterprises abroad helped in the drain of technology and created many competitors for the future has not yet disappeared.

1.3.1.6.5. Fear related to energy problems

The Industrial Revolution led to the exploitation of natural resources. This exploitation keeps on increasing rapidly. Developed countries are dependent on distant countries for their energy supply (oil and gas). Pipelines and gas pipes pass through countries which are sometimes unstable.

1.3.1.6.6. Fear related to pollution

There are no boundaries to pollution! The atmosphere and oceans are the finite receptacles. Water pollution, especially of water tables, is a major concern for the French.

1.3.1.6.7. Fear related to armed conflicts due to ideological conflicts

If the specter of a third world war seems to be far away (the Cuban missile crisis of 1962 is not so distant), the possession of weapons of mass destruction, whether nuclear or biological, by “high-risk” countries poses the question of their control. Poverty and underdevelopment are undoubtedly the breeding ground for fanaticism. But so far, the rise of fanaticism and terrorism that ensues from it appears to be the greatest danger.

1.3.1.7. *The benefits of globalization: towards global governance, reasons for hope*

However, it's not all doom and gloom! Communication at a global level can help us to know what is going on! Poor countries know that they are poor ... and declare it. Surveillance of the Earth helps to track the state of pollution, the ravages of deforestation, fire detection, construction of plants whose purpose may be risky and, in short, to monitor the state of the planet in real-time.

Scientific progress provided developed countries with a well-being which was unknown till now. Famines, although not completely eradicated, have declined significantly. China and India have become self-sufficient in food.

There is a global solidarity for the good reason that every country depends on others. Governance is gradually establishing itself at a global level. Many summits resound around the planet, aided by global conferences. Child labor, the situation of women and issues related to water and pollution are examined.

The big international companies are the holders of wealth: capital wealth and intellectual wealth. It is estimated that the top 300 companies of the world produce a quarter of the global production!

The UN tries to be the world's policeman: its blue beret peacekeepers are present in conflict zones, but its soldiers practically have no right to use their weapons. The IAEA (International Atomic Energy Agency), based in Vienna, strives to inspect nuclear power plants.

*Governance will either be global or will not exist.*

### **1.3.2. Sustainable development**

Every week, we receive an announcement of a conference or a forum on sustainable development. Industrial companies or service firms announce their engagement on this subject. All of this is hinted at in the media. Sustainable development has become an essential concept!

#### *1.3.2.1. Birth of a concept*

The following chronology highlights the essential steps that led to the concept of sustainable development; environmentalism can be considered to be its starting point.

Some of the milestones:

- 1850: David Thoreau: transcendentalism;
- 1962: Rachel Carson, *Silent Spring*;
- by 1970: the multinationals in question;
- 1971: first Ministry of the Environment in France;
- 1973: first oil crisis;
- by 1975: technological development faster than social transformation;
- 1987: Brundtland Commission: concept of sustainable development;
- 1960–1990: Internet;
- globalization, media coverage (mediacracy), space exploration (monitoring the Earth), disasters: Seveso (1976), Bhopal (1984), AZF-Toulouse explosion (2001), Aral Sea;

- 1992: Rio Summit: “First Earth Summit”;
- 1997: Kyoto protocol (global warming);
- 2002: Johannesburg Summit (Rio + 10): reducing the number of people without drinking water by 50% by 2015;
- 2005: enforcement of the Kyoto Protocol on reducing greenhouse gas (GHG) emissions in the European Union. Integration of the precautionary principle in the French constitution;
- 2009: Copenhagen Summit on climate change.

Two American figures, a century apart, have strongly influenced their age.



Was he the first *ecologist*?

At the age of 28, H.D. Thoreau lived in a small *cabin* in the woods, near a beautiful pond in the vicinity of Boston. He refused to pay his taxes, which led him into trouble. A little recognized author of his time, he was the inventor of civil disobedience and passive resistance: he inspired Gandhi and Martin Luther King Jr.

**Box 1.6.** *Henry David Thoreau (1817–1862)*

*“Sustainable development will be planetary or will not exist!”*

Humanity has to face new challenges. The list is long. We will only point out a few:

- the problems related to the depletion of energy reserves;

- the critical issue of water and population growth;
- the widening of the gap between rich and poor countries;
- imbalances caused by the rise of power in China, India, Brazil, and Russia (BRIC countries);
- commoditization of nuclear weapons, terrorism, and so on.

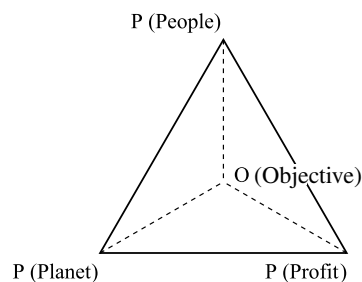
But what is meant by *sustainable development* today?

The following definition seems to be most appropriate:

*Sustainable development can be described as development that is socially desirable, ecologically sustainable, and most importantly economically viable.*

A graphical representation helps us to better understand this concept.

The 3Ps (*People, Profit, Planet*) illustrate the definition of a socially desirable, environmentally sustainable, and economically viable development.



**Figure 1.4.** *Sustainable development*

The following example shows the difficulty of the problem: locusts devastate crops in some of the countries of the Sahel. Is it necessary to use insecticides knowing that, if misused, they will pollute the soil and rivers and that the starving people will eat contaminated locusts? Should financial aid be given to the governments of these countries? Where will this money go? If global organizations take control of the problem, will they not be accused of interference?

This is an urgent problem: if insecticides are not dealt with, there will be deaths, can we expect that people have been educated, that a semblance of governance has been set up ... What should we do? The point O (O for objective) represents a desirable balance: its position in the triangle will vary from country to country; the United States does not have the same needs as a country of the Sahel.

Sustainable development means knowledge of our habitat: the planet Earth.



R. Carson was undoubtedly the inspiration for *sustainability*. A marine biologist, Rachel was among the first to understand that different species should be given time to reproduce so that fishing remains *sustainable*.

She was born into a poor family in Pennsylvania. Being a very talented student, she studied biology, especially marine biology. After graduating from *John Hopkins University*, she joined the *US Bureau of Fisheries*, when depression was at its peak, and at a time when women scientists were rarely considered and little regarded.

To survive, she began to write articles for the press.

In 1951, at the age of 44, her book *The Sea Around Us* [CAR 51] brought her fame and affluence. Americans became aware of the importance of oceans and seas. In 1952, she resigned her government job to live by her writing.

In 1945, the cessation of hostilities left large amounts of DDT, which was regarded as a miracle product because it had helped to avoid pandemics. DDT was sprayed into the air, without due care, even on residential houses. Rachel Carson realized that the uncontrolled use of insecticides can kill birds and gets accumulated in animals. She condemned their misuse in a book entitled *Silent Spring* [CAR 51], published in 1962. This book received an unexpected reception.

During the Cold War and at the time of nuclear tests, Rachel Carson increased public awareness about the dangers of uncontrolled use of toxic products, especially those with residual effects which concentrate on the food chain. As an ecologist ahead of her time, she drew attention toward the fragile balances that govern life in ecosystems. She was at the height of her fame when she lost her battle with cancer.

**Box 1.7.** *Rachel Carson (1907–1964)*



## **1.4. Our planet**

### **1.4.1. *Balances and biogeochemical cycles***

Life on Earth, such that we know of, results from an infinite number of balances which are sometimes precarious. Thus, eutrophication of an aquatic ecosystem is caused by an excess of nitrogen and phosphorus contributed to by houses, agriculture, and industry. Excessive consumption of oxygen resulting from it deprives the system of this essential element and leads to the death of living organisms. Phosphate detergents were the major agents in the eutrophication of lakes infested with algae.

Anthropogenic CO<sub>2</sub> keeps on increasing along with industrial development; it seems to be certain that it cannot be reduced naturally. It enriches the atmosphere and contributes to the greenhouse effect.

### **1.4.2. *Global warming – greenhouse effect***

Global warming is, at present, the subject of debate. Scientists and politicians share the center stage. It is now accepted that the temperature of the globe has increased by at least 0.5°C in a century. Europeans are dismayed at the gradual disappearance of their glaciers; Dr. Etienne, with many others, observed the sharp disappearance of the ice packs in the Arctic Sea. The sea level rises by about 1 mm every year.

The carbon cycle is extraordinarily complex. At present, it is considered that greenhouse gases are responsible for global warming. Human activities are responsible for the production of 7.9 Gt (gigatons: billion tons) of CO<sub>2</sub> per year, which largely exceeds the absorptive capacity of oceans and the biosphere.

The rise in sea temperature would lead to the desorption of dissolved CO<sub>2</sub>: this would cause an increase in CO<sub>2</sub> content in the atmosphere, as well as the partial pressure of water vapor, which is also a greenhouse gas. The increase in cloudiness would reflect a major portion of solar energy toward space. This would have the effect of cooling the Earth. The problem is extremely complicated!

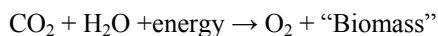
Of late, researchers have been concerned about the disturbances in the Gulf Stream: its branch that carries the warm waters of the Gulf of Mexico toward the North Atlantic would lose 30% of its intensity in 50 years; this would be due to the decrease in salinity of the North Atlantic. Will Brittany and France be covered by glaciers in the next century?

It is estimated that the water level of oceans could rise by 30 cm to 1 m by the end of the century if nothing is done to combat global warming. The archipelago of

the Maldives would be submerged first, followed by parts of Bangladesh, the Netherlands, and some of the coastal African countries. The consequences for these populations would be dramatic.

The ozone layer protects us from harmful Ultra violet (UV) rays: the deterioration of the ozone layer (ozone hole) by chlorofluorocarbons (CFCs) has led to the control of their commercialization, at least in industrialized countries; their production should be completely banned by 2030. The greenhouse gases contribute to maintaining an average temperature of 10–20°C throughout the globe: without them, the temperature would be –18°C.

Life on Earth would not exist without the energy provided by the Sun. This energy is essential for the process of manufacturing organic matter from absorbed CO<sub>2</sub> and atmospheric water, through photosynthesis, which creates biomass and releases oxygen:



The reverse reaction is respiration and it releases CO<sub>2</sub> by absorbing oxygen.

*“Energy flows and material flows on Earth are closely linked”.*

Photosynthesis is one “biogeochemical cycle” among others. The water cycle is of utmost importance. The Sun, which is a gigantic heat engine, evaporates ocean water. This water rises into the atmosphere and condenses in the form of rain and snow. The evapotranspiration of plants largely contributes to rainfall. Nitrogen, phosphorus, metals, and metalloids are also the source of biogeochemical cycles, which are essential for life.

The Sun also sets in motion vast amounts of air (wind). Along with the moon, it causes huge movements of water: these are tides and vortices, with a width of a few dozen to several hundred kilometers. These movements were discovered recently with the help of satellites. These fluid movements are of enormous importance; for illustrative purposes, let us cite only the *El Niño* and *La Niña* which had devastating effects on South America.

### **1.4.3. Ecology and ecosystems**

Ecology is considered to be of crucial importance today. The term “ecology” was introduced by Haeckel in 1866, and is derived from the Greek words *oikos*, meaning home or habitat, and *logos*, meaning science. Ecology and economics are now inseparable disciplines. Haeckel defined ecology as the study of the adaptation of

living things to their environment. The images of the Earth taken by astronauts in the years 1968–1970 have placed ecology at the forefront. Since then humanity has been aware that our planet was a finite and complex system.

By ecology, we now refer to the study of interactions of living organisms with each other and in relation to their non-living environment (biotope), which is composed of matter and energy. Ecology is no longer considered to be a sub-discipline of biology, but a discipline in itself involving all the sciences: chemistry, physics, biology, sociology, geography, astronomy, mechanics, and so on, to name but a few.

Systems theory introduced by L. Von Bertalanffy in 1968 was used to produce a systemic vision of the planet. The concept of the ecosystem introduced by A. Tansley in 1935 is particularly enriching [FRO 99]:

*“ecosystem = biocenosis + biotope”*

Biocenosis includes all living beings of the same habitat. A pond can be home to frogs, fish, crayfish, an infinite number of bacteria, water lilies, and other plants.

A pond can be a part of forest; it may be surrounded by meadows located in the same valley traversed by a river that is in turn part of a region.

The construction of a dam (anthropogenic action) on the river can radically change life in the pond. Biocenosis constantly changes the biotope: the cows that graze a meadow change it; the meadow will change over the year according to the seasons. We must not forget that the Earth is constantly changing: volcanic eruptions and tsunamis due to the interpenetration of tectonic plates are there to remind us of that.

The living environment can be considered as a set of structured systems that “fit” hierarchically in the space-time continuously. By population, we mean that the set of individuals belonging to the same species live together in the same habitat (e.g. frogs in a pond).

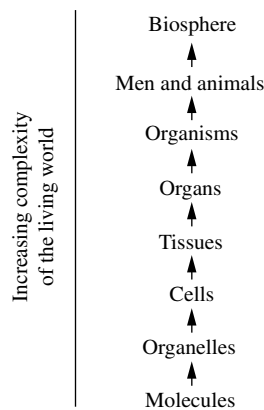
Interactions in an ecosystem are manifold. At first, there is competition for food; the food chain is one of the major characteristics of a living organism. The examination of a sea bed is significant: each population competes for food in order to survive. Parasitism, mimicry, camouflage, and coexistence are the most incredible forms for the delight of those who know how to observe: each population has its strategy to survive. Evolution is often mandatory.

To adapt itself, any ecosystem is a source of feedback that serves as a regulator. As such, the prey/predator concept is significant. The ecosystem that is home to a population of rabbits and a population of foxes is balanced by itself, too many foxes

lead to the disappearance of rabbits, which in turn leads to the decrease in the fox population, following a lack of food.

The biosphere, which is the set of living things on Earth, is divided into the following ecosystems: lithosphere, hydrosphere (oceans, glaciers, rivers, lakes, groundwater), and atmosphere. The inertia of these systems varies considerably: the effects of air pollution are much quicker than that of an ocean.

To conclude this section, we can provide an overview of ecology and consider the interaction of two key ecosystems: the urban ecosystem and the rural ecosystem. The first ecosystem, with a very high concentration of human population, produces no or very little biomass. It seems to be clear that the biomass of Central Park is of little consequence for New York. The importance of this biomass is clearly of a completely different order!



**Figure 1.5.** *Systemic analysis of the living organism [DUR 98]*

#### 1.4.4. Oceans

The oceans and seas cover 70.9% of the Earth's surface, or 510 million sq km (a thousand times the size of France) [MIN 09]. The Pacific Ocean represents half of the total surface of all oceans. The study of this system that is typical of our planet and essential for life began only in mid-19th Century. The fact is that the lands are largely located in the Northern hemisphere, whereas the Southern hemisphere accounts for 81% of marine areas, which strongly influences the ocean circulation.

Ever since the 1970s, the study of oceans (currents, salinity, temperature, dissolved gases, seismic activity) and their monitoring have been greatly facilitated by improved analytical methods (probes) and by the use of satellites. The whole

globe is now seen to be almost continuous. Altimetry satellites measure the sea level with an accuracy of 1 cm, whereas, contrary to what one might think, the sea is not “flat”. Differences have been detected in the level of the sea of 10 m!

The use of isotopes (tritium, carbon-14) has revealed the underwater currents. Oceanography involves physics, chemistry, biology, geology, climatology: it is a science in itself.

The food chain goes from the smallest organisms (plankton) to the largest animals (whales, octopus) and includes the largest living system (the Great Barrier Reef, off Australia). The wind gives rise to marine surface currents which are subjected to Coriolis forces (circulation in a clockwise direction in the northern hemisphere, whereas they are subjected in an anti-clockwise direction in the southern hemisphere). The trade winds carry water from east to west in the northern hemisphere. The Gulf Stream carries warm waters from the Gulf of Mexico to Europe; Britain benefits from this.

Surface currents generate the thermohaline circulation, or in depth-related circulation to density changes, caused by changes in temperature and salinity. *Upwelling* means the rise-up of cold water to the surface. This is one of the causes of the *El Niño* effect. This upwelling creates an intense nutrient-rich marine life. Conversely, it has been proven that in some parts of the world, surface waters plunge deeply: *downwelling*. This occurs in the North Atlantic where the water cools, its density increases, it will then dive to the bottom of the ocean heading for the Antarctic and resurface in the Pacific and Indian Oceans. Global ocean circulation has been compared to a rotating treadmill that has been measured, it takes 1,000 years to make a full turn.

The ocean and atmosphere are intertwined. They continuously exchange energy and matter. Solar radiation is the major source of ocean energy. The ocean absorbs sunlight and re-emits infrared radiation. It absorbs it at the equator and re-emits it at high latitudes. The ocean is a heat engine which redistributes heat from warm equatorial regions to cold polar regions through ocean currents. The ocean is a huge reservoir of energy and plays a stabilizing role by its inertia.

The ocean is a huge carbon reservoir (40,000 Gt). The solubility of CO<sub>2</sub> in water depends on the partial pressure of CO<sub>2</sub> in the atmosphere and the water temperature. The lower the temperature, the more CO<sub>2</sub> water can store. Areas of high latitude are CO<sub>2</sub> storage areas, where storage is amplified by *downwelling*. Warm and *upwelling* areas are the *areas of release* of CO<sub>2</sub>.

Around 1960, the movements of the Earth’s crust and plate tectonics responsible for tsunamis were understood.

### 1.4.5. Demography

Demography is the science that deals with the study of human populations in terms of quantity, concerning their size, structure, and evolution. It is based on what is most fundamental for man, life and death.

There is an exponential increase in the world's population. It took about a century to grow from 1 billion in 1830 to 2 billion by 1930. Approximately 70 years were enough to shift from 2–7 billion today (Figure 1.6).

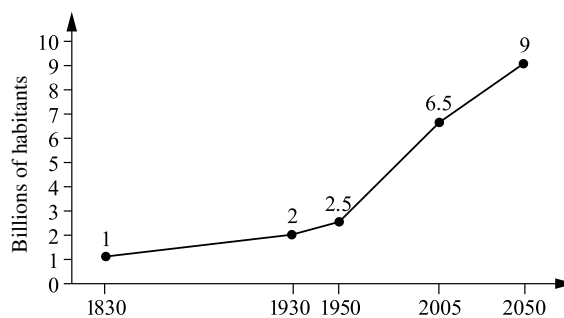


Figure 1.6. The world's population (historical and projected)

The fertility rate required for acquiring a stable population is 2.1 for developed countries and 2.5 for developing countries. Today, the world has seen its population increasing by 79 million inhabitants per year.

The UN projections for 2050 ranges from 9–12 billion individuals according to different hypotheses essentially related to the fertility rates.

The evolution of the population by geographic area (Table 1.2) shows the decrease of the European population by 2050.

Europe was the source of heavy emigration in the 19th Century and is today the leading continent for immigration.

#### 1.4.5.1. Urbanization and megalopolises

Every day 160,000 people migrate from the countryside to the cities due to lack of land and labor, and due to conflicts.

The world's population is experiencing a massive urbanization with the incredible growth of megalopolises (Chongqing, Mexico city, Shanghai, São Paulo). There are now 19 megacities with more than 10 million inhabitants.

Area/Year	1950	2005	2050*
<i>Developed countries</i>	813	1,210	1,236
of which Europe is a part	547	728	653
<i>Developing countries</i>	1,706	5,254	7,840
Africa	224	906	1,937
Latin America	167	561	783
Asia	1,315	3,787	5,120
<i>Globally</i>	2,519	6,464	9,076

\*Average variant of four scenarios

Source: *World Population Prospects: The 2004 Revision Highlights*. New York Nations Unies 2005

**Table 1.2.** Evolution of the population by region/geographic zones (million)

The UN estimates that 63% of the world's population will live in urban areas in 2050.

The contrast between the north and south of the Mediterranean (democracies and aging population in the north and authoritarian regimes and exponential increase in population in the south) will undoubtedly lead to disruption in the lives of citizens of neighboring countries such as France.

Table 1.3 helps us to visualize the town/country interactions and to have a systemic view.

Incoming	City	Outgoing
People		People
Energy		Residues, garbage, chemicals
Food	Systems: hospital, education, banking, transport, roads, energy, etc.	Pollution: air, noise, polluted water, GHG (greenhouse gases)
Water	Safety: police, fire fighters, etc.	Manufactured products
Raw materials	Recreation: parks, gardens, plays, theaters, tourist attractions, etc.	Culture
Chemicals	Storage: cars, food, water, household products	Diverse riches
Manufactured goods		
Money		
Information		
Homes		

**Table 1.3.** Simplified systematic analysis of an urban area

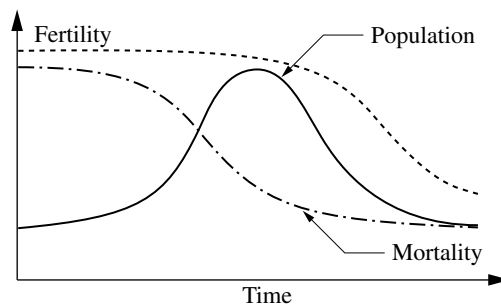
A city is a complex system, and a source of all kinds of imbalance that increase with size. A city can live only if it receives resources from non-urbanized areas. It was estimated that a city like London is in need of 60 times its area to live.

The population cluster of cities creates incredible megapolises. Boston will soon be connected to Washington via New York, Philadelphia, and Baltimore. This *strip* of 800 km will house 60 million people, that is twice the population of Canada. By 2015, Mexico city will reach 19 million inhabitants, Shanghai 15 million, Karachi 20 million, Dhaka 19 million, Beijing 20 million, São Paulo 19 million, and Tokyo 29 million. Chongqing is now regarded as the largest city in the world with 30 million people.

18 million Mexicans live in Mexico City (one Mexican in six), where the pollution, noise and crime rate has reached appalling levels. 6 million people live in slums (*barrios*) without water supply or electricity. How can these urban monsters be “sustained”?

#### 1.4.5.2. *The demographic transition*

The demographic transition is an interesting phenomenon which allows us to show the evolution of a population with the pyramid of ages. This phenomenon shows the transition from a nearly balanced mortality system and high fertility to a system in which the fertility far exceeds the mortality to reach a steady state of low fertility and mortality.



**Figure 1.7.** *The demographic transition*

This is the process experienced by all countries as they move from a traditional agrarian economy to an industrial economy. The duration of this process can take 50 years to over a century.

Earlier in this cycle, the decline in mortality is caused by medical advances, healthy eating, social progress, whereas the birth rate remains at a higher level. The



fertility decline has resulted in a decrease in population and an aging population. The age pyramid is inverted.

The population is growing strongly in mid-cycle.

Sub-saharan Africa is an example of the beginning of the cycle where the old continent is at the end of the cycle. Immigration barely compensates for the low birth rate. China, with a coercive birth control system, has virtually reached a level. Japan is in an unprecedented aging process. Its population of 117 million people is expected to fall to 80 million by 2050.

#### 1.4.5.3. *Some laws and concepts: the case of France*<sup>1</sup>

– *Median age*: age that divides the population into two classes of equal size. In France, it is 38.5 years, where 30 millions of French people are less than 38.5 years, and 30 million are over 38.5 years.

– *Longevity*: maximum duration of human life. This has not changed over the ages and is about 115–120 years. The case of Jeanne Calment, who died at the age of 122 years, is an exception.

– *Death rate (birth rate)*: number of deaths (births) with respect to the population of that year.

– *Life expectancy*: number of years left to live on average *to a fixed age*. A Russian man has a life expectancy at birth of 60 years. Compare this with 77 years for the French. Smoking and alcohol are the main cause of mortality in Russia.

– *Infant mortality rate*: number of deaths of children under 1 year with respect to the observed number of live births that year.

In France, during the late 18th Century, the population was about 30 million. France was the most populous country in Europe. Life expectancy was 25 years, 30% of children died before the age of 1. Only one out of five lived till the age of 80.

In 2000, life expectancy at birth was 77 years for men and 84 years for women. Immunization, sanitation, water supply, the virtual disappearance of hard labor, raising the level of culture, improved nutrition, and medical care are responsible for the decline in mortality.

In 2002, there were 763,000 births, representing a birth rate of 12‰. In the same year, the number of deaths was about 540,000, and the death rate was 9‰. The infant mortality rate was 4.3‰ in 2003, in which France ranked 8th in the world. It

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<sup>1</sup> Definitions and figures from the INSEE.

was 15 times higher in 1945. The risk of death decreased from birth till the age of 8–10 years. It then increased. France is the first country that saw a decline in fertility from the late 18th Century.

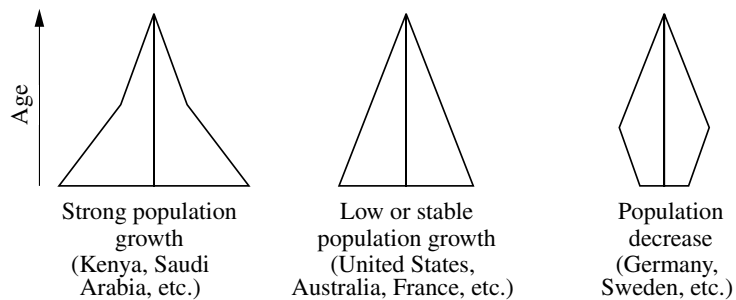
#### 1.4.5.4. *Demography and sustainability*

Undoubtedly, population issues are the key factor for sustainability taken in its broadest sense and social stability. Some believe that the world is not overpopulated and that overpopulation is not a problem, whereas others oppose this belief. “Sustainable” population is between 20 and 2 billion according to the experts: 8 billion represent an average opinion which seems to be reasonable.

It seems that the impact of AIDS in some countries, especially African countries, is not yet measured at a fair value; some of the countries are beginning to run out of labor!

#### 1.4.5.5. *The age pyramid*

The age pyramid reflects the situation of a country during the demographic transition process.



**Figure 1.8.** *Typical age pyramids*

#### 1.4.6. *Energy*

For millennia, man has used fire for his domestic needs, and to make metals and glass. He was able to harness the wind and water, using his own strength and that of the animals to move, eat ... and to make war.

The concept of energy only emerged in the late 18th Century and it is due to Denis Papin, with Carnot, Watt, Thomson, and others that we came to know about the “fire-engines”.

It took several decades to effectively transform heat energy with the advent of the steam engine, and several decades for thermodynamics to become a science,

a tough science which is not the most popular among students. The Industrial Revolution and all the technological advances it brought with it were based primarily on mastering energy, energy from the “king” of energies, coal, and then oil/petroleum and gas in the 20th Century, which are energies that are easier to extract, transform, and transport.

Hence industry has used non-renewable fossil fuels. Coal is derived from the transformation of plants which have been there for hundreds of millions of years, while oil/petroleum is formed from plankton.

The welfare of rich countries has led to the consumption of energy without precedent. The inhabitants of these countries now have light at the flick of a switch, cook their food on a stove, and fill the fuel tank of their car. Apparently, this situation will continue, and fossil fuels will run out, since the emerging giants – China and India – have enormous energy requirements.

Energy consumption is one of the major disparities between rich and poor countries. Sustainable development is inconceivable without equitable access to energy. Energy, along with water, is the great problem, the biggest challenge that humanity is facing in the 21st Century: this challenge is about providing reliable energy at a cost compatible with the development of the whole world, thereby protecting the environment, particularly by maintaining the level of CO<sub>2</sub> in the atmosphere at a reasonable level to avoid global warming.

#### 1.4.6.1. *Some figures on energy*

The world now consumes about 9 Gtep (gigatep), say 9 billion teo/p (tonnes of equivalent oil/petroleum). The distribution is approximately as follows: 37% of energy from oil/petroleum, 22% from natural gas, 24% from coal, 7% from nuclear, and less than 3% from hydropower.

The global average consumption is about 1.5 teo per capita. The disparities are huge: an American has 7.9 teo/year against 3.7 for a European, and 0.2 for the inhabitants of Bangladesh. It is to be noted that 1.6 billion people do not have access to electricity.

The so-called renewable energies relate to hydropower, biomass, wind, solar, geothermal, and use of ocean currents; these energies represent only 10% of energy worldwide (7% in France).

The global oil/petroleum consumption is now about 80 million barrels per day. A barrel is 159 liters. So, it is about 12 million tonnes of oil/petroleum that the planet “burns” each day, 4.4 billion tonnes per year. The United States consumes a quarter of that production and can meet only 50% of their needs. Former US President George W. Bush said that it was intolerable that the first country in the world

depends on Saudi Arabia for its future, and has begun explorations in Alaska. One cannot ignore that the U.S. dependence on energy influences its foreign policy.

1.4.6.2. *What will be the case of energy in future? What will we do about it in the future?*

According to the experts, the years 2040–2050 will face the *Peak Oil crisis*, that is to say, the period when oil production will become lower than demand. Optimists, who, based on a similar situation which happened during the oil shocks of 1973 and 1980 claim that unexplored reserves exist. It is true that we are extracting an average of only 30% of what is in the reservoirs.

Processes for enhanced oil recovery (EOR) have been developed, but they will be used only when the cost of oil exceeds \$100. Oil shale and tar sands, from heavy oils (Canada, Venezuela), represent considerable reserves, but are difficult to use: again, it's all about the price and process.

Gas should “survive” oil for two to three decades. The use of shale gas was made possible by the use of horizontal drilling which seems to double the reserves of natural gas; Will we still able to afford it! *It is henceforth accepted that the era of cheap oil is over. What will the fuel rates of our cars be?*

The energy risk is perhaps the biggest threat for industrialized countries which depend on developing countries for their supply. Two-thirds of proven oil reserves are in the Middle East. Moreover, the Middle East, Central Asia, and Russia own 80% of natural gas reserves.

The fact that the world and especially the United States are no longer investing in refineries poses a huge risk to the economy, just as Hurricane Katrina ravaged New Orleans in August 2005 which left the United States in a situation of instability causing serious economic consequences.

Coal has reserves for centuries and can be “reborn” if  $\text{SO}_2$  is eliminated and  $\text{CO}_2$  is sequestered. Techniques exist and continue to be improved.

Nuclear power has produced many fears after several disasters of which the one at Chernobyl in April 1986 remains the target of environmentalists because of the risk inherent in the plants and storing of radioactive waste. Uranium reserves will exist for about 2–3 centuries. France, which has 59 power plants set up for a nominal capacity of 63 GWe (gigawatts of electricity) has proved the reliability that could be achieved in this type of procurement. France now plays a major leading role with the ITER program (fusion reactor). Fourth-generation plants, with improved yields, are being studied.

Renewable energy, whose interest is growing in view of concerns over greenhouse gases, can contribute to a certain independence with respect to oil.

France, the second largest agricultural country in the world, is focusing on the use of biomass (biofuel program or diester). However, it would take a quarter of France's industrial crops to meet about 10% of their energy needs. Wind power, the darling of environmentalists, is likely to remain marginal, but in times of shortage everything counts. There would have to be 25,000 wind turbines of 1 MW to meet 20% of the present needs of France.

There is no doubt, at least in developed countries, that energy savings must be revived, especially in terms of housing and transport. Many programs were created in 1973 and significant progress has been made, but the fear had vanished, and the effort has slowed.

The energy issue will remain for a long long time! Efforts should continue on research.

#### **1.4.7. *Water***

Water is life. Without water, no economic development is possible! And yet ... a billion people (one in six people) lack drinking water, 2.4 billion people lack water to meet their basic hygiene needs. The fourth World Water Forum held in Mexico in March 2006, re-emphasized this. It is estimated that water-borne diseases killed about 8 million people in 2004!

The basin concept has emerged recently and highlighted the political problems associated with it. The water of the Jordan is without doubt one of the causes of conflict between Palestinians and Israelis.

Turkey is the water tower of the Middle East. It began the enormous construction project of 22 dams and 19 hydroelectric plants to irrigate 1 million hectares in Kurdistan. Turkey can control the Tigris and the Euphrates, thus Iraq and Syria. The Nile and the rivers that are attributed to it give life to 100 million people belonging to 10 countries. The expected increase in world population will be faced with a water problem/scarcity: conflicts are not far off!

#### **1.4.8. *What will be the future for French agriculture?***

Agriculture has shaped the French landscape. French agriculture, the second largest agricultural society in the world, leading the way for wheat, wine, and sugar beet, is in a transition phase. Yields of more than 100 q/ha (quintals per hectare) for wheat were obtained by seed selection, with new tilling methods and ... by the use of pesticides and fertilizers.

But the number of farms is decreasing; the forest grows by 170,000 acres each year. Some areas are becoming deserts. The countryside is no longer only seen as a food producer, but is also considered as a recreational area for the urbanites and especially as an actor in the protection of the environment. French agriculture and forestry are now considered under the aspect of the validation of their biomass.

Beet, producing sugar, grain and starch, may lead to ethanol through fermentation. The esterification of rapeseed oil and sunflower oil result in diesters, called biofuels, alternatives, like ethanol, to petroleum products. Usage of waste (straw, etc.) and timber generates energy. The forest is a storage for CO<sub>2</sub> and wood energy, as has been the case for thousands of years.

The race for the increase of yields of agricultural production is the root cause of much of the pollution of groundwater and coastal waters by pesticides. The cultivation of GMOs raises hitherto unknown fears. It is therefore a question of controlling agriculture and forests today, which should take into account the economic, environmental, social aspects respecting the specificity of each region. The debate is just beginning! We bet that it will last a long time.

### **1.5. The company of tomorrow. Some thoughts**

*Companies in developed countries are companies based on science and technology.*

These companies have taken advantage year after year of technological knowledge with an incredible speed, sometimes by despoiling the least developed countries and thus widening a gap growing between them and the rest of the world.

It is the *industrial tool*, taken in the broadest sense, which is at the root of these changes. It is that which transforms fossil and plant resources into chemicals, transportation means, power generators and to provide society with a growing number of goods and services.

The question on the future of the planet, which increasingly appears as a finite system”, which a few decades ago, to the general public seemed to be a system without limits, is the question of *what is to be produced, how and where we want to produce?*

The company must keep the best of its traditional operation but must take into account the new requirements that the term “sustainable development” has highlighted.

The company now faces an unpredictable world where hype (some speak of mediocracy) amplifies phenomena beyond reason. Terrorism and financial scandals across the world bring a new unbearable dimension to the world.

The bankruptcy of Lehman Brothers in September 2008 took the world by surprise and has caused an unprecedented crisis, whose effects are ongoing at the time of writing. Countries are on the brink, the debt of some of these companies, like that of France, is stunning. The *subprime* crisis in the United States raises the question of the merits of capitalism: do we have the right to speculate on what does not exist? Where did the money go?

The “virtuous” skilled engineer, from whom greater clarity is requested in his work, can he remain in a world ruled by finance or cash flows which are opaque or to say the least destructive of value?

One of the major projects in the world, the most discreet, perhaps, is that of IFRS (*International Financial Reporting Standards*), financial tools whose role is to ensure, among other things, the accounting transparency of enterprises, the correct validation of assets and liabilities to restore the confidence of citizens who are asked to invest their savings [LEM 10]!

### **1.5.1. *Emerging countries***

Emerging countries of BRIC (Brazil, Russia, India, and China) and probably soon, South Africa, not to mention the four dragons, will weigh heavily on the global economy with their economic weight, strong growth, demography, and desire to progress.

The West cannot impose its politics and undoubtedly its vision on the rest of the world! What will be the result of this inevitable clash?

The case of China is significant in this regard: at the risk of repeating ourselves, we may wonder if the 21st Century will not be Chinese!

#### **1.5.1.1. *China yesterday, today, and tomorrow***

Until the early 16th Century, China was a closed world. It did not communicate, and carried out business with the outside world only through the small enclave of Macau given to the Portuguese in 1577; this would be the starting point of the Italian Jesuit Matteo Ricci who waited for 20 years to reach Beijing during the Ming dynasty [CRO 57]. Ricci, the first Sinologist, reached China to become a respected scholar.

China is a “Still” world as Alain Peyrefitte wrote [SAL 97] but a world perfectly organized and well administered. The English opened up this world through the ignominious Opium War which ended with the Treaty of Nanking in 1842 (unequal treaties as the Chinese call it).

China was partially occupied by the West and Japan from 1842 until the foundation of the People's Republic of China (PRC) in 1949 by "Chairman Mao".

Mao's "reign" ended with the Cultural Revolution from 1966 to 1976 and his death in 1976.

President Deng Xiaoping (1904–1997) brought about an Enlightened Socialism in his country, and propelled it in a few decades to the pinnacle of the big players. This was the result of the work of a population of 1.3 billion industrious people, used to living with few means while working tremendously hard.

China, the world's workshop and, especially for the United States, has an enormous wealth of coal, metals, rare earth to its name. Tibet is the water tower of Asia.

China has enormous challenges ahead for the Chinese interior to improve their standard of living rather than focusing on the coastal strip from Canton to Shanghai via Tianjin and Qingdao, thus holding out the prospect of improving China's living standards.

It is already apparent that China will not have the fleet of cars equal to that of the European Union (540 cars/1,000 inhabitants) or to that of the United States (800 cars/1,000 inhabitants) as against 40 approximately for China.

China will therefore be confronted very quickly with changes in society like the developed countries.

### **1.5.2. *What are the values for tomorrow?***

It would take about three Earths to meet the needs of humans if they all had the same standard of living as that of France, five planets to have that of the United States.

The nations will be forced to find ways to deal with an impossible situation.

New values need to be found!

The engineer and especially the process engineer will be required to contribute to the evolution of the world.

An irony, which history does not lack, while "Communist" regimes disappear or give way to socialist regimes or even right-wing regimes, Karl Marx (1818–1883), author of *Das Kapital* [MAR 83], returns to center stage with this question: "what value should be given to work?".



### 1.5.3. *A new company for a new society*

Globalization intensifies competition, but it creates opportunities.

The concept of sustainable development is not the latest media term/concept in fashion: it will persist. Humanity is realizing that its living space is finite, and that our behavior today will affect the lives of generations to come, especially if the world's population increases by 50% within 40 or 50 years. This is true for energy, the environment, and the use of our resources.

The information revolution is not over. Technological advances are occurring at a high frequency, making obsolete the transformation processes and organizations. Along with a company that is based on IT, a new forward-looking concept can be added: a knowledge-based society.

*Knowledge management* is necessary because of the fragmentation of knowledge generated by the increasing complexity and the proliferation of technology and by the mobility of required or subjected individuals.

The company will have to manage its intellectual capital. New technologies of information and communication technologies (ICTs) play a role in making individuals work together and therefore facilitate the sharing of knowledge, especially tacit knowledge, knowledge specific to the individual which cannot be written and conceptualized, in contrast to explicit knowledge, which exists in reports and memos. The reconciliation of the company, the customer and its suppliers will continue. The company will also catch up with the society, the communities where it operates. The transparent company, and corporate citizenship are not just words. The company will always be judged on its profit, but this is not the only criterion.

The employee, in response to this changing world, will be forced to train throughout his life. Immediate access to information will result in lower hierarchical levels, the individual will become more and more specialized, but will learn to position himself between the provision of upstream information and the downstream information that awaits him. The concept of added value, that is to say the amount of the contribution of the individual to society, will take a higher value.

The employee, riveted to the screen of his computer, corresponds more practically with the world but is, in fact, increasingly isolated: a strange paradox. Globalization will need to adapt to multiculturalism.

What about the concepts that we have tried to develop in this book, organizations from which he is inspired? They will continue, but become more and more fluid so that the company gains in responsiveness, in adaptability in a changing and unpredictable environment.

The major functions of the company still have good years ahead of them, because man needs more and more references since everything will be complicated in the long run. But all these functions will be forced to evolve.

*The entrepreneurs of tomorrow are those who will be able to explain this.*

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## Chapter 2

# The Two Modes of Operation of the Company – Operational and Entrepreneurial

The company moves to the rhythm of two basic modes of operation: the operational mode and the entrepreneurial mode [DEC 80]. Figure 2.1 shows the process of moving from research toward the industrial process unit C which is represented by a black square. This new process unit will be integrated into an existing facility where process units A and B are already functioning. This facility includes administrative services such as management, Human Resources (HR) department, purchasing department, shipping and receiving, and so on, support facilities, necessary for its operation such as the treatment plant for effluents, production of utilities, and maintenance.

The creation of the new plant C will induce changes in the host plant:

- technically: increased requirement of utilities, additional means of pollution control, storage, and shipping of the new product;
- economically: development of new overheads corresponding to the new requirements in manpower and maintenance;
- in terms of manpower: it will be necessary to hire new staff, train them, and possibly qualify the existing staff, who will be employed in plant C.

So, the plant and company face their highest level in the existing management when managing new businesses.

The aim of this chapter is to describe the two basic modes of the company: the operational and entrepreneurial functions.

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Chapter written by Jean-Pierre DAL PONT.

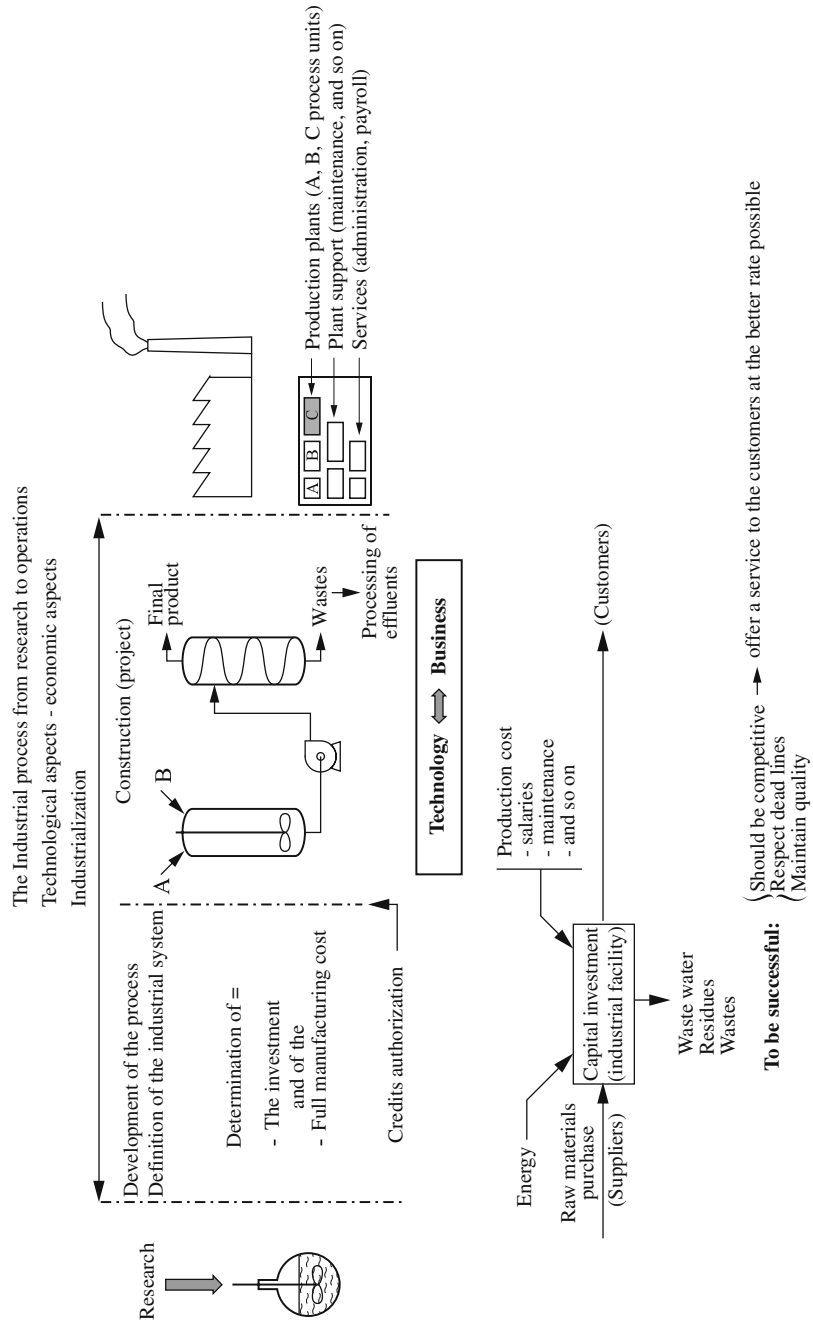


Figure 2.1. The industrial process

## 2.1. Operational mode

The operational mode or management of operations (research, production, administration, etc.) corresponds to the daily management, in order to *generate the profit* essential for the company to meet its current expenses, overheads of which are salaries of the employees, purchase of raw materials and supplies, expenses related to investment, maintenance, repayment of loans and debts, compensation of shareholders, and so on.

The operational mode consists of managing everything currently available in a prudent manner, one might say that it means to make the most of the industrial tools in place. The daily management that perhaps does not have the entrepreneurial glitz and adventure must generate profit and is the “nerve center” of any development.

The company usually monitors itself by using balanced scorecards and by measuring the deviations from the plan and standards.

*There is no performance without measurement.*

Analysis of sales by volume, price, and margin is the indicator most immediately accessible with the status of inventories and work in progress. It is the most immediate indicator of economic health (good or bad).

The manufacturing site has to measure its specific consumption of raw materials and utilities (steam, water, electricity, nitrogen), overheads, and scrap rate. This is the technical analysis of the operations.

The frequency rate of work accidents, claims, absenteeism, analysis of major dysfunction such as technological accidents and damage to the environment are indicators of its “mental” health. Nowadays, more and more attention is paid toward psycho-social problems; stress which is one of these problems is a phenomenon that is spreading more widely with some serious consequences on individuals and the company itself.

*Do not take the term “daily management” as “day-to-day” because it is actually about measuring, evaluating the performance of the company over time, comparing with what was expected (objectives), drawing lessons from it and taking the appropriate corrective action.*

### 2.1.1. Management – company structure organization – organization chart

#### 2.1.1.1. Management

R.A. Thiétard [THI 99] defines management as “the act or art or the way of leading an organization, managing it, planning its development, and controlling it”.

The author states that the word management probably has the same Latin origin as *ménagement*, the 16th Century French word, derived from *ménager* and which means set carefully and skillfully (Petit Robert dictionary, 1976).

Management applies to all areas of business operations. Its essential components are as follows, according to the same author:

- planning;
- organization;
- activation;
- control.

The company management lies within a world that is increasingly unpredictable, complex, and paradoxical. The management must adapt to take into account globalization, hyper-communication, and new requirements in terms of liabilities with respect to the environment and sustainable development. The company must be *agile* enough to meet these new challenges.

The world is no longer dependent on the Western culture resulting from the Europeanization of the world, as we have already mentioned in the chapter on the history of the company.

Globalization – “glocalization” to use a neologism – mixes cultures. The company has to consider this both in its home country and in countries where it operates.

This new situation is particularly palpable in the *headquarters* of multinationals where there can be executives of all origins, an Italian may be in charge of the Asian sector, an Asian of North America, and engineering entrusted to an American. Is there any wonder that English has become the language of business? These people need to know the company, understand its organization, goals, values, and skills. They must understand whom they work for and who is working for them.

Organization charts, job and function descriptions should be brought to the attention of all. The following section aims to explain this briefly.

#### 2.1.1.2. *Corporate structure – functions*

For Pierre Conso and Farouk Hemici [CON 01], “the company is a particular form of organization. It is an organization whose aim is to produce and exchange”. “An organization is an association that proposes specific goals” (Petit Robert dictionary, 1996). The organization is undoubtedly the most visible part of management [THI 99].

Structuring an organization means:

- defining the tasks to be accomplished and the human and financial resources to achieve this;
- establishing the means of communication, coordination as well as the different functions and individuals within them;
- energizing the individuals; this is activation according to Thiétard.

#### 2.1.1.3. *Functions*

A function is defined as a set of activities bringing together skills of the same type (production and finance). A century ago, Henri Fayol distinguished six functions: administration, technical, commercial, financial, security, and accounting functions.

One can classify the functions into three categories:

- operational functions (*online*);
- support functions (*on staff*);
- transverse functions.

The *operational functions* include:

- top management;
- purchasing;
- production;
- logistics (distribution)/*supply chain*;
- marketing/sales.

The *support functions* include:

- human resources;
- finance;
- administration with management control, information technology, accounting, agreements and legal department, and communication;
- audit;
- research and development.

The *transverse functions* concern:

- quality;
- health, safety, and the environment (HSE).

Each function contributes to the studies, projects, major decisions, implementation control, and so on. Under the same name the same function can have its nature, degree of freedom, style, mode of operation, responsibility, and connection to the top management vary greatly depending on the company.

Thus, industrial management can be either *online* (hierarchical), that is to say, in direct charge of the plants and take responsibility for production, or “*on staff*” (functional liability of staff) and have a “dotted line” connecting with the industrial “*online*” major divisions to share experiences, identify issues for industrial development, working methods and to ensure the general development of the execution of the domain.

The size of the company also has a considerable impact on the segmentation of the organization; in a small company, the same person can have multiple “duties”. For example, a boss can act as both Chief Financial Officer (CFO) and Director of Human Resources (DHR).

#### 2.1.1.3.1. Operational functions

##### *Chief executive officer*

The Chief Executive Officer (CEO) embodies the power; he has the power of decision-making. The function of the top management also has a legal status: they represent the company as a corporation. The Chief Executive Officer is the main contact for shareholders who elected him which ensures his legitimacy. He is also the boss of the company in the sense that he is the supervisor of all the employees.

On the basis of the size of the company, top management may include Vice-presidents (VP), who have decision-making power in their respective fields. The CEO, VPs and the bosses of large support functions (HR, CFO, etc.) constitute what is commonly referred to as the board of directors, the executive committee, the strategic committee, or the *corporate*.

CEO styles change depending on the individuals. A corporate culture: the result of years of “cohabitation” is difficult to change: it takes several years to curb it. The CEO can be very authoritarian and centralist or, on the contrary, may tend to decentralize or delegate.

*Corporate* size can vary in large proportions. If the CEO wants to control and measure everything, he will tend to surround himself with a powerful *corporate*, very often not well recognized by people online who do not perceive the added value. *Corporate* controls will be exercised by multiple reports, many meetings, and committees of all kinds. It may cause dilution of liabilities, lack of entrepreneurial spirit, a gap will separate those who know and those who do. A very small *corporate* tends to motivate the performers who feel “empowered” with a risk of lack of control and therefore slippage.



There is no quick fix. Everything depends on the people, the organization in place, and the corporate culture. We should also note that the management style can be very authoritarian and litigious in sectors which are in crisis or non-profitable and much more flexible in high growth sectors such as might be the case in the branches of high-growth countries.

#### *The representation of the company*

The CEO is the sole authority of the company. He has the signature authority in the corporation. He commits the company to third-parties when purchasing a company and signing major contracts. The CEO does not specifically seek the agreement of the Board before taking a major decision. He can justify it *a posteriori* to the Board who can sanction it.

The CEO reports on the results, justifies his actions, proposes a course of action, and defines the major objectives for the forthcoming years. He plays out his own future. A shareholder buys and sells the shares in the company following what he thinks to be his personal interest but, if the shareholder is *volatile*, the company is normally *stationary*.

The CEO represents the company to the media whose importance will be increasing. The company mostly considers him to be its president. In the role of spokesperson, the CEO appears in the press, appears on the radio and television. From this point of view, next to the obligation of results, the ethics of the company are becoming more important.

Finally, the Board can lobby at a government, political, union level, and so on.

#### *Definition of the strategy*

The Board is responsible for the corporate strategy, as we have defined it. It is important to define the broad guidelines and the main areas: amalgamations, assignments, partnerships, and major projects are a reflection from the general public and shareholders of such shares.

#### *Management and outcomes*

The Company has an obligation to produce the results, the shareholders have entrusted money and want to take dividends from it or profit from the increase in their capital. For this, the Board is in charge of the overall organization of the company, its structure and mode of operation. The budget has a specific importance: mandatory approval by the Board, it engages all stakeholders in the company. It is responsible for appointing executives to key positions.

The Board must, increasingly, define an ethic, thereby setting the values of the company: economic values, with performance targets (such as return on capital incurred); social morality toward individuals (respect for humanity, freedom from discrimination, compliance with laws, etc.), the environment (no major pollution, no catastrophic accident, a policy for product stewardship), and third-parties (business practice, attitudes toward developing countries, etc.).

One of the roles of certain support functions and the transverse processes is to ensure the consistency, compliance with procurement, and regulations that the company has to set up.

#### *Purchasing – supply department*

According to M. Darbelet [DAR 98], the procurement functions are to provide the company with the goods (raw materials, finished or semi-finished products) and services necessary for its operation at low costs, and within deadlines responding to the needs of the company. It therefore determines the profitability, quality, and price of the products sold, production, and delivery times. It belongs to the logistics/*supply chain* of the purchasing function whose role is to:

- evaluate, select suppliers, and supply;
- negotiate with suppliers;
- order;
- monitor and receive the order.

The modern approach is about establishing buyer-supplier-partnerships. The company then seeks to gain a competitive advantage by establishing strategic relationships with a limited number of suppliers, especially due to the fact that some so-called strategic raw materials are in the hands of a limited number of suppliers, or even countries. Globalization and the emergence of some countries led to a fierce competition that aggravated the depletion of natural resources.

Some raw materials such as copper may be at risk within 10 years, their prices soaring, reflecting the shortage, and speculation. It is not just oil/petroleum that will cause problems!

#### *Manufacturing*

The production system is the heart of the industrial company as its equipment and plants will release the finished goods, the basis of creation of its wealth.

The typology of means of production is extremely broad. Petroleum refining, the assembly of an Airbus, household appliances, pharmaceutical chemistry, crafts, and

printing will make use of very different tools, methods, and organizations. In addition, as mentioned earlier, the company raises the question of whether to do it themselves or outsource (it now uses this term rather than contract out).

It also raises the question of where to produce? In a global economy, the question amounts to asking whether to produce abroad. The manufacturing process cannot be conceived without the procurement, distribution, and maintenance processes.

In the first approach, we can distinguish the *process industries* from the *manufacturing industries*. *Process* is often synonymous with continuous, because large process industries (oil/petroleum, heavy chemicals, cement industries) work in continuous flow. The manufacturing industry produces discrete, that is to say, unique products that can be extremely large in number and can be of various sizes (cars and bolts). Contractors make a unique project for a client; this is the case of engineering and construction. Their operational mode is based on project management.

The process industry talk about processes and they are studied by research and development (R&D) and industrialized by an engineering and design department or by engineering firms. It is the planning department that, in the case of manufacturing industry, defines the process (line) and equipment to implement. Managing the production system is managing people, workflows, and techniques. Scheduling, a real conductor, is responsible for managing all the phases of manufacturing, including those assigned to subcontractors, taking into account the constraints of the industrial tools, procurements, inventories of finished goods, and work in progress. The concept of flow, now managed by the ERP (see below), resulted in the concepts of production following the principle of “just in time” (JIT), discovered by the Toyota Company in the 1960s. This is a “pull system”, supported by the downstream, i.e. by customer demand. One does not produce for the sake of it, but only what is necessary to avoid creating stockpiles beyond the necessary. But there must be good estimates, at the risk of losing sales if there is a surge in demand.

The factory or the plant is inconceivable today without a quality program and HSE program. Compliance with procedures is most likely one of the essential features required in manufacturing. We cannot imagine a successful company without a performing manufacturing tool. Companies and countries that have ignored it have lived to regret it, for example, the United States, a country of “great American cars” invaded by Japanese cars.

Performance, besides the pure technical success includes “zero defects”, whether in quality, safety, environment, and waste.

Let us also recollect that the production system can sometimes require very large investments relative to turnover. Strategic investments, whose profitability will be effective (hopefully) after long years, can be a significant source of risk.

#### *Logistics (supply chain)*

Logistics, a relatively new term introduced recently into corporate vocabulary, now refers to all flows irrigating the company: financial flows, physical flows of raw materials and finished goods, as well as information flows. The flow of information relates to the domain of transportation, storage, import-export, IT, and so on.

Martin Christopher [CHR 92] is the developer of the *supply chain* concept, which states that: “*The goal is to link the market place, distribution network, manufacturing process, and procurement activity in such a way that the customers are serviced at higher level and yet at a lower total cost*”. This is a very promising concept of a systematic vision of the company, its suppliers, and customers.

#### *Sales, marketing*

The commercial function is one of the key interfaces between the company and its environment. Usually, this function includes the trade itself, with its network of sellers (sales force in direct contact with the customers) and marketing. The latter is in charge of market research, and includes product managers, advertising. The sale in a larger sense includes a major number of operations:

- managing the sales force in market segments, countries;
- distribution of products;
- processing of orders and billing;
- logistics and sales administration;
- statistics, scorecards, planning, inventory management, procurement, and after sales service.

#### 2.1.1.3.2. Support functions

##### *Human resources department (HRD)*

From a policy defined by the Board, the HR department must ensure that the company has the necessary human resources in terms of quality and quantity, and in time in order to ensure proper operation. Staff motivation is an essential component.

##### *Management of personnel*

#### Employment

The employee is related to the company by an employment contract which, apart from the status of the post, location, and mission, defines the salary. Salary may have, especially for executives, a variable part related to performance.

### Career management and training

A career cannot be envisaged today without variation, the expatriation of which is an important variant. It equally cannot be considered without further training to upgrade the knowledge and adapt the employee to new assignments.

The definition of the job is a complex issue. It has a technical component, skills, and human components: leadership, accountability, initiative, and so on.

### Social and legal obligations

Relationships with unions and the settlement of social conflicts are a major component for businesses of a certain size.

The HRD has a role of collective management of the employees and management of individuals. It must play a major role in all processes of corporate restructuring, i.e. *re-engineering*. New forms of organization require the necessary support to redefine the responsibilities and relationships between the individuals and cannot do without a HR worthy of the name.

### *Finance department*

The finance department makes use of the data provided to it by accounting (see below). As a result, there is some confusion. Accounting in itself is pure and simple. The finance department is involved in the management of the company and, as such, it interprets the results and, sometimes, it gives the result for publicity in media!

The main goals of the finance department are:

- to control the capital of the company, the financing plan;
- to maintain financial equilibrium. It manages cash, which reflects the creditworthiness of the company. The company needs cash to meet its commitments: without cash, there is a stop in payment, that is to say, it can no longer pay its debts that have reached maturity;
- to seek means of funding.

In the case of major investments, the finance department shall make the calculations of profitability, research funding, and assess the risks of the investment. A new word has appeared, finance engineering, which includes fund raising, banking portage, *leasing*, and so on.

Currently, the CFO is very often found alongside the CEO in boards and presentations of results to the specialist press, which reflects his importance.

### *Administration*

#### Management control

Management control has gained considerable importance in most companies. Its role is to collect information on regular dates, process it, and inform the CEO using balanced scorecards and indicators. The budget of the company is one of the main items of control. The budget is established for the calendar year based on hypotheses, like growth of the country, market trends, evolution of exchange rates. It is part of management control to attract the attention of the CEO on deviations with respect to the forecasts, to explain and sometimes propose solutions.

### *Information technology (IT)*

IT is a major technological revolution of the 20th Century: no company can do without it. Software companies claim that the future belongs to those companies that will master this discipline. It is difficult to contradict it, as the management of the company depends on it.

IT manages all financial flows and human and material resources, to provide the current situation, analyze performances, and so on.

Computer technology has created new management methods. ERP (Enterprise Resource Planning) integrates accounting, business management, procurement management, and production not to mention e-commerce (e-business), which creates a new type of relationship between the company and its customers.

To paraphrase a famous saying, we can say that if the computer is a good servant, it is a bad master, as it serves the company and not the other way...

The role of the IT department is to choose and adapt the ways of processing information that its "customers" need, and to ensure its maintenance, in other words to adapt the systems based on the needs.

### Accounting

Accounting aims to provide information for the company. It is divided into two categories:

– general accounting works across the company. It periodically updates the status of assets (balance sheet and income statement). It measures the financial flows in and out. In this context, it meets the legal requirements, which is the tax return;

– cost accounting focuses on the business, operating cycle, product costs, overheads of plants, and so on. It is an essential element in managing the business and all related matters in general.

Large groups are required to present a consolidated balance sheet, that is to say, to take into account their subsidiaries or holdings. The newspaper *Le Monde* on August 7, 2002 ran an article entitled “Accounting standards in the heart of stock exchange scandals”. The collapse in world stock markets in the summer of 2002 is attributed to a lack of confidence of shareholders with respect to the companies after the collapse of Enron, Aol.com, and Vivendi Universal. It is the lack of visibility and difficulty of reading the results that are at the root of these problems, which involve billions of dollars.

An essential but difficult element is the evaluation of assets. Some large companies have bought other companies at increased rates, sometimes well above their *real value*. This is the famous *good will*, synonymous with overrating.

The crisis which began in 2009 after the collapse of Lehman Brothers in September 2008 shows the opacity of certain banking operations, their derived products where no one can find their way around, a system where the central profit of the capitalist system leads to excess; a strange paradox, as capitalism seems to be the only viable system since the advent of the Industrial Revolution.

#### Legal – intellectual property

The activities of the company that involve third-parties are the cause of a multitude of contracts to be drafted in accordance with the laws of the countries where they operate. This may include contracts for supplies, engineering contracts in the case of construction of physical assets, subcontracts, services (security, maintenance, etc.), and so on.

*Joint-Venture* (JV) has a particular character. Let us consider the example of a company that wants to practice in a new country, it chooses to partner with a local company that puts at the disposal of this company, its sales network, means of production, and so on.

Many Western companies have thus moved to settle in China, India, Japan, and other Asia-Pacific countries. These operations can sometimes be difficult if commercial success is not attained or if promises are not kept. In these cases, the *Joint-Venture* contracts are critical. It is not always easy for “Western” expatriates to live with it!

Intellectual property of the company is protected by filing patents and trademarks. *In the US, the “Lawyer” is a key player in the company, nothing can be done without his advice. This reflects an aspect of American lifestyle where the “Judicial quarrel” is pervasive. The American wants his “civil rights” to be the guarantee of his “liberty” as honored.*

#### Communication

The company must make its products known (advertising, brochures, leaflets, booklets, etc.), give off an image that attracts the shareholder, and thereby facilitating the hiring of senior executives and especially young graduates. This is called external communication.

Internal communication is intended to inform all employees of main events, the *success stories* to create a *sense of belonging* and pride, an easy role to play when things are going well, but difficult when things go wrong.

#### *Audit and expertise*

The Board can attach an audit function which is responsible for checking the application of procedures in place (including accounting procedures), the quality of information issued, contract enforcement, the integrity of assets, and so on.

*Internal audit* is generally composed of a multidisciplinary team of bright young graduates led by the seniors: it enables the newly hired young people to quickly understand the business from each and every angle.

The *external audit* is performed by qualified persons outside the company, including accountants and auditors, who have a legal role. The Board can also be attached with experts, industrial management is an example of this.

The purchase of assets and companies requires a particular audit. It is necessary to know the value of what one is buying and what can be taken from it, and assess the risks and opportunities over time. It is about the comprehensive diagnosis of the property to be bought, in terms of human potential, technologies, markets, products, and organization. The term *due diligence* refers to such essential but difficult activities! Multidisciplinary teams must get an idea what one plans to purchase over a very short time!

#### *Research and development (R&D), innovation*

*R&D* covers different concepts according to the company. It can be basic research that is about data acquisition which can be used in the future. It can be



about applications if one tries to find the applications for existing products or to meet the needs of customers with existing products. Large groups often focus their resources on impressive R&D centers, a real showcase of the company. To survive, the company must innovate; that is to say, find new products or new applications for existing products. In chemistry, a purer product can satisfy new markets: electronics, for example, required the provision of ultra-pure products.

Research is also at the intersection of marketing, production, and sometimes purchases and sales. Research is now conducted in a project mode, that is to say, the effort is targeted and the result is measured. The improvement of existing processes can lead to significant gains.

One way to measure the effectiveness of the research is to see its contribution margin to turnover (sales) and profit. The research may represent 1% of sales for traditional companies and 12–15% for high technology companies (such as pharmaceuticals) and almost 100% for some small size start-ups.

It is not just the research that provides ideas. Ideas come from the market and manufacturing as well. Continuity in research is a delicate problem: should one continue or abandon? Breakthrough analysis shows that technological *breakthroughs* take years of effort.

This is nothing new since Edison: “*Invention is 99% perspiration, 1% inspiration*”.

#### 2.1.1.3.3. Transverse processes

Organizations become increasingly more matrix, as they become more and more global and more and more complex. The search for dedication of individuals leads to structures called “flat”, that is to say, with a limited number of hierarchical levels. The decrease in the number of “managers” leads to a lack of control which is replaced with the establishment of transverse procedures of “governance”. Let us cite areas concerning quality and HSE.

#### *Hierarchical power – influence – expertise*

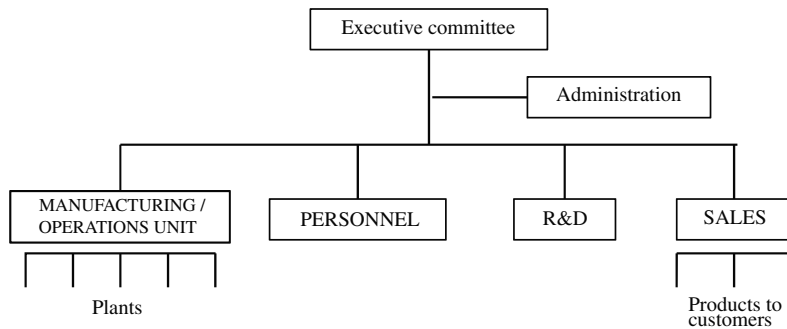
*Strictly speaking*, the “Corporate”, whose role is governance, derives its legitimacy from its proficiency. The interfaces are sources of conflict: these conflicts are inevitable and must be managed.

#### 2.1.1.4. *The organization*

The division of labor is necessitated by the physical limitations of individuals – one person cannot do everything! – and the need for different skills – one person cannot be competent in everything!

The organization chart displays the organization of the company by establishing graphical hierarchical relationships and functional entities within it. We are going to describe the three basic organization charts in the following.

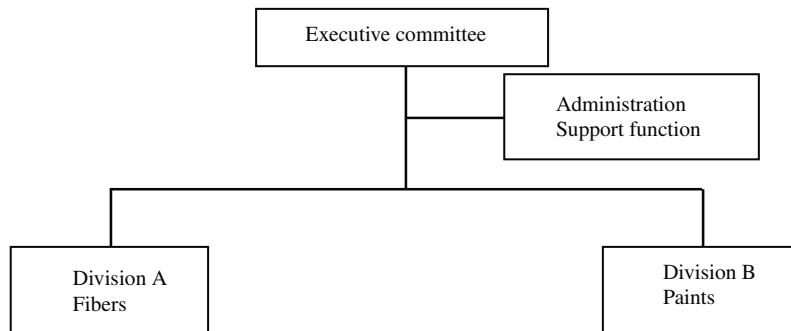
2.1.1.4.1. Organization by function



**Figure 2.2.** Organization chart of organization by function

Organization by function is an old type of organization which is directly inspired by “Fayolism”. The same skills are grouped under the same management, whether it concerns production or sales.

2.1.1.4.2. Organization by operation



**Figure 2.3.** Organization chart of the organization by operations

Organization by operation is market oriented. Each division is a practically independent company, managing its own plants, sales, marketing, and sometimes its research. Divisions pool the functions of Board (HR, legal, etc.). Engineering and research, among others, are pooled to achieve the critical mass of expertise and experiment equipment.

NOTE.– Divisions are commonly named SBUs (Strategic Business Units).

The “internal agreements” are passed between the divisions and corporate functions, neither without difficulty nor without much debate and lamentation (everything is too expensive! The competence of players is criticized).

This type of organization was established for the first time in the United States by DuPont de Nemours in 1921 [NDI 01]. It was, for this company, a managerial revolution that would allow the company to return to profit! Quotes from the book by Pap Ndiaye:

– “the industrial departments were from then focused on products rather than functions”;

– “the department of paint and varnish, for example, was henceforth free to choose the marketing strategy that suited it”;

– “departmental decentralization was an unexpected consequence, the continued existence of the cultures specific to each department”.

There would be at DuPont the culture of the mechanics (explosives), the culture of the chemists (dyes), and the culture of the chemical engineers (ammonia technology of high pressures).

#### 2.1.1.4.3. Matrix organization

Matrix organization has emerged because of the importance that the concepts of product-market and globalization have taken. A product can have many applications and can be used in different markets. Thus, a biopolymer can be used in formulations for cosmetics, drilling muds, paints, and food ingredients: it will be marketed by different divisions and trade-offs are often necessary.

The function of the *product manager* is a relatively new concept; the person concerned has a transversal, cross-divisional, cross-market role to promote his product, he intervenes in manufacturing, research, and marketing.

The organization chart shown in Figure 2.4 illustrates a multinational case to gain a foothold in Asia. Largely staffed divisions A and B in the home country are undeveloped in Asia. They are therefore grouped under the same management; this “local” director has two bosses in the home country who will lead a global policy, and he will report to the “Asia” CEO who could be Asian.

The *industrial manager* will have many people to interact with! The plant manager will receive many visitors who want to see the process units at the origin of the product they are dealing with.

The matrix operation is far from that recommended by Henri Fayol: knowing that each individual has only one boss! Let us add to this the culture shocks and we

will measure the difficulty to create cohesion in the business once it acquires a certain size. It is the role of governance to ensure the cohesion of the company by sharing common values with its players.

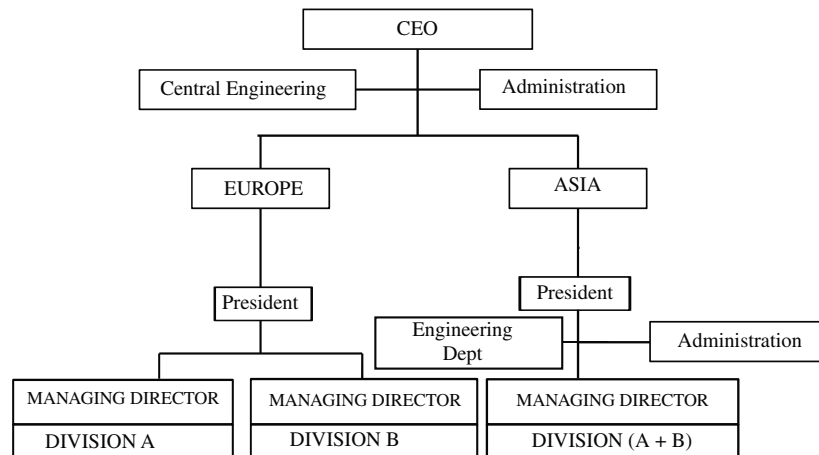


Figure 2.4. Organization chart of matrix organization

### 2.1.2. Corporate governance

The concept of governance is relatively new and results from the inclusion of the concept of sustainable development in the management of the company, thereby trying to be transparent and “democratic”. The term “democratic” implies that decisions will be made after consultation with the majority and for the general good.

Governance can thus be defined as a set of *best practices*, or procedures that will allow the *governance* of the company with a set of *ethics*, hence conforming to a set of affixed *values*. Governing includes both setting targets and *measuring* the differences between planned and actual ones.

In the following section, we will focus on two major tools of governance related to *quality* and *HSE* (health, safety, and the environment).

#### 2.1.2.1. Quality

The concept of quality is as old as the world. The saying “a satisfied customer is a customer who returns” has probably been around since the beginning of time. Quality implies two components: customer satisfaction, the end user, and avoiding wastage during manufacturing. Both are related: the quality of the finished product requires control of the industrial process that involves both machines and operators. What happened at the Hawthorne plant is significant.

*A little bit of history - the Hawthorne plant (Chicago)*

The plant belonged to the *Western Electric Company*, a subsidiary of *Bell Telephone Laboratories*, and largely produced telephone equipment. It was a flagship and experimental plant. In the quality department, created in 1924, Shewart invented the first control card.

Samples were taken at regular intervals along the production lines; their characteristics were analyzed statistically to alert the managers and workers about the possible slide of the manufacturing process. This was the beginning of *statistical process control* (SPC).

SPC would be of great importance during World War II, in weapon production. Its success continued uninterrupted in the years that followed and was the basis of the modern Six Sigma approach.

It was in the Hawthorne plant that Juran, Edwards, and Elton Mayo, one of the founders of work sociology worked. They can be regarded as the fathers of modern quality control and SCP (see Box 2.1).

We will return in Chapter 10, devoted to “Japanese methods”, to quality approaches in the land of the rising sun, methods that Deming and Juran largely contributed to putting in place. We will discuss Deming in more detail.

To make it simpler in the following, we will not use standard notations, but we will just define a few terms. The purpose of this chapter is not in fact to make the reader, an expert in quality but, hopefully, to interest him in it, and to awaken in him a concept of considerable importance.

#### 2.1.2.1.1. Quality: basic concept

The maxim: “quality is customer satisfaction” summarizes the purpose of this concept. There are many definitions of quality, among them: “Quality is saying what you do, doing what you say”, is the one which implies that the company has implemented procedures after analyzing all its processes. We will return to the concept of the process in Chapter 13 devoted to “Change Management”.

To simplify, at this stage, let us say that a process is an identified activity, like placing an order, launching a product, analyzing a finished product, and so on. A process can be described by a procedure or a set of procedures that are *written* documents.

*William E. Deming* (1900–1993), a statistician, was one of the greatest figures of modern quality control. He integrated quality in the management system of the company as summarized in his famous “14 points”. This was the beginning of TQM: *Total Quality Management*. Deming was regarded as a demigod in Japan. The Japanese have founded the Deming Prize for quality.

*Joseph M. Juran* (1904–2008), an electrical engineer, published the “Bible” on quality management in 1951. This book was reprinted several times. It covered all the aspects of quality and that was applied for a wide variety of companies. He was invited to Japan in 1954 and he predicted in 1966 that Japan would become a champion of quality in the following 20 years.

*Armand V. Feigenbaum* (born in 1920), a statistician, published *Total Quality Control* in 1951. The success of this book is undeniable. We owe to him the concept of the hidden plant, i.e. the proportion of plant source of off-spec products.

*Peter F. Drucker* (1909–2005), a prolific author, was a consultant at very large companies and had worked for the Wall Street Journal from 1975 to 1995. He was one of the big-shots of international management.

*Philip B. Crosby* (1926–2001) invented the “zero defect” concept. He established the principles of cost of quality and non-quality.

**Box 2.1.** *The great masters of modern quality control in the US*

Let us consider placing an order for some goods: Who expresses the need for it? Who selects the suppliers? Who approves the final choice? Who receives the goods? Who authorizes the payment?

Quality is also about providing the customer with a tangible or intangible product (result of research, software), a service (bank loan, rental car, etc.), *at the price he is willing to pay*.

To use an old image, quality is not selling a Rolls Royce at the price of compact car nor vice versa: selling a compact car with the quality of a Rolls Royce. The customer has acquired the concept of quality/price ratio. The goal of the value analysis is to optimize this ratio. *Quality is customer satisfaction at the right price*.

2.1.2.1.2. Quality assurance (QA)

The term quality assurance can be misinterpreted; it lies with the company to implement a number of steps to ensure the customer is *assured* that the company

with whom he is related is doing “quality” work. It is about creating a sense of *confidence* among the customers.

The customer who visits a supplier and finds a good reception, good organization, and proper settings will trust it from the beginning.

#### 2.1.2.1.3. Total quality management (TQM)

The modern concept of quality includes *all* processes of the company. Today, one tends to prefer the term *process* to function; “Process” has a connotation of added value and a broader sense that “function” does not have.

There is talk about *quality control*, QA (*quality assurance*). TQM (*total quality management*) is the term most widely used today. We *manage* quality and we *manage* using quality.

Quality, is doing it right from the beginning, faster, better, and more efficiently than the competition. Quality has become an economic weapon, and it must provide a competitive advantage. The modern company must satisfy its partners and “*stakeholders*”, that is to say, all those who have a stake in the company:

- customers, in the classical sense. Without them, there is no business;
- employees: they are the engine of the company. Without them, nothing happens;
- shareholders: they placed their money and thus their confidence in the company;
- suppliers: they are increasingly partners who contribute to certain processes of the company such as design, maintenance, and distribution;
- society in the broadest sense: the country, governments, communities, and certain NGOs.

We must not forget to mention the people who are close to dangerous plants.

The image of the company depends on what its *stakeholders* think of it: *profit no longer justifies everything*.

#### 2.1.2.1.4. Establishment of a quality management system (QMS)

The quality management system (QMS) comprises all procedures from the top of the hierarchical pyramid to the base and allows everyone to know what to do and how to do it. The individual knows what to expect from the upstream and knows what to give to the downstream of the organization.

The company that decides to have a quality approach will select a *system of reference* and implement it by making the most use of external consultants or training part of its staff in order to create an infrastructure of experts who are guarantors of the QMS.

The success of such an undertaking, whose establishment can last over 2 or 3 years, requires the commitment of management. This is the *sine qua non* condition, without which the fight is already lost. That is why the Board may decide that the quality manager must report to them.

A set of procedures will constitute the “quality manual” of the company. If the system of reference chosen is ISO 9000 (see below), the quality manual will be configured as described below.

#### 2.1.2.1.5. Documentary structure of the quality management manual

Authority giving the final agreement	Document structure	Document's field of implementation	Availability of documents
Management Executive team	Level 1 Management manual	Handbook of quality management	Clients
Quality department	Level 2 Process	General organizational procedures	Customers (documents consulted on the spot)
Head of department	Level 3	Implementation handbook Process description	Documents Absolutely confidential “Operators only”
Quality department and related services	Level 4 recording – filing		

**Table 2.1.** *Documentary structure of the quality manual*

The documentary system has a pyramidal structure. The top level generates the documents of the level that is directly beneath it. This manual can be the manual of a company, a plant, a division, or a business unit. The principle of *subsidiarity* is necessary; which implies that an activity is executed by the appropriate level that is “*as low as possible*”.

Let us provide an example: a foreman must have the organizational chart of his process unit and the list of his staff up to date. It can vary several times a year after



hiring, transfers, and departures. He must be at level 3. Otherwise, in the spirit of quality, one must modify the materials at a rate that is unacceptable as it is unnecessary.

Quality systems have led companies to loss by overabundant procedures. Nobody knows where they stand, everybody is confused!

The company that embarked on the “quality journey” seeks an *accreditation*, that is to say, a certification about the fact that the procedures in its QMS are actually followed in the field. It will be for outside agencies, generally independent, to issue this certification after a number of audits.

#### 2.1.2.1.6. Quality and accreditation organisms

In France, many quality-promoting organizations have emerged in the 1950s. The French Association for Standardization (AFNOR), founded in 1926, focused on quality in the 1970s. AFNOR represent France in the *International Organization for Standardization* (ISO) established in 1947 for the development of standardization to facilitate exchanges between countries. The *European Foundation for Quality Management* (EFQM) was founded in 1988. ISO TC 176 is the ISO committee responsible for the standardization of quality systems.

The idea behind the ISO standards is that all companies have a single reference manual and that the resulting quality system is audited by a duly accredited third-party. The company is thus certified and can boast about a quality system that works.

*Accreditation* is one of the bases of QA. NATO was at the origin of accreditation in the field of the weapons industry.

#### 2.1.2.1.7. ISO standards

The ISO published the first version of the 9000 series of standards for quality management in 1987; these standards were revised in 1994 and 2000: we talk about ISO 9000, version 2000. This revision of standards was primarily made to inject continuous progress and make management tools to take into account the study of processes and leadership.

The ISO 9000 (version 2000) standards include environmental management, but not safety. We talk about the integrated management of quality.

Briefly, there are four ISO 9000 (version 2000) standards:

- ISO 9000: fundamentals and vocabulary;
- ISO 9004: advice for improving performance;
- ISO 9001 requirements;
- ISO 19011: audit quality and environment.

Certification is the equivalent of an academic degree. The ISO reference manual corresponds to knowledge, tests to be passed by the company. The examiner is an independent accreditation organisation which, in France, may be the AFAQ (French Association for Quality Assurance), the first certification agency established in 1988.

Being certified is an important element to creating quality assurance among customers. It is an essential goal. For the company, if the assurance works well, then everything works well. The certification process itself is preceded by an internal self-assessment, blank audits to detect abnormalities that must be corrected before the final test.

#### 2.1.2.1.8. Other reference systems, price, quality

There are a multitude of reference manuals. Industrialized countries, organizations, corporations, and associations develop culturally appropriate reference manuals based on their requirements. The automotive industry has a specific reference manual, QS 9000, the weapons industry has its own QA system. Renault developed the reference manual EAQF 94 to evaluate suppliers and plants and AQTE (autoévaluation, qualité totale de l'*entreprise* – self evaluation, total quality of the company), to analyze all business activities. The reference manuals can be considered as a set of rules of conduct.

The pursuit of excellence, quality awards: quality awards are excellence awards! These include:

- in Japan, the Deming Prize established in 1951;
- in the United States, the Malcolm Baldrige Award established in 1987;
- in Europe, the European award for quality created in 1992 by the EFQM (European Foundation of Quality Management).

#### 2.1.2.2. SMS and risk management

##### 2.1.2.2.1. Safety control

The total quality management (TQM) approach of the company includes increasing the management of health, safety of people, goods and products, the environment, and generally all the risks inherent in the company. A company is subject to many risks of all sizes. By definition it is a risky undertaking. Its creation, which requires a down payment, is made in the hope of future gains. *The entrepreneur is one who is willing to take risks.*

The majority of people yearn for the security that can be defined as “*a situation where one has nothing to fear, the peace of mind that they get from it*”. Few people on Earth can enjoy this enviable state throughout their lives. Human activity has risks: as man is moving, working, enterprising, and playing sports, he will be

subjected to risks that will be due to him or he will suffer because of others or the environment in which he is located.

The French, in their history, have never lived so long. However, they are increasingly conscious of living in a risky society which is based on science and technology (*Science & Technology based Society*). This society is made fragile and complicated by the interconnection of networks created by new technologies: telecommunications, transport energy, financial system, medical system, and so on. Asbestos, GMOs (genetically modified organisms), new drugs, cell phones, nuclear energy, and new technologies in general, are new sources of concern; they add to the concerns due to unemployment, insecurity, and the degradation of the environment.

This legitimately raises a number of questions: can modern society control it, manage those risks, or at least reduce them to an acceptable level as globalization, rapid technological changes, terrorism, increasing global population, and the energy crisis looming on the horizon, are all sources of imbalance and instability? The dramatic events of September 11, 2001 in New York and Washington DC have heightened the concept of *vulnerability* because of their size and the fact that they were not foreseeable.

#### 2.1.2.2.2. Hazard, risk, accident, acceptability of risk, and product risk

In everyday language, one often confuses *hazard* and *risk*. These two concepts are the foundations of safety, so it is necessary to understand them [LAU 03].

##### *Hazard*

This is an integral property of a product; it is a situation, a condition, a practice that carries in itself the potential to create/cause damage to people, property, and the environment. Sulfuric acid is a *hazardous* product, which causes very serious burns.

Knowledge of hazards is essential to control the risks that are caused by them. Most industries often have to face the same hazards as practically all industries use chemicals, electrical energy, or set parts in motion. Some industries, however, have specific hazards: the case of the hazard of radioactivity in the nuclear industry.

Risk assessment involves a large number of sciences and technologies: medicine, chemistry, physics, mathematics, metallurgy, mechanics, fluid flow, computer science, environmental science, geopolitics, statutory law, and so on.

##### *Risk*

This is the probability of occurrence of harm from exposure to a hazard. It is a dreaded event. Risk is the component of two parameters, *probability* (or frequency) and *consequence*:

$$\text{Risk} = \text{consequence} \times \text{probability}$$

Probability is expressed in number of occurrences per unit of time. We often take a whole year. Thus, a probability of  $10^{-2}$  means that the risk might occur once in every 100 years. The greater the probability and the greater the consequence, the greater the risk will be. If there is a risk, there must have been an exposure to the hazard and there must have been a contact.

Let us consider several examples. Sulfuric acid will be a source of *risk* if one approaches it, and it can spread. Anyone carrying a phial of concentrated acid takes risks if he climbs up or down a staircase where he can fall (exposure).

On a very steep mountain, snow is a hazard for the mountaineer. He is taking risks when climbing the mountain (contact). The change in weather conditions, a shift from a beautiful sunny day to dense fog will increase the probability of the risk to the climber. He will be exposed to greater risk if his skills are not sufficient to overcome the obstacle or if he is on his own alone and is not roped to an experienced guide.

#### *Accident*

This is defined as an undesirable event resulting in damage to people, property, and the environment; it is a loss. An accident can have immediate or delayed consequences. An explosion can lead to sudden death. Pollution of a river or a lake in small doses can take months or sometimes years to show the harmful effects. It is accidents that one wants to eliminate.

Let us show some examples based on significant accidents:

– “Plus jamais ça, ni ici, ni ailleurs (never again, not here nor elsewhere)” is the name of the group of persons created in Toulouse after the explosion of a warehouse of ammonium nitrate at the AZF plant, on September 21, 2001: the explosion caused the death of 30 people, caused considerable damage to the surrounding residents, and destroyed the plant. This “chemical” accident occurred after other accidents such as Bhopal in India in December 1984, the biggest industrial disaster of all time which resulted in the deaths of around 5,000 people; one will never know the exact number of victims as thousands of people are still living near the plant in extremely precarious conditions;

– March 24 1999, a fire in the 11.8 km long Mont-Blanc tunnel killed 39 victims; it took 56 hours for the firefighters to extinguish the fire. Counsel for the families of the victims said that “the disaster was destined to happen ... Everything was going well in the best tunnel of the world”;

– July 25 2000, a Concorde aircraft crashed into a hotel a few minutes after takeoff killing 113 people: a piece of metal on the runway was probably the cause of this tragedy;

– November 15 2003, in Saint-Nazaire (France), the fall of a single gateway on the *Queen Mary 2*, the largest cruise ship ever built, a technological marvel, caused the death of 15 people a few weeks before the maiden voyage;

– in France the 2003 heat wave caused excess mortality estimated at 14,000 people, mostly elderly people: France, normally organized, administered, equipped, was caught off guard;

– in France the roads killed “more” than 4,264 people in 2009 (12 per day on average) and injured 83,911 (230 a day on average) among which about 4,000 with severe consequences.

#### *The acceptability of risk*

The French react very differently to the announcement of accidents. They accept the massacre of dozens of highway victims over a long weekend, but there will be much more criticism regarding accidents caused by industrial activity. Residents near a factory are at risk but its workers are much more at risk and there are inconveniences to those near the factory as opposed to those who are far away. One can talk about the accepted risk. *Zero risk does not exist! The risk arises from the existence of hazard!*

#### *The nature of the risks*

Each of us meet lots of risks in our day-to-day life. To make an exegesis of risks in a company, would require a full development.

One will only deal with a few elements:

– the employee is a source of major risk. He can cause misoperations unintentionally through negligence or incompetence, or through ill will;

– industrial hazards are through fire, fire accident, destruction of equipment, and serious injury to people and the environment. Statistics of insurance companies show that 70% of SMEs that have had a serious incident (e.g. fire accident) stopped working after a few years. Long and repeated strikes could cause the shutting down of a factory;

– technological risks can be the hacking of know-how, the marketing of products that have bad side-effects in the long run (medicines and plant protection chemicals);

– financial risks are related to exchange rates, payment issues, major investments that do not provide the desired result etc.

The five major risk factors are grouped together and shown in Table 2.2.

Risk	Examples
Natural	Lightning, earthquake, landslides, volcanic eruptions, floods, fires, cyclones, tidal (tsunami), storms, avalanches, and drought.
Economic (Company)	Inadequate management, lack of long-term vision, competition, regulations, loss of experts, information hacking, heavy investment, labor disputes, patents, exchange rates, customer insolvency, product safety, litigation, failure of suppliers, risks related to innovation (new products), organizational changes, risks associated with acquisitions (buy-out, setting up abroad etc.), risks associated with production and distribution, malice, terror, IT, purchasing.
Professional	Occupational sickness/illness (physiological problems: physiological changes (silicosis), functional alterations (loss of sleep), psychological issues: stress, loss of sociability etc.), and occupational accidents.
Transport, travel	Transport of dangerous goods; Transport of people (represents half of all deaths in the industry)
Technology	Product risks: burns, poisoning; Explosions: gas, powders (flour, wheat, sawdust, divided metal, organic products, etc.); Biological hazards including viruses; Nuclear risks: radiological hazard, contamination by radioactive material; Fire hazards; Spills risk: air contamination, soil, surface water, groundwater pollution; Structure risk: collapse (Roissy Terminal 2E in May 2004); System failure: power failure, computer failure, failure of communication (e.g. heat wave in France in 2003).

**Table 2.2.** Major categories of risk

### *Product stewardship*

Product stewardship implies the consideration of the impact of a product on the environment from its manufacture, use and possible recovery (from cradle to grave). This concept must be taken into account in the process of product design, lifecycle assessment (LCA), and its implementation.

### *Risk management*

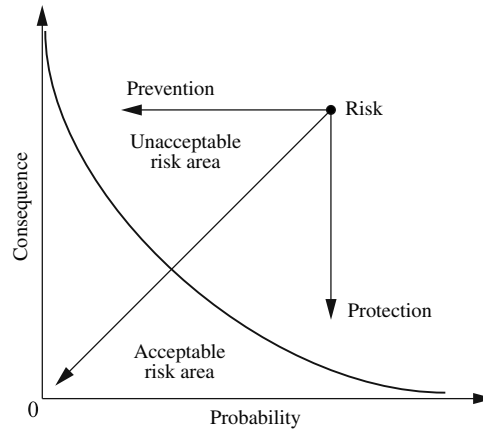
Managing risk is about playing on its probability of occurrence and/or the magnitude of its consequences to bring it to an acceptable value. The decrease in the probability is *prevention*; it tries to act on the source (prevention is better than cure, goes the popular saying).

Preventing fire in an industrial building can require the removal of flammables, moving away from the sources of ignition (open flames, internal combustion engines) and banning smoking. Our mountaineer climbs down if the weather is not good. The decrease of the *consequences* is *protection*. The above discussed building will be equipped with fire extinguishers, sprinkler systems, emergency exits, smoke control, and so on. Our climber will leave with a helmet, ice axe, blanket, and means of communication.

The “*iso-risk*” curve is the curve which marks the boundary with the two theoretically distinct zones: the area where the risk is acceptable and where it is not (Figure 2.5).

<i>Very serious</i>	Acceptable risk	Unacceptable risk	Unacceptable risk	Unacceptable risk
<i>Average</i>	Acceptable risk	Unacceptable risk	Unacceptable risk	Unacceptable risk
<i>Not serious</i>	Acceptable risk	Acceptable risk	Unacceptable risk	Unacceptable risk
<i>Minor</i>	Acceptable risk	Acceptable risk	Acceptable risk	Acceptable risk
<i>Consequence</i> <i>Probability</i>	<i>Very low</i>	<i>Low</i>	<i>Average</i>	<i>Very strong</i>

a)



b)

**Figure 2.5.** a) Acceptability grid of risk versus consequence and probability;  
b) iso-risk curve: prevention and protection

Risks vary greatly according to the time period or country. To give just a few examples, Japan suffers on an average of one earthquake per day of highly variable amplitude. The Japanese live with it. Its buildings are usually designed to withstand earthquakes. Precautions to be taken are made subjects to be taught in school and with appropriate exercises. Foreigners can find on the bedside table of their hotel rooms instructions to be followed in English and a pocket-size flashlight.

Let us not forget financial risks: “*Managing a company is managing risks*”, some managers argue to the point where “*Risk Management*” has become a major feature of large corporations. The man on the street is confused by the sums involved in the “business”, that compromised companies like Enron, a company based on energy and whose bankruptcy hit Wall Street. Vivendi made headlines in French newspapers for months. The man on the street and, *a fortiori*, the shareholder, are surprised that the audit firms and the auditors have not raised any questions from time to time to update the existence of questionable practices!

In order to control the risks of a system, basic knowledge about the hazards is required. Which company would dare to establish itself in Japan without taking into account seismic hazard?

As an illustration, let us consider the case of domestic gas causing casualties and widespread destruction of residential buildings. The risk assessment specific to domestic gas requires knowledge of the conditions for the explosion and should calculate the effects of the explosion. One will talk about explosive and flammability limit, minimum ignition energy, deflagration, detonation, the speed of the flame spread or shock wave, and overpressure. It is therefore an expert work. It is understood that the control of risks through hazard identification is a *job for specialists*.

#### 2.1.2.2.3. The identification and management of risks<sup>1</sup>

NOTE.— The reader may profitably consult articles on *Risk Management Treaty (Treaty SE)* in *Techniques de l'Ingénieur*.

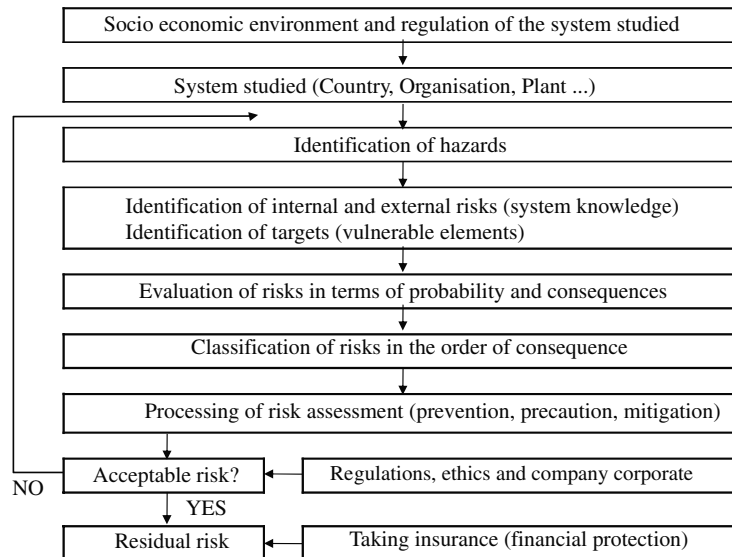
Figure 2.6 shows the *flowchart* for the general method of assessment and risk management of a given system. The system can be an organization, a service company, an industrial company, a plant, a storage facility, and so on.

The system studied “immerses” itself in a statutory socio-economic environment, which has its own cultural characteristics and hazards. The same process unit of production built similar to Marseille or in mainland China will certainly be subjected to external risks that are very different.

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<sup>1</sup> General methodology [DAL 10, LAU 03].





**Figure 2.6.** Flow chart of identification and risk management

The various stages of this process consist of:

- hazard identification;
- risk identification;

– identification of targets for each component. The system is broken down into basic components, each of which will be the subject of study. For example, storage of liquefied gas (propane, butane) alone deserves special consideration. This is an evident source of risk; a gas leak can cause an explosion. The storage facility destroyed in a fire accident in a nearby plant in turn becomes a major risk. Liquefied gas is a source of hazard, storage can be a target. The hazard is even greater as the storage is close to houses (obvious target) or communication lines;

- quantification of risk in terms of probability and severity;

– risk classification in order of importance. In the safety review of an existing plant, we will at first treat the most significant risks;

- reduction of risk to an acceptable level.

The level of acceptability, we have seen, is difficult to determine. Figure 2.5, consequence-probability-acceptability grid of a feared event, is a selection guide. If the feared event is “estimated” to be in a box of acceptable risk, one evaluates the residual risk which, we remember, is never nil. In the case where the risk is deemed

unacceptable, the process is repeated. The residual risk can be covered by an insurance policy; this is the case of fire protection.

### *Systems analysis and risk assessment tools*

#### Systems analysis

There are about 60 systems analysis methods for controlling potential risks. Some are simple, others are more complex and all require practice and practical experience in the area studied for those who use them.

As mentioned earlier, risk identification is done on each system component. The methods mostly used are the PAR, HAZOP, FMEA, and the methods based on trees (Table 2.3).

Methods	Qualitative	Semi-quantitative	Quantitative
Inductive	PAR, FMEA, HAZOP, MOSAR, <i>What-if</i> , HACCP	FMEA, HAZOP	Hazan, fault tree, event tree
Deductive	Fault tree		REX

**Table 2.3.** *Classification of risk analysis methods (Indicative only)*

We distinguish between deductive and inductive methods. The former is from a real or perceived event to determine the causes of it. The second is from a probable failure and seeks to determine the consequences.

List of methods (indicative only):

PAR: preliminary risk assessment

FMEA: failure modes and effect analysis

FMECA: failure mode, effects and criticality analysis

FTA: fault tree analysis

ETA: events tree analysis

HAZOP: hazard & operability studies

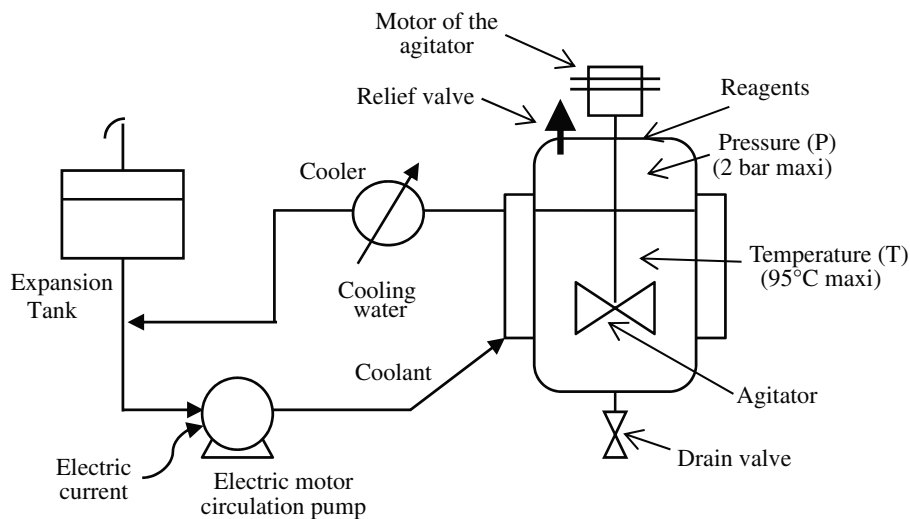
HAZAN: hazard analysis

HACCP: hazard analysis, critical control points

MOSAR: organized and systematic method of risk analysis (France)

REX: feedback

As an illustration, Figure 2.7 shows an agitated chemical reactor, maintained at a desired temperature by a loop consisting of a pump and a heat exchanger supplied with cooling water. This reactor can be part of a process unit of production of an active ingredient of pharmacy encompassing other reactors, distillation columns, various devices for separation and purification. This facility will serve to fuel our thinking in what follows.



**Figure 2.7.** Case study: batch reactor site of an exothermic reaction

#### Preliminary risk assessment (PRA)

This method is widely used before using more sophisticated methods. It is essential at the time of the preliminary studies of a project. Various hazardous elements of the project are identified and potential risks are assessed. This chapter does not go into detail, but the feared events and their potential consequences are listed. We are only concerned about the possibility of reducing the risk.

**EXAMPLE 1.**— A plant under study uses a liquefied gas (propane, butane), usually stored in a refrigerated vessel. The risk will be acceptable or not acceptable based on the distance of houses and heat sources. In this case, the PRA will be decisive in choosing the site.

EXAMPLE 2.— The temperature of the reactor shown in Figure 2.7 is normally 90°C, it must not exceed 95°C, beyond which there is a risk in excess pressure due to the decomposition of the reaction mixture. It is a risk but we know that we will control it; the means to implement it are known and their costs are usually acceptable. The project can be continued.

#### HAZOP method

The HAZOP method (*Hazard & Operability Studies*) was developed by ICI (Imperial Chemical Industry) in the 1970s. It aims to ensure that the system keeps its integrity throughout the course of its operations and, in particular, during the transitional phases (startup, shutdown, and maintenance).

Its implementation by a multidisciplinary team must be made on process flow diagrams and plans. It is well suited to process industries. It aims to identify the possible deviations from normal operating parameters by seeking the causes of it and determining the consequences of it, therefore, the possible risks incurred. To do this, we use keywords (words or guides) such as “more than”, “less than”, or “no” that are applied to temperature, pressure, flow, and so on. The temperature of the reactor mentioned above must be maintained at a maximum of 95°C. It may exceed this value (deviation) if there is no longer agitation, if there is an excess of reagents, and if the cooling system no longer works.

The agri-food industry uses the HACCP (hazard analysis, critical control points) approach designed to identify the critical factors of manufacturing processes.

#### Tree methods

The so-called “tree” methods are a tree-like graphical representation of successive intermediate elements whose chain will lead to the feared event. If the feared event requires the conjunction of two intermediate events, gate is an AND gate (see Figure 2.8).

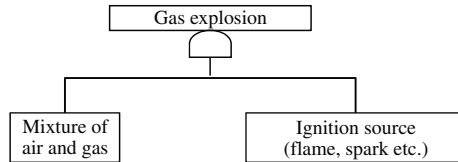
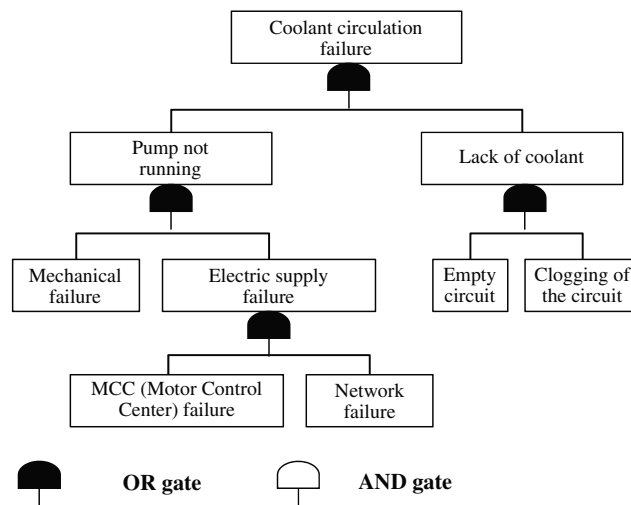
Let us take two examples as proposed in Figure 2.8.

EXAMPLE 1.— The explosion of a mixture of gas and air will require a source of ignition of a specific energy level. If the feared event may occur or if two or more intermediate events occur independently: the gate is an OR gate.

EXAMPLE 2.— The loss of circulation of the loop in Figure 2.7 may be due to mechanical failure of the pump OR to the lack of coolant.

#### Fault trees

This deductive method is either from an event that actually happened or from a feared event. Selected *a priori*, the event constitutes the head of the tree or the top event. It works from the top down.

**Example 1: gas explosion****Example 2: absence of coolant circulation in the case presented in Figure 2.7****Figure 2.8.** Examples of construction of fault tree

This method is extremely useful for the analysis of real accidents, and is a key element of feedback. It allows enriching the knowledge about the system, by identifying weaknesses in order to take adequate actions to ensure the probability of the occurrence of the same type of accident is greatly reduced.

**Event trees (consequence trees)**

This is an inductive method. On the basis of breakdowns or possible failures, the method will try to analyze the behavior of the system. The starting point is an initiating event.

Let us use again the example shown in Figure 2.7. There raises the question: what happens if there is a power failure? Obviously, the electric pump will stop and by consequence the coolant will no longer circulate, the reactor temperature may rise if the feed of reagent is not stopped immediately.

#### Failure mode and effects analysis (and criticality) (FMEA/FMECA) methods

These methods are extremely common in the manufacturing industry. It involves identifying the effects on the system of each failure mode of each component (FMEA). The FMECA studies the criticality of the consequences in more detail. Example: What will happen with a bicycle if the brake cable of the rear wheel breaks down?

Previous methods may be used separately but, in most cases, in complementarity, allows the system to analyze in detail all its components, to identify its risks and to assess the consequences of it. The ultimate goal is, of course, to manage risks, reduce them to acceptable levels, and deal with the residual risk. The so-called tactical risk management will be applied to both the organizations as well as to its supply chain, and to networks (transport, electrical, etc.), industrial tools, consumer products, and so on, throughout their lifecycle. The basic principles that have already been mentioned consist of prevention, protection, and mitigation, which consist of mitigating and minimizing the damages caused by accidents.

#### 2.1.2.2.4. Safety

##### *Safety design*

No inventor, architect, designer or process engineer wants their product or project to be the cause of accidents. And yet ...

##### *General principles*

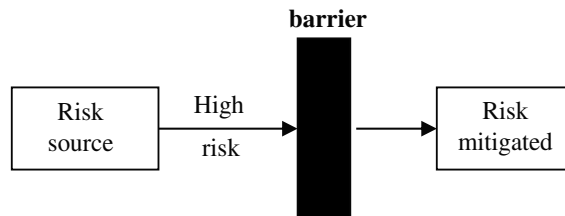
At present, any design uses the *value analysis (VA)* and *functional analysis (FA)* methods invented in the United States during World War II. The FPS (functional specifications), established by the client destined for the general contractor, must absolutely specify the constraints generated by risk analysis (see Chapter 9, “Project Management Techniques: Engineering”).

##### *Barriers (protective features)*

This concept was originated in the nuclear industry, whose main risk is the spread of radioactive materials. The idea is to protect the people and environment by confining hazardous materials. The reactors used in France are of PWR-type (pressurized water reactors), which implement three barriers:

- the fuel is kept in a zirconium shaft;
- the reactor itself is enclosed in a casing;
- the last barrier is a concrete vault lined by a metal wall that covers the reactor and primary circuit.

This type of defense is illustrated in Figure 2.9.



**Figure 2.9.** Principle of establishing a barrier

In depth defense enhances the safety of industrial systems by increasing their resistance to “attacks” of any kind and especially the ones originated by human or technical misoperations. Technical barriers can be:

- *static*: a firewall slows down the spread of the fire; a hazardous reactor can be installed in a blockhouse closed on three sides and the fourth open onto an earth dam (the possible “shrapnel” caused by an explosion can be stopped), storages of hazardous materials can be buried, submerged in water, and so on;

- *dynamic*: sensors, measuring instruments contribute to make the system safe. Example in Figure 2.7: an abnormal rise in temperature will cut the supply of the reagents. Another barrier would be as a last resort to empty the reactor contents into a blow down vessel containing a neutralizing agent;

- *organizational* (or administrative or procedural): trained operators must comply with instructions, written procedures that require them to take action in the case of the drift of the system. These administrative procedures are inexpensive; they reflect the fact that operators are entrusted.

Technical barriers, especially dynamic, evidently complicate the system of which they may form an integral part and be themselves a source of hazards if they are not maintained in good working condition. A highly “instrumented” system can be very difficult to start. The “redundancy” of various safety features and alarms can cause untimely shutdowns that disturb the operators.

Construction safety (realization of the project)

Any construction uses codes, standards, and must abide to regulations. Risks can be minimized by the use of specifications more stringent than what is normally necessary or required:

- increasing pressure design (as a result it will be necessary to perform the tests at a higher pressure!);

- choosing more sophisticated materials that are totally corrosion resistant to fluids in use: stainless steel 316 instead of steel 304;

- total X-ray of the weldings;
- eliminating flanges and gaskets (the cooling circuit of Figure 2.7 can be completely welded ... but in order to dismantle it, it is necessary to cut it ...);
- choice of intrinsically safer pieces of equipment: the circuit pump may be of the hermetic or magnetic drive type: therefore, one need not worry about the leakage of the mechanical seal (although the pump may be more expensive!).

#### Safety at the end of lifecycle

No company producing goods today can ignore the fate of its product at the end of its lifecycle. At present, car manufacturers must consider the recovery of vehicle components and the fate of their component products (paint, plastics, heavy metals). The French are increasingly concerned about the pollution of groundwater by herbicides, fungicides, and insecticides that helped to lift their agriculture to the forefront globally. “Farming” must meet certain distances of groundwater, to limit the prescribed doses, and so on.

#### Protection, mitigation

*Protection* against the hazards, which aims to reduce their consequences, can take many forms:

- equipment that can be subjected to explosions will be equipped with relief valves, relief traps, and vents connected to ducts that lead explosive products toward a place where circulation is prohibited (in Blaye, France the explosion of wheat silos had 11 victims);
- control rooms will be designed to withstand the pressure wave caused by a possible explosion;
- sensors, controllers (of pressure, temperature, flow) that continuously monitor the system are all watchdogs designed to keep the system within operating limits where the risk is under control!
- water curtains can reduce the spread of toxic clouds;
- fire protection is an integral part of any facility as well as personal safety equipment: helmets, goggles, gloves, safety shoes, proper clothing, and self contained breathing apparatus save many lives. Let us just look at our firefighters fighting against forest fires.

*Mitigation* is intended to mitigate the damage of accidents when they occur: in general, reducing all that is a source of energy such as temperature, pressure, quantities used, speed, and to ensure that flow of solids, liquids, gases in case of spill are oriented in a direction where their impact is minimal.



The plant layout plays an important role: emergency exits, fire escapes, easy access during emergency (ambulances, fire trucks) enable to reduce the consequences of disasters. At first, it is necessary to save human lives and protect the property as much as possible.

As discussed, the Seveso Directive requires the establishment of an “internal operation plan” (IOP): this is implemented under the authority of the person in charge of the site. From potential accident scenarios, one defines the means and actions to be implemented to address the residual risks such as fire, explosion, and spill of harmful products.

When the consequences of an accident go beyond the local management capabilities, administration can implement a special intervention plan (SIP). This plan will take over the management of relief operations. These plans must be exercised to be effective! These exercises often reveal shortcomings that are the least unexpected; sirens not working, emergency electricity generators that do not start, lack of procedures, misunderstanding of staff, who confuse reality and exercise and do not go to the shelter designed for ultimate personal protection points fixed in advance ...

Communication with neighbors is essential when the accident has consequences that go beyond the limits of the plant. Neighbors must be informed and told about it, trained in the case of a severe accident. They must know beforehand what has to be done; do they have to shut themselves away in their homes and stay by the phone or evacuate through determined routes? The interruption of rail and automobile traffic, proximity of schools, hospitals, nursing homes create much additional difficulty. The more and more aggressive intervention of the media may create additional difficulties.

### 2.1.2.3. *Cost and time management – concept of accounting*

#### 2.1.2.3.1. Investment management

This theme is addressed in Chapter 9.

#### 2.1.2.3.2. Profitability criteria

##### *Basis for manufacturing cost evaluation – Full Manufacturing Cost (FMC)*

NOTE.– The concepts developed below were those in force in the Rhone-Poulenc. The names may vary depending on the policy of the companies. But, the basic concepts that every engineer should know are the same.

The FMC is the sum of the proportional costs (PC) or variable costs, and non-proportional costs (NPC) or fixed costs:

$$FMC = PC + NPC$$

The PC vary with the tonnage unlike the NPC that are fixed.

*Proportional costs (PC)*

The PC include the cost of raw materials (RM) and utilities (UT) and are expressed in \$/kg. The cost of raw materials and utilities is obtained from their purchase price or price per unit and the specific unit consumption:

$$\text{Costs RM/kg} = \text{Price per kg} \times \text{Specific unit consumption (SUC)}$$

SUC is expressed in kg/kg and is higher than the stoichiometry because the reaction yield is never 100%. SUC may be:

- the budget values;
- The actual unit consumption; this one can be smaller than budget in the case of process improvement or greater in the case of process deterioration.

The PC depends on the price of chemicals and raw materials consumption. The chemist in charge of research must calculate the PC from the beginning of the study. The cost of certain strategic raw materials may depend on negotiations with the supplier. This can be a major variable of a project that will only succeed if there is an agreement with the supplier.

The *proportional costs* are mainly independent of the percentage of load of the process unit. In fact, there may be improvement or degradation of performance according to the load (percentage of the minimal capacity).

Generally, the cost of utilities (in \$/kg) decreases if the rate increases because the energy losses are practically constant.

*Non-proportional costs (NPC)*

Non-proportional costs of the product (NPC) include:

- direct NPCs that represent the labor costs (LC) of manufacturing (direct and supervisory), maintenance, and laboratory work:

$$\text{Manpower direct in } \$/\text{kg} = \frac{\text{hours} \times \text{cost per hour}}{\text{tonnage produced}}$$

The maintenance costs include the cost of labor, spare parts, and the cost of contractors.

Laboratory costs are inclusive of costs of routine tests (control of operations) and analysis done on request (Figure 2.1).

*NPCs are direct costs that new process unit created at the plant who hosted it.*

– indirect NPC or SPC (specific plant charges) Plant overheads (OVHD).

A process unit which will be located in an existing plant will benefit from its infrastructure:

- administration: general management, personnel department, accounting, and so on;
- support functions: fire department, security department, first aid center, utility production, waste water treatment, shipping and receiving, and so on.

Proportional Cost (PC)	SPC	Raw material cost in \$/kg	Production cost in \$/kg
Raw material 1	3.0 kg/kg	0.30	0.90
Other raw materials			0.20
Total raw materials			1.10
Utilities (electricity)	10 kW/kg	0.06	0.60
Other PC			0.10
Total utilities + PC			0.70
<b>Total PC</b>			<b>1.80</b>

NPC and depreciation	NPC in k\$/year	Product cost in \$/kg
Labor:	3,600	0.24
Maintenance: 1.4 M\$/year	1,400	0.09
Other costs = fixed costs + taxes + plant OVHD	6,000	0.40
<b>Total NPC (excluding depreciation)</b>	<b>11,000</b>	<b>0.73</b>
Depreciation of 8 years: 70 M€/8	8,750	0.58

Analysis of the full manufacturing cost	€/kg	FMC %
PC	1.80	57.9
NPC	0.73	23.5
Depreciation	0.58	18.6
<b>Product cost</b>	<b>3.11</b>	<b>100</b>

**Table 2.4.** Example of product manufacturing cost highlighting proportional cost

SPC is some thing like the *property tax* paid by the product to the plant.

SPC is *broken down* on products using keys defined with the accounting service. For example, the costs of administration can be broken down proportionally into the number of operators on each process unit.

The NPC will vary greatly depending on the size of the process unit, the percentage of the plant load, i.e. the percentage at which the plant is run in terms of percentage of the industrial capacity, the size and organization of the host site. Unlike the PC, NPCs are not easily accessible; they will depend on the plant organization and efficiency.

#### *Cost analysis*

Let us consider a process unit with the following characteristics:

- capacity: 15,000 tons/year;
- investment: 70 M\$;
- maintenance costs: 1.4 M\$/year (2% of investment);
- staffing (number of operators): 60.

#### *Indicators of the analytical income statement (AIS)*

The AIS includes several profitability indicators: contribution margin, gross margin (GM), operating income (OI), earning before tax (EBT), net income (NI), and so on, as shown in Figure 2.10.

*Contribution or contribution margin* is calculated by subtracting the PC from net sales (NS). This is the most easily accessible profitability criterion. If the contribution is small, the case is hopeless; one must reconsider the chemical process (raw materials, performance) or the purchasing policy.

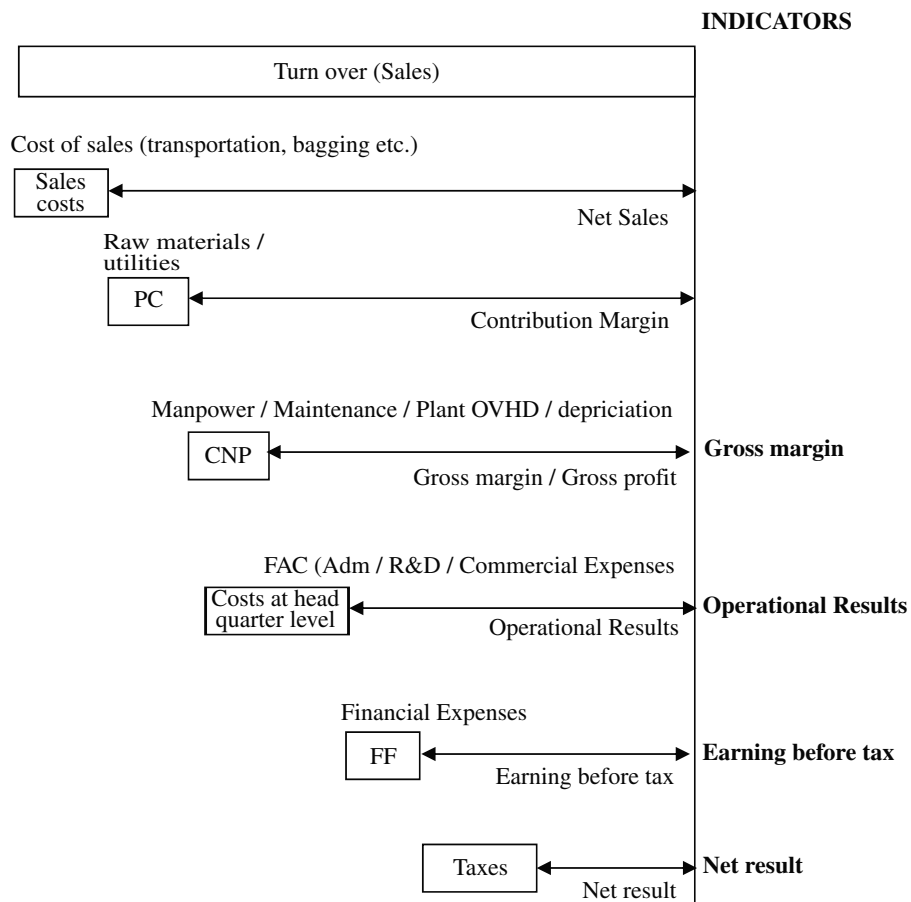
*The contribution shows whether one is a good chemist and/or a good buyer: this is a vital indicator.*

A low contribution margin leaves no hope of profitability; it is the result of a bad choice or difficult access to essential raw material(s) or a sale price that cannot be increased.

This is the case of “*commodities*”; customers can easily find substitutes.

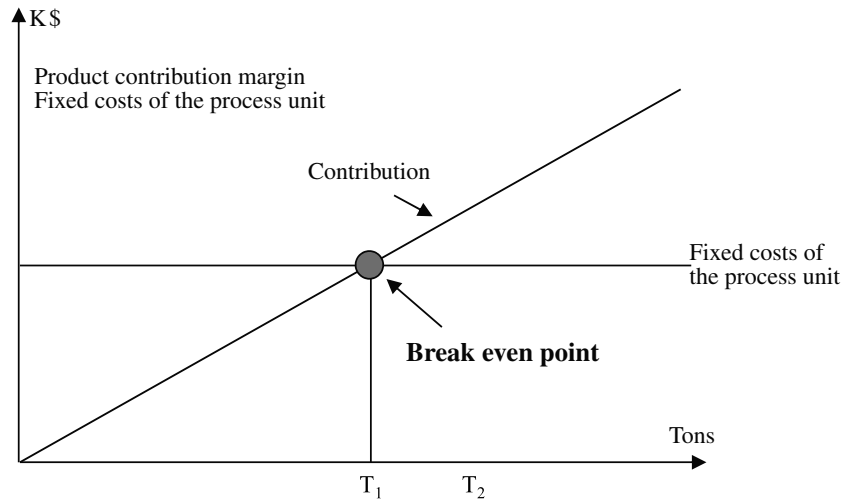
The value of the *minimum contribution* for the activity to be profitable depends on the sector of the chemical industry. As an example the following economic sectors should have a certain contribution margin if one can expect a profit:

- fine chemicals: contribution > 40%;
- agro-chemicals: contribution > 60%;
- pharmacy (the high contribution needed for the pharmaceutical sector is due to the high cost of research, high cost of manufacturing and huge investments costs of production facilities): contribution > 80%.



**Figure 2.10.** Analytical income statement or profitability indicators

We define the “*break even point*” of the process unit as the intersection between the product contribution (contribution margin) to the fixed costs of the process unit (NPC): it is expressed in tonnages. This concept is illustrated in Figure 2.11.



**Figure 2.11.** *Illustration of the concept of break even point*

Under tonnage  $T_1$ , the product contribution does not cover the fixed operating costs of the process unit. It is necessary to reach  $T_2$  to begin to cover the over-heads, research, depreciation, and financial expenses, so as to start making money.

*Gross margin (or gross profit)*

This is obtained by subtracting the NPC from contribution and depends on the size of the process unit: a competitor who has a process unit several times larger can have an economical advantage, provided that his process unit is running at full capacity.

It also depends on the operating conditions:

- number of operators;
- maintainance cost (a process performing well on a chemical basis may be penalized if it uses high pressure, exotic materials).

The process unit can be penalized by a poorly managed, non-performing plant, with high indirect costs.

*The gross margin shows if it is a good performing manufacturing plant.*

Let us consider the previous example and calculate the cost and gross margin based on the plant running at a certain percentage: a percentage of the nominal capacity, and let us consider the case of the plant running at 50% of nominal capacity. The results are summarized in the following table.

	Product cost in \$/kg	CM and GM (%)
Selling price of the product = \$6.00/kg		
FMC at plant nominal capacity PC = 1.80 and NPC = 1.31	3.11	
Product cost at 50% of the plant nominal capacity PC = 1.80 and NPC = 1.31 × 2	4.42	
CM = $[(6.00-1.80)/6.00] \times 100$		70
GM with a nominal capacity = $[(6.00-3.11)/6.00] \times 100$		48
GM to 50% of the nominal capacity = $[(6.00-4.42)/6.00] \times 100$		26

**Table 2.5.** Example of calculating the gross margin of a process unit based on the load

NOTE.— The contribution margin (CM) is independent of load rate.

The gross margin (CM) is halved from 48% to 26% when the operation rate is reduced by half: the impact is almost considerable.

In the case of a new process unit, there is a question about its rated capacity (tons/day), whereas for an existing process unit, one can only consider the plant load of operation.

The first concern, building very big (with a risk of under-utilization) leads to big overloads and significant depreciation: investment must be reimbursed! In contrast, building very small can lead to a lack of sales. A competitor who has a larger workshop will have lower NPC provided the plant is saturated, thus better margins and a more aggressive trade policy.

In this type of dilemma, the answer can be sought from among these four options:

- be the first on the market (move fast);
- make use of modular facilities hoping that they can be at least partially for other productions. This can be realistic for the fine chemical sector including pharmacy where conventional batch reactors for instance are extensively used;
- outsource entirely certain steps of the process in order to decrease initial investment and therefore decrease the risk;
- use multipurpose workshops (<1,000 tons/year).
- this is an option valid for capacities in the order of magnitude of 1000 Tons per year.

*Other indicators*

OM	Operating margin = operating profit + amortization
EBITDA	<i>Earning before interest taxes, depreciation and amortization</i>
OM/EBITDA	“Money that is available”
CE	Cost of capital employed = Net fixed assets + (working capital)

**Table 2.6.** *Profitability indicators**Other criteria of profitability*

Pay back (simplistic)	= [Amount of the investment (k\$) / Gain (k\$ / year)] = years NOTE.– The gain can be from contribution (performance gain) or from operating margin
Capital intensity	= Total investment/sales turnover
IRR	= Internal rate of return
RCE	= Return on capital employed = operating margin/CE

**Table 2.7.** *Other criteria of profitability**The downward spiral of fixed costs*

Let us assume that in the plant schematized in Figure 2.1, process unit C is stopped. The activity considers that the product from C is no longer profitable.

Fixed costs *absorbed* by C must be allocated to other products (they are usually not absorbed at the corporate level). This is particularly the case of SPC (specific plant charges). Therefore the cost of process units A and B increases, then their margins decrease. The activity responsible for the product from B may lead to the closing of process unit B ...

*The absorption of fixed costs is a key concept in industrial life!*

**2.2. Entrepreneurial mode, project management – the operational/entrepreneurial conflict**

*Entrepreneurial mode* is to change the existing *by managing a project portfolio* from the strategic plan so that the company can evolve [DEC 80].



It is a condition *sine qua non* for its survival; it is about influencing the running of the company to give it new direction.

Current management techniques give the name *project to any set of operations related to a change*. The company has to monitor its projects, especially the physical investment projects that must be followed in terms of cost, schedule, quality, and profitability. These concepts are developed in Chapter 13, “The management of change”.

Project management involves all functions of all areas of business operations. Its essential components are listed in Figure 2.12.

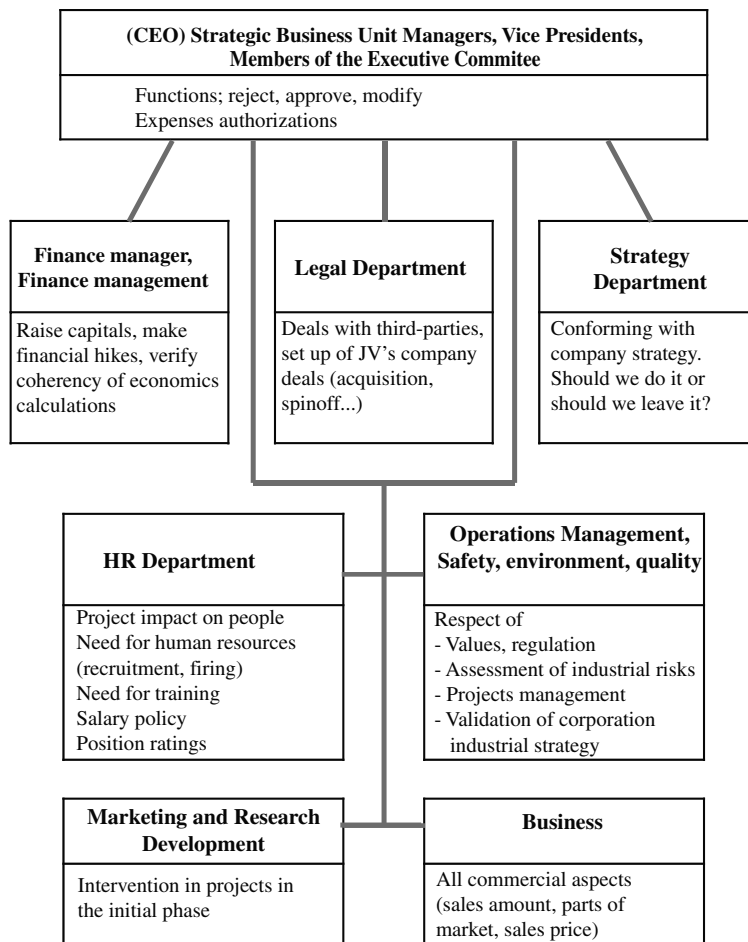
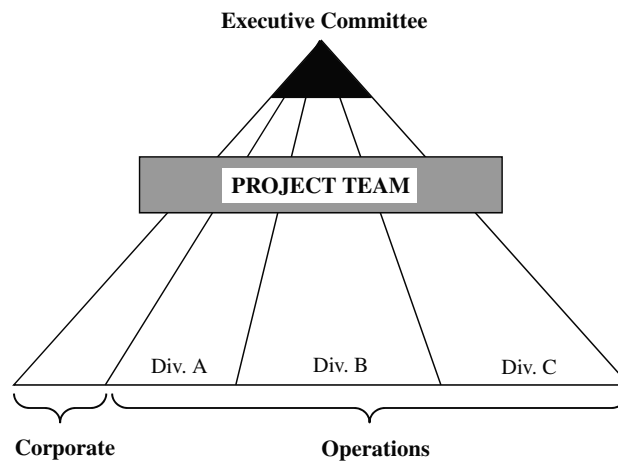


Figure 2.12. The project and the major business functions

A company cannot allocate large human resources to an activity whose future is uncertain. This applies to preliminary projects or studies covered in Chapter 6, “The industrialization process: preliminary projects”.

It will, therefore, *draw* existing resources to form a temporary team or project group which will conduct the study as far as possible until it is decided either to continue or to stop.

The project team is often composed of members from the *corporate* and members “taken” from business activities (Figure 2.13).



**Figure 2.13.** Positioning the project team in the corporation

This organization is, actually, a source of potential conflict, as a result of:

- dilution of responsibilities, an “online” person in charge of a specific duty is managed by a temporary boss different from the real one for activities not regarded as essential most of the time;
- the workload imposed on people who in addition to their daily work have to spend “hours” on an additional tasks.

*Conflicts still exist. The problem is to solve them!*

This “*respiration*” of the operational and entrepreneurial company is one of its major features. It has impacts on its employees. Some will find there a pleasant distraction on a daily basis at the risk of abandoning the existing with sometimes unfortunate consequences.

Some will refuse to the extent where they can turn away from the assignment entrusted to them.

*Industrial life is no easier than other parts of life.*

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## Chapter 3

# The Strategic Management of the Company: Industrial Aspects

The company must constantly review the suitability of its products to be marketed, in terms of volume, quality, and value of use in the medium- and long-term. It must ensure the compliance of the products and its production facilities with regulatory requirements, compliance with its ethics, which includes more and more components of sustainable development.

These considerations lead to reflections and studies that will involve both its organization and production facilities. They are at the origin of the strategic plan.

The finalized strategic plan consists of projects or more precisely, studies, preliminary projects, which will have to be evaluated over time, in terms of opportunity, investment, and feasibility.

For 30 years, companies have had to deal with economic globalization and increasing competition; and there are practically no more barriers to trade and communication. In this context, they are obliged to define their strategies at the global “village” scale, which is still suffering from the repercussions of the financial crisis generated in the United States in September 2008.

The production economy that prevailed in France during the “Glorious 30 Years”, which followed World War II, paved the way to a free market economy. In the good old days, one had to only produce: the customer had to take only what he was offered. It didn’t take more than two decades for the free market economy to become predominant!

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Chapter written by Jean-Pierre DAL PONT.

*The customer is king again!* He is the focus of all concerns; his satisfaction is the major challenge of the supplier. He has too much to choose from for mass consumption products. He wants to be served better and faster. This requires increased flexibility on the part of the company and higher quality products, therefore it requires its operating mode to be reconsidered constantly. The survival of the company lies in its economic performance.

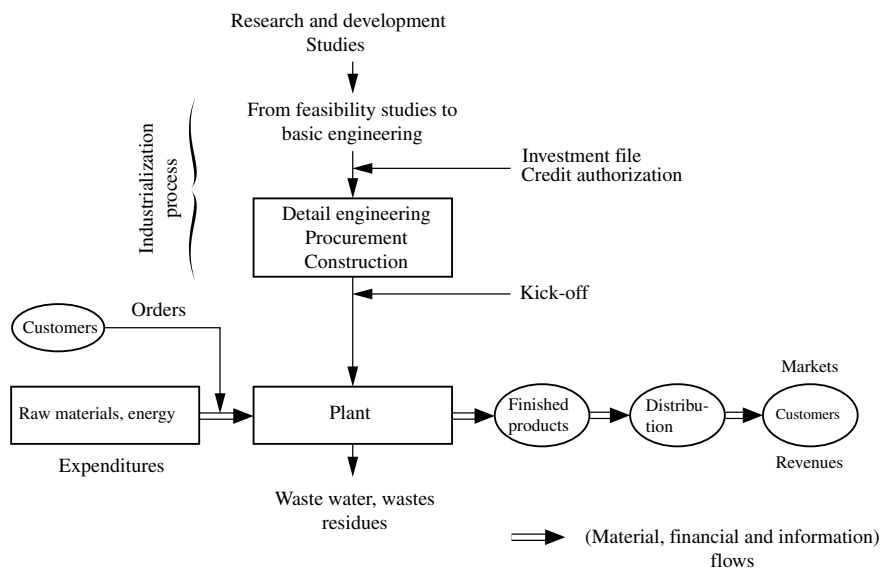
### 3.1. Systemic view of the industrial company

Let us look at Figure 3.1.

The vertical part of the figure shows the process of industrialization, starting from the result of studies and research, which further leads to a production facility. This approach is described in Chapter 6 (“The industrialization process: preliminary projects”).

The concept of the *supply chain*, particularly introduced by Christopher [CHR 92] in 1976 covers the processes included from customer orders up to the distribution of finished products. It requires the mastery of material, financial, and information flows, which is illustrated in the horizontal part of the figure.

The production facility requires an initial investment. Its operation involves expenditures concerning:



**Figure 3.1.** Systemic vision of the industrial company

- the purchase of raw materials and energy;
- operating costs, manpower, maintenance, charges related to long-term assets, human welfare, property and environmental costs;
- storage costs and costs related to distribution of finished products.

For there to be a profit, the sales proceeds should cover the charges of invested capital, the direct and indirect costs of the plant, not to mention the management, research, and marketing costs.

### 3.2. Strategy and strategic analysis of the company

Strategy is a long-term vision: a vision of what the company would like to do and how it wants to do it, which markets it wants to be present in, with how much penetration, what products it wants to market, and in which countries [DEC 80, QUI 95, THI 84].

With the subjects to competition, market trends, and aging of its products and processes, the company has to think about its future and define the elements that are necessary to ensure its continuity.

It must do so in time; *managing means foresight!*

In addition to the profit, its continuity depends on *the control* of all its processes that guarantee an operation without adverse events. The adverse events include technological disasters; the Bhopal disaster led to the disappearance of the Union Carbide Corporation, a company that was 100 years old. In France, the AZF disaster led to the disappearance of part of the industrial base in Toulouse.

The company's strategic vision consists of developing so-called strategic objectives that are formalized into operating plans which include human and financial resources and planning required for their completion.

In what follows, we will focus specifically on the technical aspects involving research, process research methods, and their relationship with the business.

Strategic analysis rests on two pillars:

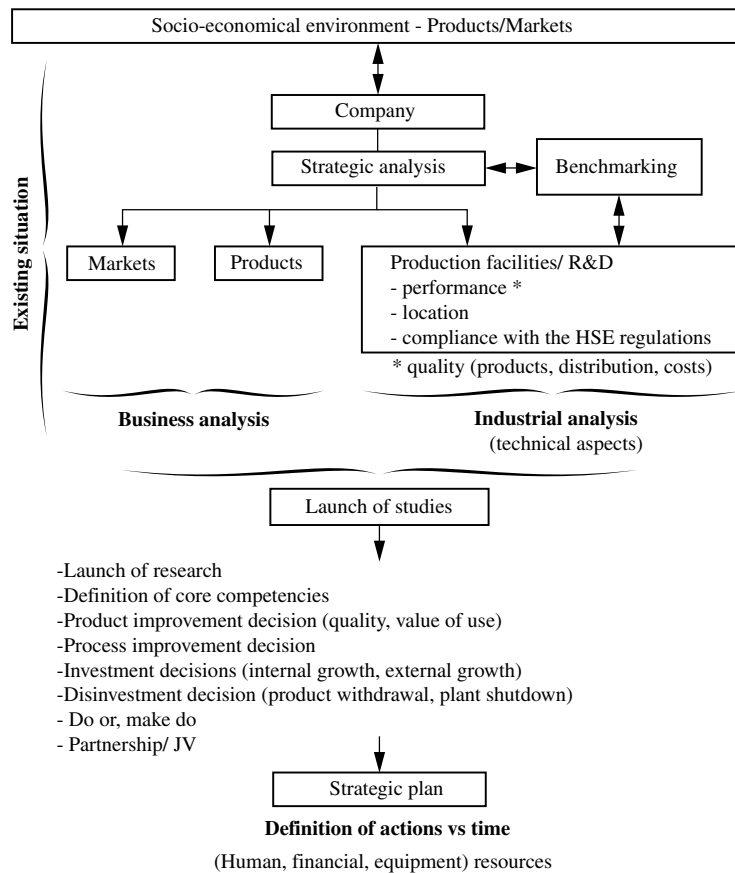
- the markets/products relationship and industrial analysis.

The markets/products relationship is denoted by business analysis in Figure 3.2.

NOTE.– The word *business* merges the terms of business affairs, operations, and markets.

Markets are numerous, of varied sizes and are very diverse: automotive, pharmaceuticals, construction, cosmetics etc.

The industrial analysis in Figure 3.2 focuses on all the technical facilities (laboratories, engineering), plants, workshops, distribution facilities (stores) as well as the subcontracting tools, the various industrial holdings including those in *joint ventures*, commonly referred to as JVs.



**Figure 3.2.** Principle of the strategic analysis of the company (technical aspects). Establishment of the strategic plan

Definition of JV: *strictly speaking*, JV refers to a joint venture made by two or more entities who combine for the better hopefully, although sometimes for the worse. A key characteristic of a JV is the percentage of partner ownership. If there are two partners, the one who holds at least 51% has the control ... in principle.

The markets/products analysis may show extreme cases:

- in a given country, the company has a leading position with significant market shares (penetration), products that respond best to the customer's needs, in accordance with the operative as well as foreseen regulations, products considered "greener" than those manufactured locally by competitors, a first-class *supply chain*;
- in another country, the situation is absolutely different: low penetration, products surpassed by those of competitors, products to conform with the regulatory perspective. Products are imported whereas the competitors manufacture locally, which gives them a significant advantage.

The analysis of the production facility can reveal:

- a first class facility, implementing the best process to date, which results in comfortable marginal incomes reflecting a choice of appropriate raw materials, good yields, and controlled energy consumptions.

Satisfactory gross margins show a suitable production capacity, a workshop design that provides optimized operating costs for manpower and maintenance.

The concepts of cost and profitability are discussed in more detail in Chapters 2 and 9, which are dedicated to "The two modes of operation of the company: Operational and Entrepreneurial" and "Project management techniques: Engineering", respectively.

The analysis of the facility can reveal that a process is outdated, when the operating costs are too high, when the plant requires major parts to be upgraded, and when the production capacity is too low and does not meet the market demands. Against the backdrop of the given country, growth can be very high, very low, or moderate. The political situation can be either stable or unstable and the economy can be either thriving or ailing. The latter considerations require a *benchmarking* approach and risk analysis.

### **3.2.1. Strategic analysis tools**

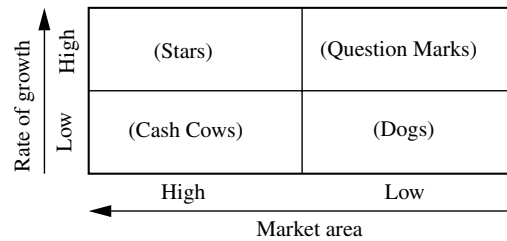
Consulting firms use their own tools; we will mention three of the most commonly known tools.

*External benchmarking* aims to compare itself with competitors. The comparison relates to the respective market shares, product quality, and their functionality and selling prices and, in general, the strengths and weaknesses of each of them. It is essential to try to predict what competitors are going to do. In large groups, *benchmarking* can be *internal*: comparison of industrial sites, processes, and so on.



The *BCG analysis* of the Boston Consulting Group consists of positioning a product and a company on a graph that has the market share taken by the analyzed entity on the abscissa and the ordinate the growth rate of the market where it operates.

The BCG matrix has four areas. On the basis of its position, the entity may be called a Star, Question mark, Dog, or Cash cow (see Figure 3.3).



**Figure 3.3.** *BCG matrix (Boston Consulting Group)*

The terms used are self-explanatory.

Being in a fast-growing market where one's market share is significant (Star area) is better than being in a market that has no hope and where one has no significance (Dog area).

The *SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis* considers all the criteria denoted by each letter of the acronym.

It is a method of analyzing the organizational, business, and competitive environment of the company in order to define the strategic as well as tactical and operational action plans. It is a handy diagnostic tool that favors rational decision-making in key areas. It can be applied either to a product in a project or to an idea within a company.

The SWOT analysis examines the four key factors of strengths, weaknesses, opportunities, and threats of every sector of the company. The analysis can be carried out on the business plan, marketing, competitor analysis, process development, research, and so on.

It is performed as a team, similar to *brainstorming*. But contrary to this very open technique, the SWOT analysis is controlled, as it is based on the setting up of questionnaires (one for each factor) for which the team tries to provide answers. Each questionnaire can include up to 15 selected questions.

The methodology consists of grouping these key factors (strengths/weaknesses and opportunities/threats) into pairs and making two diagnoses, one in the internal

environment (the organization) and the other in the external environment (the market).

The strengths may result from a solid patent portfolio, recognized brands, integration of raw materials, loyal customers, and so on.

It is the opposite in the case of weaknesses.

	<b>Positive</b>	<b>Negative</b>
Internal	S STRENGTHS	W WEAKNESSES
External	O OPPORTUNITIES	T THREATS

**Table 3.1.** *SWOT matrix*

The relevance of the SWOT analysis is based on the creativity of the work group and its richness in ideas. The selection of questions is a crucial element: so is the quality of the conclusions.

**3.3. Development of the strategic plan: its deliverables**

As a rule, strategic analysis is conducted by sales offices, marketing, research, industrial management, and often with the help of outside companies: it is a collective effort. The company may manage the plan that coordinates all the studies. Major decisions can be examined by all the functions of the company as described in Chapter 2.

Projection into the future, with all the difficulties that can be guessed, is clearly essential.

The top management is responsible for the strategy of the company. It is important for them to define the main orientations and axes. Mergers, cessions, partnerships, and major projects reflect these types of actions from the public and shareholders.

The development of the strategic plan requires the most diverse studies encompassing the commercial and technological aspects.

These studies, which require time, expertise, and financial resources, must follow the PARETO analysis (see Chapter 13 which is dedicated to the management of change), which is the effort spent should be proportional to their importance.

These preliminary studies normally lead to:

- the launch of new research to find new products, new markets for new applications, new chemical routes, and new processes;
- the abandonment of research in unfavored sectors;
- highlighting of the need to improve certain products and processes, to find commercial advantages, and to satisfy new customers and new regulations;
- the withdrawal of products that are unprofitable or detrimental to the image of the company;
- the study of physical investments in relation to the creation of new plants and manufacturing sites. This is called *internal growth*;
- company buyouts, the formation of partnerships and subcontracts; this is called *external growth*;
- the abandonment of products and markets;
- the sale of assets. This is called *disinvestment*;
- the closure of sites;
- the reconsideration of the mode of organization of the company; this is called *re-engineering*.

This diagnosis, if pursued seriously and without complacency, will highlight the strengths and weaknesses. The strengths of today can become the weaknesses of tomorrow: products can turn out to be very profitable today, but are at the early stage of a downward phase without having replacements, because research has not been launched on time. There are many examples. The concept of time is a key concept.

The development of the strategic plan leads to a set of preliminary projects whose study methodology is the subject of Chapter 6.

An important result of the strategic analysis is the study of the technologies used and the resulting vocations.

### **3.4. Technological choices and vocations**

Technolog(y)/(ies) form(s) the very basis of the company's know-how.

We can define technology as the set of means of studies, application, engineering, process, and all that makes up the know-how necessary for the design and implementation of industrial facilities.

Technology originally meant the rational study of techniques that were synonymous with the know-how of manual jobs; the know-how of the carpenter, the mason, and the glass maker. Much later, it meant the knowledge required to manufacture a product; iron techniques, ceramic techniques, and so on.

In modern parlance, one speaks of new, state-of-the-art and high technologies. They are the object of desire, trade, and espionage. This is the knowledge asset of the company that it strives to safeguard and develop.

A technological breakthrough happens when a technology surpasses an existing technology by making significant, indisputable progress; for example, the jet airplane replaced the propeller airplane.

A technological breakthrough also refers to the emergence of a new domain. This holds true for information technology, biotechnology, as well as an artifact as modest as the “post-it” note of the 3M Company, which took 10 years of effort for the industrial development and marketing [NAY 93]. Who can do without the “post-it” note nowadays?

The implementation of a technology as defined above uses expertise which is now known as “competencies” that implicitly include the know-how of employees.

The field of biotechnology involves biologists, chemists, process engineers, and project engineers, who know for instance how to define a specific piece of equipment that can be easily sterilized.

The term *core-competencies* is used to define the skills that the company cannot do without if it wants to excel in the field of activity specific to it. This term therefore implies the know-how and men who vouch for it.

Defining the *core-competencies* is a difficult task; which technician should be hired, what training should be given to existing employees, how can they be made to develop so that they become suitable for the company?

This is one of the first responsibilities of the human resources department, which is in charge of selection, training, staff development, and defining the company’s “core competencies”.

#### *Case study*

Two companies, one dealing with basic chemicals (Company A) and the other with specialty chemicals (Company B), have the characteristics listed in Table 3.2.

The corresponding *core-competencies* are tentatively given in Table 3.3.

Company	A	B
Field of activity	Basic chemicals	Specialty chemicals
Number of raw materials	A few	Several hundreds
Number of products	4	600
Tonnage/products	>10,000 tonnes/year	10–1,000 tonnes max/year
Flows	Continuous	Discontinuous/batch
Number of plants	Four specific plants	Six polyvalent/multiproduct plants
Investment	Heavy	Low
Type of sale	Catalog	Value in use
Application laboratory	No	Yes, very near to customers
Customer support	No	Yes
Distribution mode	Bulk and over the fence	Drums

**Table 3.2.** Characteristics of two companies: company A with basic chemicals – company B with specialty chemicals

Company	A	B
Operations Manager profile	Mechanical/chemical engineering	Customer oriented chemist
Customer orientation	Low (Sales on catalog)	Strong (customer support)
R&D	Low (technological watch)	High (several small pilots)

**Table 3.3.** The core competencies of companies A and B of Table 3.2

The company faced with technological choices must select technologies where it already has assets and the technical advantages it wants to develop. It must decide the technology that it wants to abandon, either because the upgrading effort would require excessive means of available resources, or simply because they concern low priority markets that will be abandoned in the medium or long-term. The company is forced to make choices and take risks that are sometimes painful with serious human consequences. This is a difficult and courageous task. It is very difficult to recognize that the company is not doing well in some domains because it did not know how to handle the necessary changes! Time is a formidable judge.

Strategic management requires planning, i.e. a clear formulation of objectives over time implied by the concept of multiannual budgeting and a multiyear plan (usually 3–5 years). The objectives should be *measurable* in terms of sales volumes, amount of investment, and human resource requirements.

The questions that will be raised by strategic analysis proposals constitute many preliminary projects, studies that have to go through a selection process. These preliminary projects or studies will be evaluated in terms of cost, risk, and opportunity. This is the theme of Chapter 6.

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PART 2

## Process Development and Industrialization

## Chapter 4

# Chemical Engineering and Process Engineering

### 4.1. History of chemical engineering and process engineering

From time immemorial, man has tried to transform substances found in mines or agriculture, into a variety of materials, consumer objects, and manufactured objects, in order to meet his basic requirements, to protect himself or conquer, to communicate, and to embellish his living space.

However, it was only in the 16th Century that what could be called the embryo of the chemical industry began to appear, which saw the Venetian Republic import, produce and export chemical products: aqua fortis (nitric acid), spirits of salt (hydrochloric acid), dyestuffs, and so on. The end of the 18th Century marked the rise of this industry, especially with the development of the manufacturing of sulfuric acid by the “lead-chamber” process and then with that of soda ash by the Leblanc process in 1791, who set up the first soda ash plant in Saint-Denis close to Paris.

The notion of *process*, without being explicitly used, gradually became established. It refers to the interaction of raw materials by using production facilities, purification of the resulting product, and disposal of residues. This process requires human and financial resources ... and customers. An industrial process is usually represented on paper by what is called a process flow diagram.

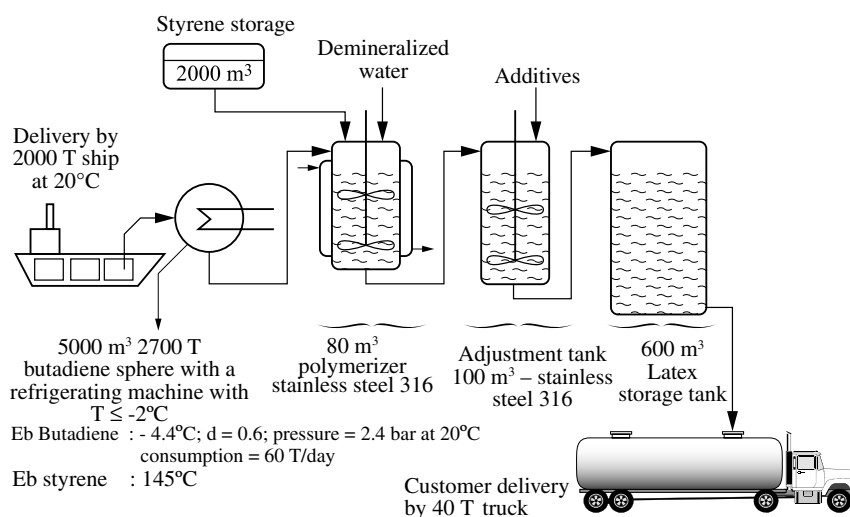
The diagram shown in Figure 4.1 represents the concept of a latex plant for construction in China along the Yangtze River. It implements the copolymerization

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Chapter written by Jean-Pierre DAL PONT.



of butadiene with styrene monomer. The latex produced is used in paper coating and also in the manufacture of paints.



**Figure 4.1.** Simplified diagram of a latex plant (capacity: 300 T/day)

Gradually, as the demands for inorganic and organic products continued to increase and diversify, engineers were faced with equipment problems; equipment is necessary to make the products interact and to purify the products resulting from the reaction. Materials resistant to corrosion also had to be found. The same product started to be produced by different chemical means. This was how Ernest Solvay introduced the Solvay process, also known as the ammonia-soda process, in 1867. This process being more economical, gradually replaced the Leblanc process, which finally disappeared in 1915.

#### 4.1.1. Chemical engineering

At the beginning of the 20th Century, in the United States, chemical engineering was born. More precisely, at MIT (Massachusetts Institute of Technology) with the arrival of Professor William H. Walker in 1902, as the head of the Chemical Engineering Department. Chemical engineering was no longer just the combination of industrial chemistry with mechanics. It began to shape itself as a specific discipline. Soon, the profession was organized and the AIChE (American Institute of Chemical Engineers) was founded in 1908. The formulation by Arthur D. Little of the concept of “Unit Operation” in an internal MIT report in 1915 represented the

last big step in these beginnings, a decisive step for the development of the field: “Any chemical process, in whatever scale conducted, may be resolved into a coordinated series of what may be termed “unit actions”, as pulverizing, mixing, heating, roasting, absorbing, condensing, lixiviating, precipitating, crystallizing, filtering, dissolving, electrolyzing, and so on. The number of these ‘basic unit operations’ is not very large and relatively few of them are involved in any particular process ...”.

The book *Principles of Chemical Engineering*, published by Walker, Lewis, and McAdams in 1923 can be considered to be the first basic book of the new discipline. Canadians translated *Chemical Engineering* into “génie chimique” in French. This term “génie chimique” was again used by Professor Cathala during the foundation of the “Institut du génie chimique” in Toulouse, France in 1949. Chemical engineering emerged as a major technology, in equal terms with electrical, civil, and mechanical engineering.

The prodigious development, in the early 20th Century, of the petroleum industry and the parachemical industry, which used the raw materials coming from refineries, gave chemical engineering an unprecedented boost. It also played a major role in the development of American chemical companies by following in the footsteps of DuPont.

The company founded in 1802 by Eleuthère Irénée DuPont along the banks of the Brandywine River (Delaware), started by manufacturing gunpowder by improving the process used in the powder mill of Essonnes near Paris. Most of DuPont’s managers were graduates from MIT.

The chemical engineers had calculation methods to size the pieces of equipment such as distillation columns, pumps, and heat exchangers. At that time, many operations were more of an “art than science”. This was true, for example, in the case of solution crystallization, which started to be studied in depth in the 1940s. The crystallizers were then progressively calculated and used on a scientific basis furthering the chances of success.

*Chemical engineering* grew enormously in the United States between the two World Wars (balance science, mathematical tools, applied thermodynamics) with the support of a very rich literature with the publication, for example, of the first edition of “Perry” (*Chemical Engineering Handbook*) in 1934 and the book *Principles of Chemical Engineering* by Hougen and Watson in 1937.

However, we should not forget the role played by some French in the 19th Century, for example, Eugène Péclet (*thermal effects*) or Jean-Baptiste-Cellier Blumenthal and Ernest Sorel (*distillation*).

In the 1940s, chemical engineering effectively contributed to the American war effort which saw the construction of factories in record time to produce synthetic

rubber and fuel, and huge factories for the production of fissile materials: uranium 235, plutonium, with methods never used before.

Other technological revolutions would follow. In 1960, the book by Bird, Stewart, and Lightfoot, *Transport Phenomena*, discussed the aspects of material, energy, and momentum transfer in detail. Meanwhile, Octave Levenspiel's patents of nobility on chemical reaction engineering constituted the discipline of study of reactors. This discipline aimed at characterizing reactors and thereby improving the efficiency and selectivity of reactions. The second half of the 20th Century saw the emergence of biotechnology and agri-food engineering.

At the same time, the skills of engineering firms responsible for the design and construction of the plants was completely changed by the emergence of information technology. Equipment calculations that had taken days, or even weeks, were done in minutes. Physical (plastic and wood) plant models were replaced with virtual computer models; Indian ink disappeared from the engineering and design department.

*The chemical industry moved closer toward the customer:* the concept of the *product* was distinguished from *commodities* such as sodium hydroxide, sulfuric acid, *specialty* chemicals with valuable use; high-quality shampoo contains up to 20 components and must meet sophisticated specifications.

The term *product engineering* refers to the techniques involved in the design and manufacturing of products. Thus, nanotechnologies deal with extremely refined products, be it solid particles used in cosmetics or textile fibers imitating natural silk.

The production techniques that gained a new impetus in Japan after World War II created the concept of flows: material flow, information flow, and human and financial resource flow. The production units, whether continuous and dedicated to the manufacture of a single product, or discontinuous and multipurpose – that is, manufacturing many products – were automated. The control system used sophisticated sensors, online analysis, and programmable logic controllers. The factory, whether it produced a few products of 10,000 tons per year or several hundred products, ranging from a few kilos to several hundred tons, per year, used administrative data processing to manage the operations and maintenance.

The 1960s saw an awareness from the general public regarding the chemical industry in general. The first oil crisis in 1973 and major industrial disasters like Flixborough (1974), Seveso (1976), Bhopal (1984), and AZF, Toulouse (2001) had a significant impact and continued to attract media attention. The concepts of health, safety, and the environment, denoted by the acronym HSE, began to influence the operating mode of industrial companies, whether in developing new products, designing or managing new production tools, or storing, transporting, and supplying the manufactured products to the customer.

## 4.2. Process engineering

### 4.2.1. Objectives of process engineering

By 1980, particularly in France, a federal concept slowly emerged based on the fact that many industries used the techniques and methods of chemical engineering.

The petroleum and paracheical industries, coals chemistry, pharmaceutical and healthcare industries, steel industry, basic chemicals, specialty chemicals, cosmetics, electronics, agri-food, cement, paper, glass, fertilizers, ores, plastics, energy, water purification, and environmental protection industries, just to mention the largest ones all use the concepts developed by chemical engineering over a century.

Process engineering is “the set of knowledge necessary to design, analyze, develop, construct, and operate, in an optimal way, the processes in which the material changes”:

- its shape, state of aggregation, or dispersion;
- its physical state or physico-chemical properties;
- its chemical nature [VIL 83].

Process engineering, is therefore involved in industrial sectors whose economic significance is considerable. It should not be confused with industrial chemistry whose purpose is to study the properties of chemical products and their manufacturing processes.

What has just been discussed clearly shows the knowledge-savvy reader the wide variety, extreme complexity and enormous scope covered by process engineering. What follows is not exhaustive! We only hope that it will show that chemistry, which is present everywhere today cannot act alone. Any chemical reaction, either beneficial or harmful, is a link in a chain of physical processes that we will discuss briefly.

### 4.2.2. The scientific bases and basic tools of process engineering

Process engineering is built from a set of basic scientific disciplines, including:

- *mathematics and computer science* to equate, model, and simulate the processes;
- *thermodynamics* for all energy aspects, chemical thermodynamics for phase equilibria, interfacial phenomena, and so on;
- *chemical kinetics*;

- *fluid mechanics* (mixing, transportation, and flow of fluids);
- *transportation phenomena* – “physical kinetics” (transportation of materials and energy);
- *the mechanics of porous and dispersed media*.

The interaction of these disciplines led to specific developments like for example in:

- the domain of “mixing” (single- and multiphase);
- the domain of reactors (chemical and biochemical reactor engineering);
- the “traditional unit operations” that have already been mentioned, that is, distillation, crystallization and solid line (filtration, drying), solvent extraction, and so on;
- chromatographic techniques;
- membrane separation techniques;
- the engineering of material development and products with complex structures, and so on.

Process engineering commonly uses the notion of *driving force*, which can be compared with a voltage responsible for *transfers*, by analogy with electricity:

- a difference in temperature: a hot fluid heats up a cold fluid (see Figure 4.8);
- a difference in concentration: under the effect of temperature, methanol, which is more volatile, will enrich the gaseous phase of a water–methanol solution; this is the basic principle of distillation.

Process engineering has also developed tools and concepts specific to it, such as the concept of the *theoretical stage* or *counter-current* to ensure systematic contact between phases.

The engineer draws the process flow diagram, which is a *visualization* of the industrial process and will be documented, that is how one tries to determine for each line, that is, physically for each pipe, the temperature, pressure, flow rate, and chemical composition of the corresponding flow; this task is sometimes difficult because one needs to know “what is happening”, and therefore be able to analyze chemically the flow and to have the appropriate measuring instruments.

This list would have been incomplete if the prodigious progress of process engineering in the 20th Century had not introduced specific technologies besides chemical engineering that could be described as classic. These include, among others, the following disciplines:

- electrochemical engineering (e.g. electrolysis of sodium chloride – table salt – to produce chlorine and sodium hydroxide);
- metallurgical engineering (extraction of metals from ores then refining);
- photochemical engineering (processes using light energy as a means of activation of the reaction);
- biochemical engineering including industrial fermentation, which is of considerable importance (brewing, vitamins, enzymes, drugs, food additives);
- agri-food engineering (freeze-drying, pasteurization, freezing, etc.).

A special place must be given to product engineering which covers all the know-how that enables us to develop and manufacture these products with specific functions. The active ingredient(s) are associated with formulation auxiliaries. For example, a herbicide is suspended in water using surfactants in order to be sprayed effectively.

The vast majority of installations in developed countries are now instrumented and automated. The *control system* is inseparable from the process.

It should also be noted that process engineering is currently being developed in a highly competitive economy in which the majority of disciplines require multidisciplinary teams. In addition to being a good technician, one must have a strong background in economics, particularly to determine the justification of certain investments, process modifications, and the launch of technical research.

Project management, the ability to work as a team and to communicate are techniques, sometimes described as “soft” skills, which, in addition to the “hard” skills, work toward making process engineering a discipline in itself.

### **4.3. The chemical reactor**

A reactor is any piece of equipment where a chemical, biochemical, or nuclear reaction occurs. This reaction transforms molecules into other molecules. This is at the heart of the material transformation processes.

There are many classifications of reactors. This is the very broad domain of reaction engineering which is based on chemical and physical kinetics.

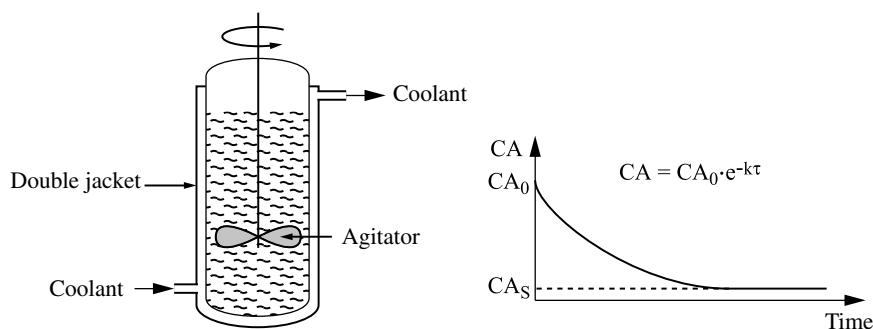
#### **4.3.1. Classification of reactors based on the method of feeding**

The first criterion for classification is whether it uses the *continuous or discontinuous operating mode*:

– the *continuous mode* is well adapted to the typical large tonnages of the inorganic industry (sodium hydroxide, sulfuric acid, fertilizers), petrochemical industry (ethylene), basic chemicals industry (phthalic anhydride, phenol), agri-food industry (confectionaries), and so on;

– the *discontinuous mode* (closed reactor) and semi-continuous mode (semi-continuous reactor) are suitable for tonnages limited to a few hundred or few thousand tonnes per year, especially when it is necessary to manufacture many products in the same workshop in successive *campaigns*. This holds true for the pharmaceutical, fine and specialty chemical (cosmetics, agricultural chemistry, etc.) industries.

A stirred reactor, equipped with a double jacket is shown in Figure 4.2. This reactor is also said to be closed, because the reactants are loaded at the beginning and they remain in the reactor until the end of the reaction. This is the simplest device; it reproduces the round bottom flask on a larger scale.



**Figure 4.2.** (Discontinuous) closed reactor

From now onward, we should note that another classification criterion relates to the nature of the system involved: we could talk about a *single-phase system* or a *multiphase* or *heterogeneous system*.

Real reactors often have complex reactive configurations, but they can sometimes be represented by a typical configuration called an “ideal” configuration, or by a combination of several of these ideal configurations.

In the case of continuous reactors, there are two types of ideal configuration:

– *continuous stirred tank reactor*, where the composition of the reactive mixture is uniform throughout the volume (Figure 4.3);

– *plug-flow reactor*, where the reactive mixture in the reactor progresses through sections perpendicular to the direction of flow, like a piston in a cylinder (Figure 4.4).

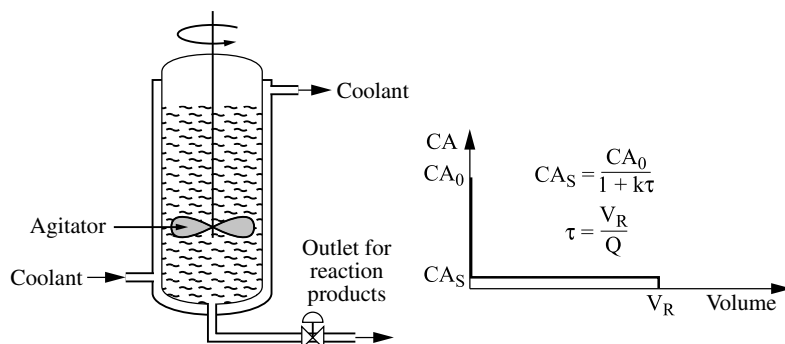


Figure 4.3. Continuous stirred tank reactor

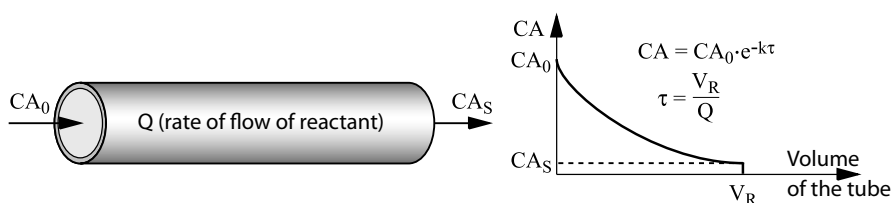


Figure 4.4. Plug-flow reactor

This type of reactor is well adapted to the continuous mode and large tonnages. A very important application relates to the production of ethylene by steam cracking. The tube of about 8 cm in diameter is placed in a furnace which is heated by gas or fuel. The residence time, defined as the ratio of tube volume to the rate of flow of reactants, is less than 1 second.

### 4.3.2. Classification according to the phases present

#### 4.3.2.1. Gas/liquid system

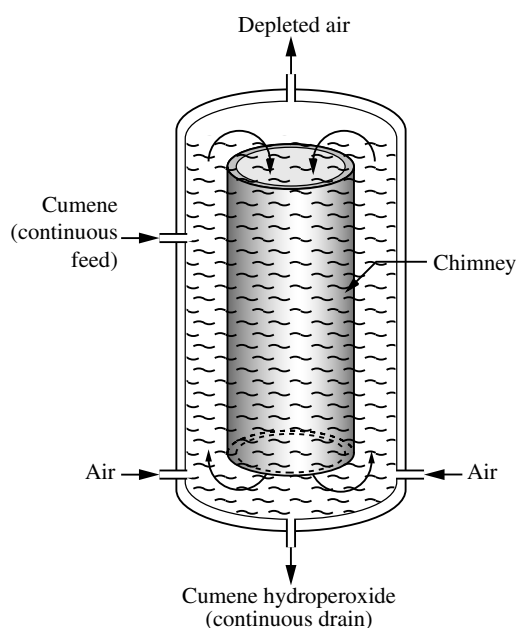
The reactor can be semi-continuous or continuous. The gas is brought into contact with the liquid by means of mechanical agitation (by injection in a turbine or self-priming using a suitable moving body), by recirculation through ejectors, or simply by dispersion at the bottom of the reactor in the absence of mechanical agitation (bubble columns, gas-lift reactors).

The continuous oxidation of cumene by air into the corresponding hydroperoxide, an intermediate of *phenol*, uses this type of reactor (Figure 4.5). The reactor, whose volume can exceed 100 m<sup>3</sup> provides a wide fluid retention.



In column scrubbers, the gas which is to be purified passes through some contacting devices by means of counter-current, where the gas and scrubbing solution come into contact.

The scrubbing is *systematic*: the higher the gas rises in the column, the more impurities are removed from it and the more it interacts with “strong” scrubbing solution, because the solution has not reacted much. The washing solution flows toward the bottom from tray to tray. This is the very important principle of *counter-current*.



**Figure 4.5.** Gas-lift or G/L reactor

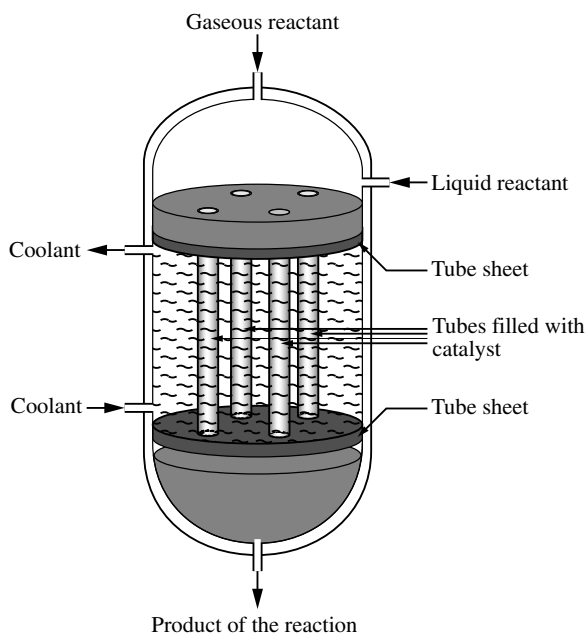
#### 4.3.2.2. The fluid/fluid/solids system

The solid can act as the catalyst whose role is to increase the rate of the reaction. The solid(s) can either be the *reactants* alone, or the *reactants* or *products of transformation*. Examples include the rotary kilns used in cement works or continuous reaction of ore with sulfuric acid to produce phosphoric acid in stirred tanks.

The so-called catalytic or even heterogeneous reactors in the case where the catalyst is a solid, have to take into account the diffusion process. The reactants should have access to “*active sites*”, located mostly within the *pores* of the catalyst.

For this reason, it is necessary to consider the morphology of the catalyst (balls, cylinders, etc.), its porosity, means of connecting fluids/catalyst, which must be strong enough so that the *diffusion process* is not the *limiting process*.

The reaction rate, removal, or supply of calories are factors that are to be considered in the design of reactors. Figure 4.6 represents a multitubular reactor in two-phase flow (trickle bed). In this case, the reactor is in fact a fixed *tube sheet* exchanger; a coolant flowing through the shell provides the calories needed to raise the temperature of the system at startup, and *removes* the heat of reaction in at a steady-state.



**Figure 4.6.** *Multitubular catalytic reactor*

We have already mentioned that the reactor is the heart of the process. The characteristics of the purification systems, systems for the extraction of marketable products, for the separation of by-products, the disposal of products with no market value (residues), the amount of wastewater to be treated, and the amount of unreacted reactants to be *recycled* will all depend on its efficiency and selectivity.

The reactor design must consider the thermal aspects. The removal of the heat from the reaction often poses a difficult problem. The addition of coils inside the

stirred tanks, an external circulation system through heat exchangers requires process studies that are sometimes difficult.

The reactor is often the most dangerous part of the production plant. It must be properly instrumented to control the flow rates as an increase in temperature may cause thermal runaway. It is necessarily equipped with safety devices, such as relief valves, blowdown, and an additional system of reaction blockers. Very often, the control devices are doubled or even tripled; this is called redundancy.

The reactor can also use very advanced construction techniques in the following cases, which are far from being restrictive:

- implementation of high temperatures or increased pressures;
- use of *exotic* materials such as metal alloys, which are difficult to process, graphite and enameled steel;
- very large volumes (several hundred m<sup>3</sup>).

All these examples once again illustrate the complexity and scope of chemical reaction engineering (CRE).

#### 4.4. Bioreactors

Bioreactors differ from conventional reactors by the nature of the catalyst, which is an *enzyme* and most often a *set of enzymes*. Apart from this, the basic principles stated above remain the same.

Let us recollect that an enzyme is a protein endowed with a special catalytic power. Enzymes may come from animals, plants, and especially microbes.

The enzyme is therefore a *biological catalyst* which, as such, is specific to a molecule. It quickens the transformation of the molecule without undergoing any transformation itself. It reacts only in pre-determined pH and temperature ranges.

There are two major classes of *bioreactions*.

##### 4.4.1. The enzymatic bioreactions

*Enzymatic bioreactions* involve making one or more enzymes act on one substrate in order to transform it. The most classical example is starch hydrolysis using *amylase* that can hydrolyze it in glucose. This is how sugar syrups are manufactured from corn for confectioneries and cakes. It is also the reaction which,

in brewing, converts the starch from malt into fermentable sugars in the presence of yeast. The corresponding bioreactors differ a little from chemical reactors, except that they operate at moderate temperatures (less than 70°C in general), because of the heat sensitive enzymes.

Bioreaction, which is undoubtedly the most significant reaction in terms of tonnage, is the curdling of milk under the action of *rennet*, which is the starting point for cheese making. Rennet is a protease which causes the coagulation of casein: that is the formation of “curd”.

The enzymes are never pure, despite undergoing purification operations. It follows that the reactions generated by the enzymes are many in number and complex.

#### 4.4.2. *Bioreactions using microorganisms*

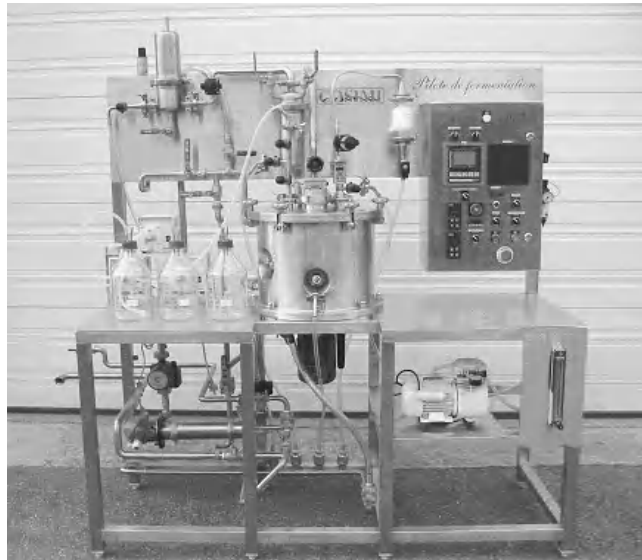
Bioreactions that employ microorganisms are also enzymatic reactions by the fact that the living cell functions through enzymatic systems that are specific to it.

These microbiological bioreactions, also known as *fermentations*, are even more widespread than the previous ones and have been since the dawn of time. Indeed, the fermentation of sweetened juices in order to produce alcohol, has been used (for the happiness and misery of humanity ...) probably, since man first picked fruits and squeezed them to extract its juice. Many food technologies at present use these food fermentation processes: wine making, brewing, distilling, cider making, and so on. These latter bioreactions are carried out in relatively simple devices, which are open to the air and where the temperature and sometimes pH may be controlled. However, they require some amount of industrial hygiene.

The same will hold true for the bioreactions for the synthesis of molecules, for the pharmaceutical industry (e.g. antibiotics or certain vitamins) or food for humans (flavorings, thickening agents, rennet, etc.). These reactions are carried out in completely controlled sophisticated reactors where sanitization must be strictly maintained.

Figure 4.7 represents a laboratory bioreactor.

Thus, the production of penicillin in a 50 m<sup>3</sup> reactor will pose a number of problems for the process engineer. All these problems must have a suitable technical solution, after the biochemist has defined the *nutrient medium* and selected an efficient *strain*.



**Figure 4.7.** *Laboratory bioreactor used to test the raw materials and new production methods*

One must:

- define the feeding conditions of the fermenter in nutritive substances;
- specify the agitation to maintain the homogeneity of temperature and concentration;
- remove the heat of the reaction by using double jackets or coils immersed in the device;
- bring in filtered air under pressure and distribute it properly at the base of the fermenter;
- select and build material that can be sterilized with steam from the isolating valves up to the pipes and reactor.

Bioreactions or, more generally, biochemical reactions do not only occur in industrial reactors. A pot of yogurt, a cake in the oven, steak roasted in a pan, good wine aging in a barrel or a bottle, a “risen” bread (these are beer yeasts which, by producing CO<sub>2</sub>, form holes in the dough), are the media where reactions associated with heat and material transfers (sugar, water, oxygen, etc.) take place.

Still closer to us, we can consider that every living organism is an extremely complex and efficient bioreactor!

## 4.5. Transportation and transfers

### 4.5.1. Transportation and handling of fluids

Fluids must be carried in pipes, compressed and mixed in the vessels. Liquids and suspensions have a flow rate of a few  $\text{cm}^3/\text{h}$  to several thousand  $\text{m}^3/\text{h}$ ; the pressure can reach hundreds of bars; the temperature can be cryogenic or rise to hundreds of degrees. Fluids may be Newtonian or non-Newtonian and have high viscosities. To solve these problems, equipment manufacturers offer various *pump* models: conventional centrifugal, peristaltic, gear, multistage centrifugal, vortex, piston, lobe, vane, and so on.

Similarly, *compressors* can be piston, rotary, centrifugal, or axial compressors. Fans, especially in aerualics, deal with high flow rates and low heads.

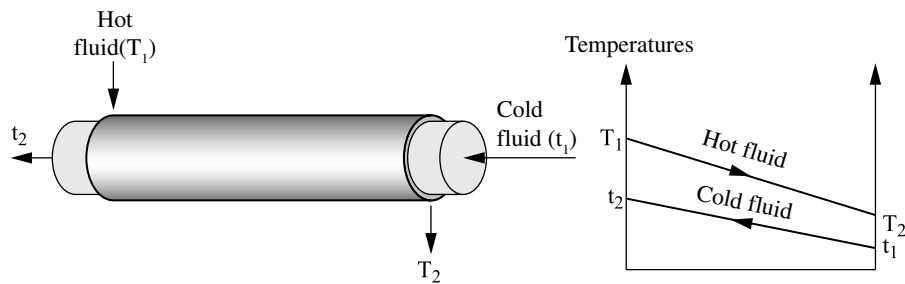
*Mixing* is a discipline of considerable importance, since reactants should be brought into contact, solids should be maintained in suspension, and dye pigments should be dispersed in viscous solutions.

*Impellers* can be fitted within tanks of several hundred cubic meters capacity (fermenters, mineral industry) and can be driven by engines of a power of several hundred kilowatts.

### 4.5.2. Heat transfer; power, cooling, and heat generation

*Heat exchangers* are a tool common to all industries. They are used to heat, cool, conserve energy, evaporate, and condense.

Figure 4.8 shows the simplest heat exchanger, the double pipe heat exchanger, used here with counter-current.



**Figure 4.8.** Double pipe heat exchanger

The amount of heat exchanged  $Q$  (kcal/h) obeys the following equation:

$$Q = U \cdot A \cdot \Delta t$$

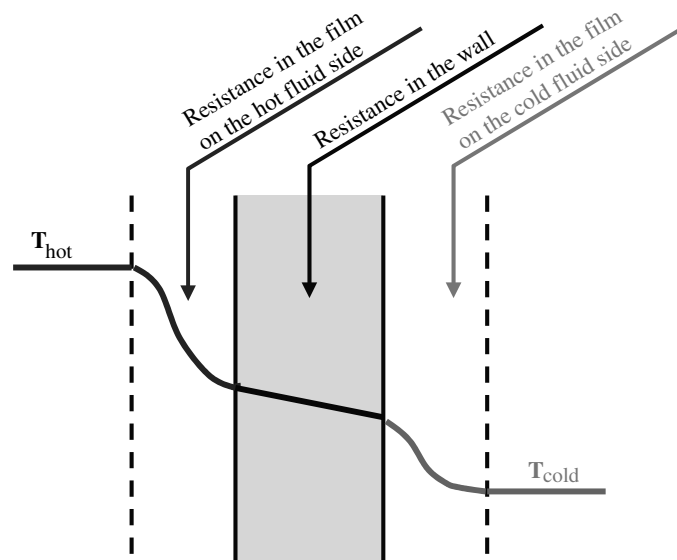
with  $U$ , the transfer coefficient in  $\text{kcal}\cdot\text{h}^{-1}\cdot\text{m}^2\cdot\text{°C}^{-1}$ ,  $A$ , the exchange area in  $\text{m}^2$ , and  $\Delta t$ , the *mean* temperature difference between hot and cold fluids.

Chemical engineering is now used to calculate  $U$  and  $\Delta t$  in a few minutes, due to computer programs. Here again, exchangers can vary from a few square meters to several hundred square meters in surface area. They may be tubular heat exchangers, plate heat exchangers, spiral heat exchangers, cross flow heat exchangers, and so on.

Figure 4.9 illustrates the resistances to transfers: through the film of the warm and cold sides and through the metal of the tube wall.

Steam generation in oil-fired, gas-fired, and coal boilers, cold production in *refrigerating machines*, and *turbo-alternators* driven for the production of electricity come under the *energy* domain and obey the laws of thermodynamics.

Any plant needs *utilities*: steam, cooling water, nitrogen, brine, and so on. Station *utilities* are important for large tonnage products, such as chlorine, sodium hydroxide, and so on. They are less important for specialty chemicals.



**Figure 4.9.** Resistance to heat transfer in a heat exchanger

### 4.5.3. *Transfer between two immiscible liquids*

Liquid–liquid extraction is an important operation in fermentation to extract the active ingredient from the broth, in the inorganic and rare earth industries.

The principle is based on the *difference in solubility* (driving force) of a solute contained in a solvent, such as water, and an *extractant* insoluble in water, such as IPE (isopropyl ether).

At the laboratory scale, IPE can be added to the solution in a settler tank that is stirred and then allowed to settle down: the solute passes through into the IPE. We can repeat the process several times with fresh solvent. The solution is often separated from the extractant by distillation.

Industrially, the operation is performed in columns similar to distillation columns.

## 4.6. Unit operations

The examination of a standard unit of crystallization, represented in Figure 4.10, shows a chain of operations and techniques that we will find in many chemical processes. In this case, the installation uses crystallization, filtration, drying, evacuation and transportation of a suspension. It is from this finding that Americans have named each block a *unit operation*.

The block, which consists of separating the crystals from the mother liquor, can be achieved by filtration as shown in the diagram, by sedimentation (using natural gravity), or by centrifugation.

Filtration as a unit operation can use a significant number of different filters: rotary vacuum, filter press type, band filter, and so on.

*We see that we cannot separate the process from the equipment. There is no chemistry without equipment. The process and equipment must adapt themselves to each other.*

Unit operations are extremely numerous and varied; they have accompanied the exponential development of the process industry, as stated in the section concerning the scientific bases of process engineering. It is impossible to list them all, as there are various classifications.

In the following sections, we will just examine crystallization and distillation in a little more detail and cite the principal unit operations. The membrane technologies and those whose applications are now becoming more and more important will be the subject of a special section.



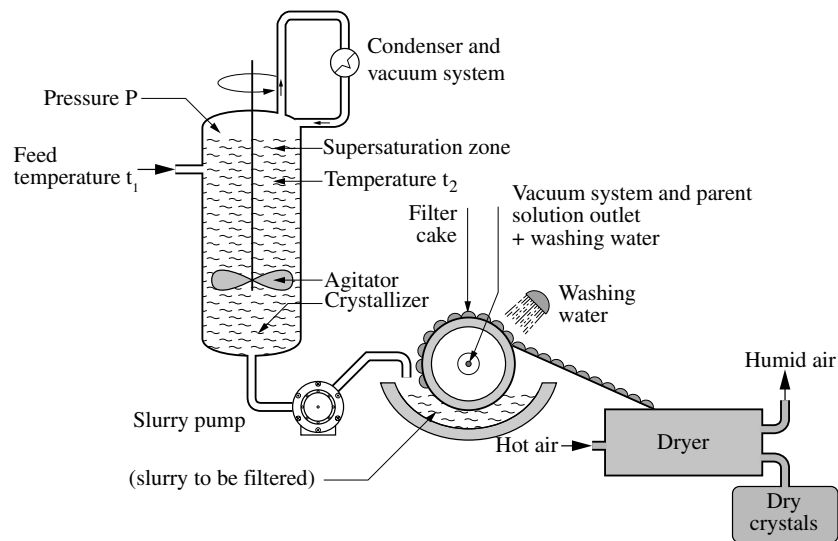
#### 4.6.1. Crystallization in solution

*Crystallization* in solution consists of forming a *crystalline* solid phase, that is *appropriated* from a solution containing a *solute*, which is to be extracted, and the solvent.

Crystallization in solution can be designed either to purify the solute, where the impurities remain in the solvent (mother liquor), or to obtain it in a solid form so as to avoid transportation when the solute is far from the production unit.

The *driving force* is the solubility. Experiments show that many products can be dissolved at a greater concentration than in equilibrium, for a time which can vary from a few seconds to several hours or even several days. This is called *supersaturation*.

The industrial crystallizer in Figure 4.10 is fed with a *supersaturated solution* at concentration  $C_1$ . It works by vacuum flashing at temperature  $T_2$  at which the solubility is  $C_2$ ,  $C_2$  is less than  $C_1$ ; there is thus the formation of a solid.



**Figure 4.10.** Crystallization-filtration-drying typical unit

Crystallization in solution is based on two essential phenomena:

– *nucleation*: the small crystals, or nuclei, which are formed first, serve as a support to the crystallizing solute;

– *growth*: to obtain large crystals, it is necessary to limit the nucleation, that is the number of nuclei and to have them grow by bringing the crystals already present in the tank into the supersaturation zone, in this case, at the surface of the *boiling* suspension. The role of the *agitator* is to perform this operation.

Some salts, for example table salt, have a solubility that varies little with temperature. From a practical point of view, crystallization is obtained by solvent evaporation in steam-heated evaporators. Salt marshes use natural evaporation due to the combination of wind and solar energy.

Crystallization is now a well-controlled process. Specialist companies offer various types of crystallizers for specific applications.

#### 4.6.2. *Drying and gas/solid contact*

*Drying* implements heat transfer and material transfer, simultaneously. There are many types of dryers: tunnel, fluidized, rotating drum, spray (milk powder), and so on. The operation can be either continuous or discontinuous (*ovens*).

*Adsorption* uses the properties of *divided* and *porous* bodies to adsorb organic compounds contained, for example, in air. A widely used adsorbent is *activated carbon* that makes up the *cartridge* of gas masks.

The solids are essentially a “separate material”, as they tend to create lumps, agglomerate together, clog pipes and pick up mass in the silos. They often generate dust and devices dealing with them are noisy.

The following operations are “mechanical” and do not involve any significant material transfer: grinding, agglomeration, extrusion, sedimentation, transportation by screw conveyor, air conveying or hydraulic transport, and sifting.

*Fluidization* consists of maintaining particles in suspension in a gas stream; this property is used to dry, to agglomerate particles and to make them react with other components. The fluidized bed acts as a pseudofluid for which the coefficients of material and heat transfer are high.

Solid-fluid separation is also a major operation. The *removal of dust* in *bag filters*, *cyclones*, and *electrostatic filters* comes under the air treatment processes. Solid-liquid separation can be accomplished by *filtration*, *centrifugation*, and *sedimentation*.

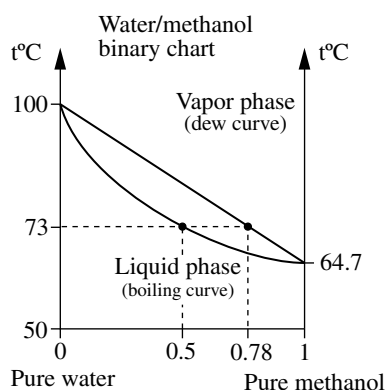
### 4.6.3. Distillation

Distillation is a basic operation in organic chemistry and the petrochemical industry. The distillation column forms an integral part of the chemical industry landscape.

Distillation is one of the oldest separation techniques as it was already known in the first centuries AD by Arabian alchemists who used it for the preparation of perfumes. For a long time it was empirical and it was only in the 19th Century that the bases of calculation and design of *stage equipment* were developed.

Distillation separates components with different volatilities, that is with different boiling points. Pure water, at atmospheric pressure, boils at 100°C; *at this temperature, water and its vapor are in equilibrium.*

Assume that we have to separate the water–methanol mixture. Methanol boils at 64.7°C at atmospheric pressure. Figure 4.11 shows the isobaric vapor–liquid equilibrium data of the water–methanol mixture.

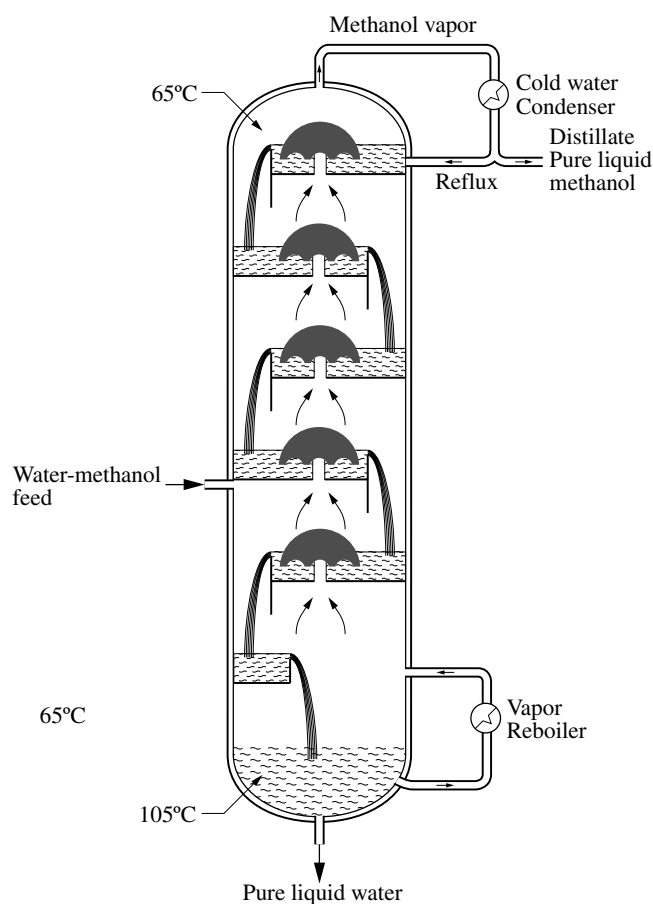


**Figure 4.11.** Vapor–liquid equilibrium data of water–methanol mixture

A mixture containing 50 mol% of methanol will boil at 73°C. *The vapor in equilibrium with the liquid phase (liquidus) will have a molar composition of 78% in methanol. It is therefore richer in methanol than the liquid. This property is used in distillation by putting liquid and vapor into contact by means of counter-current.*

The contacting device of the column in Figure 4.12 is a bubble tray. The bubble cap forces the vapor emitted by the reboiler located at the bottom of the column to *bubble* in the liquid. The liquid flows over the lower tray by an overflow (*weir*);

there is heat transfer and material transfer, simultaneously; part of the water in the vapor condenses and part of the methanol in the liquid vaporizes. If this tray was in perfect *thermodynamic equilibrium*, we would have what is called a *theoretical stage* or *tray*. The condenser installed at the column head condenses the vapors of pure methanol: part of the condensate is refluxed to provide counter-current.



**Figure 4.12.** Water-methanol separation by distillation

The distillation operation is now well-known and lends itself to computer calculation. There are methods to calculate the number of theoretical plates required to perform a given separation and to size the trays (diameter, number of caps, etc.).

Various types of contacting trays exist: valve trays, sieve trays, bubble cap trays. There are also many types of packings of the dumped or arranged type.

#### 4.6.4. *Other operations*

We have deliberately omitted many of the operations and chemical techniques, such as: absorption, stripping, evaporation, humidification, melting, solidification, molten crystallization, extractive distillation, azeotropic distillation, sublimation, dissolution, leaching, flotation, wastewater treatment, and so on.

As an example, we will discuss in a little more detail the development of operative techniques that were developed in the last decades of the 20th Century, namely membrane technologies, and we will conclude by discussing examples of challenges that process engineering has to face in the life sciences domain.

#### 4.6.5. *An example of development: membrane technologies*

Membranes that help to separate molecules at an industrial level were invented in the 1960s by the Americans, Loeb and Sourirajan. Over the last 30 years or so, these techniques have emerged in many industries as a powerful means for fine separation of components. They form the basis of many applications in food processing, chemistry, and water treatment. Examples are the retrieval of proteins in milk by-products, water purification for the electronics industry, the treatment of machining fluids in the manufacturing industry, and the reverse osmosis of seawater to produce fresh water.

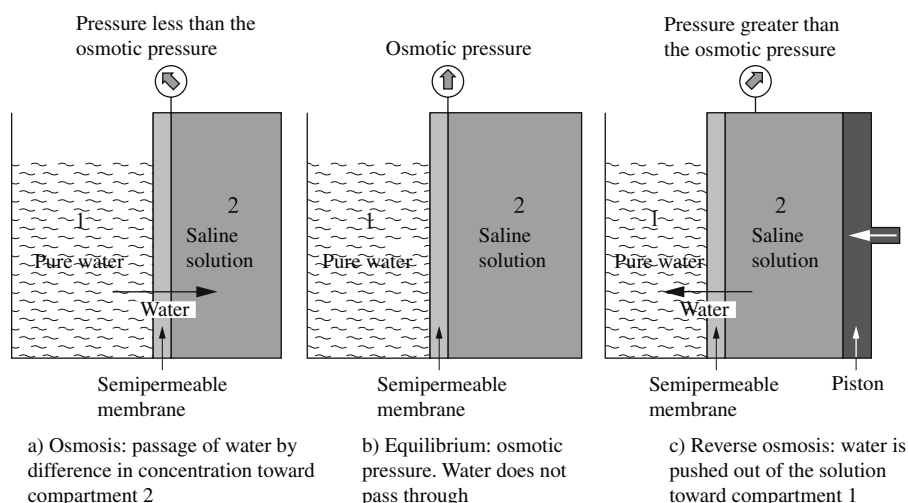
##### 4.6.5.1. *Operating principle*

The ability of membranes to perform separations is based on the principle of “semipermeability”. In fact, we know how to manufacture membranes containing thin skins of a few tenths of a millimeter thickness which, by playing on complex phenomena such as absorption, dissolution, porosity, and so on, “sort” the molecules that can pass through them. In fact, it is only an imitation of nature: without the semipermeability of our intestinal walls and kidneys, our life would be impossible. The same holds true for all living organisms: fish let in oxygen through their gills, plant roots “choose” what is necessary for the plant from the ground.

Semipermeability to water, given its importance, was the first to be studied for industrial applications (Figure 4.13).

In the schematized case in Figure 4.13, the membrane represented is semipermeable to water: the salt molecules are prohibited from passing through the membrane. This condition is essential for a spontaneous establishment of pressure in the closed compartment where the solution is found: this is the *osmotic pressure* of the solution, which is as high as the solution is concentrated. *Reverse osmosis*

consists of reversing this phenomenon by subjecting the solution to a pressure above the osmotic pressure, which leads to its concentration.



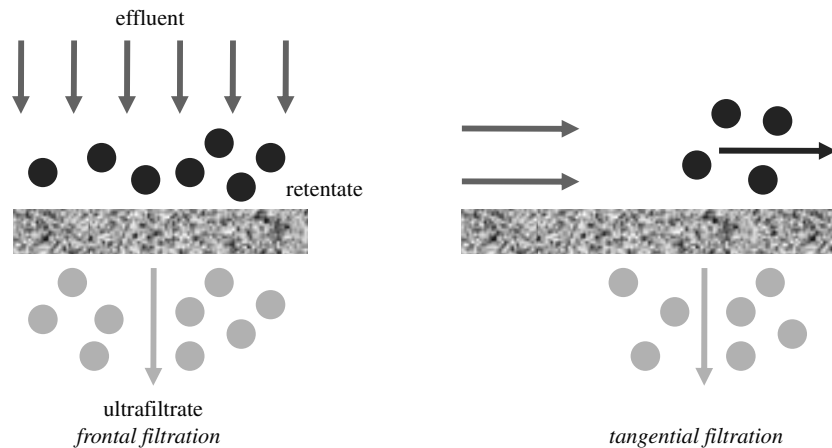
**Figure 4.13.** Osmosis, osmotic pressure, and reverse osmosis: in the case of a saline solution

Other types of semipermeable membrane correspond to the sorting of dissolved molecules. This is true in the case of *ultrafiltration*, *nanofiltration*, and *electrodialysis*. The sorting of molecules is performed based on their *molecular weight*, *shape* (linear or globular), or their *ionic charge*. The phenomena involved are complex; they depend on the porosity of the membrane, affinities between the solute and membrane, and attractions/repulsions.

Finally, some membranes are capable of sorting “particles” that can be compared to macromolecules. They may be “micelles” (clusters of molecules often having a “skin” with particular electrochemical characteristics), bacteria, fat globules, microfibrils, and so on. This operation is no longer considered to come under semipermeability; it is in fact a very fine filtration primarily based on the size of the pores of the membrane. This is the principle of *microfiltration*.

#### 4.6.5.2. The implementation of membranes

Compared with the conventional filtration of liquid–solid and gas–solid suspensions, which is also known as “frontal” filtration, membranes, at the macroscopic level, have a special operating mode (Figure 4.14): the *tangential mode*.



**Figure 4.14.** *Frontal filtration and tangential flow filtration*

Instead of bringing the suspension perpendicular to the filtering wall and making the entire carrier phase (liquid or gas) pass through the wall, the medium to be separated is circulated, at the necessary pressure, *parallel* to this wall. A part of this medium, the “filtrate”, passes through the membrane whereas the “retentate” is still circulated. This slows down the accumulation of molecules or particles against the membrane, which is an inevitable phenomenon in frontal filtration. This process avoids clogging.

The materials of the first membranes were cellulosic by nature. The membrane material at present is of either *organic* or *inorganic* in nature. They are walls with a complex structure: generally, a very thin active part with a thickness of about 1/100th of a millimeter rests on a thicker part constituting the support. The total thickness is of the order of 1/10th of a millimeter for organic membranes and one millimeter for inorganic membranes. Electrodialysis membranes are still organic.

From a *practical* point of view, membranes can be *flat* (as in the case of organic membranes resting on grooved supports that can withstand applied pressures), flat but spirally wound, more often tubular (tubes of a few millimeters in diameter) or “hollow fiber” (microtubes less than a millimeter in diameter). The assembly of these basic elements into “modules”, with an area of about 1 m<sup>2</sup>, represents a part of the know-how of equipment manufacturers.

An *installation for membrane separation* thus consists of modules and pumps for pressurizing and circulating the liquid and various tanks (Figure 4.15).



**Figure 4.15.** *Industrial plant for desalination of seawater*

Temperature control systems, for example with the help of a heat exchanger, must be prepared to maintain the overall temperature at 50°C. It should also provide for means of declogging (often by reversing the direction of liquid flow in the membranes) and cleaning (by alkaline and acid solutions, and sometimes by enzymes that can break down the proteins constituting the clogged layer).

These installations operate either *in cycles*: the liquid is treated by tank loads one at a time, or *continuously*. Periodic stops are however needed to unclog and clean the membranes.

#### 4.6.5.3. *Description and use of various membrane techniques*

The oldest membrane technique is *reverse osmosis*, whose principle has been stated above and which is used to separate the water from a solution. The usual procedure used in industry to concentrate solutions is based on evaporation. But in the case of products sensitive to heat, this process has the disadvantage of deteriorating the product (in the case of sugar solutions, the heat causes them to brown). A workaround is to operate in vacuum in order to lower the boiling temperature, which complicates the operation. One can use the same process to make pure water from brine. But the energy cost is high. Reverse osmosis does not have these problems ... but it has others: membranes are fragile, susceptible to clogging and unusable with concentrated solutions, as in this case, the osmotic pressures is very high, which can lead to operating pressures in the order of 60–80 bars, which in turn complicates the installation and results in high operating costs.

Other types of membranes are capable of carrying out sorting of different types. The most commonly used are *ultrafiltration* membranes, which allow small molecules including water to pass through, but retain the “large” molecules.

The most important application concerns the separation of serum (or “whey”) from cheese. In the conventional manufacturing of cheese, the coagulation of casein can cause it to separate, in order to make cheese from it, from the solution (serum)



containing the other constituents of milk: lactose, salts, non-coagulated proteins, and some fat. This liquid was once discharged into a river, which had serious environmental drawbacks such as excessive growth of algae that consume oxygen to the detriment of fish. The industrialists, aware of the richness of this serum, strived hard to put it to good use rather than to throw it out. One of the methods put forward was to extract the proteins in order to use them as an ingredient for butchers and bakers. The technique that gained significance was *ultrafiltration*. The membranes retain these proteins in aqueous solution: this “retentate” can be dried under sufficiently mild conditions to retain its use value qualities: binding properties, emulsifying agent, and so on.

The other major dairy use of ultrafiltration is to question the process of cheese-making itself. This process involves coagulating casein, as described above, to make curd, which is drained in order to separate the serum. The draining phase is relatively long and difficult to control. Hence, the idea of ultrafiltering the milk itself, which allows us to extract the serum, and then to curdle the retained fraction that contains casein. Draining is no longer necessary, or its duration is greatly reduced since the serum has already been withdrawn. This technique, called “MMV”, named after its inventors Maubois–Mocquot–Vassal, who were INRA (*Institut national de la recherche agronomique*) researchers, is now used in France and many other countries. However, it should be noted that the cheese produced, after the ripening phase that remains essential, does not have exactly the same characteristics as cheese manufactured by traditional processes, especially since incoagulable proteins are partly retained in the curd instead of being filtered out in the serum.

The automotive industry also uses the ultrafiltration technique for treating liquids resulting from machining. These are oil emulsions in the water used to lubricate and cool the metal cutting tools. The separation of the oil phase of these liquids after use allows the discharge of clean water and sometimes reuse of the oily portion.

Ultrafiltration also has applications for treating electrophoretic painting solutions used in the automotive and mechanical industries. This painting technique involves immersing the metal part in a bath containing the emulsion paint and using an electric field to exert a pull on the paint on the metal part. Here again, ultrafiltration can separate the “painting” phase from the aqueous phase before setting the latter aside.

In these examples, the potential of membrane technology for environmental protection can be noted.

In the biotechnology domain mentioned above, ultrafiltration modules can be coupled with biological reactors to extract from the reaction medium, the molecule

produced while leaving the catalyst cells and/or enzyme of this reaction. The efficiency of the reactor is improved, as the product of the reaction, when it accumulates, inhibits the reaction itself.

*Nanofiltration* is a recent technique: one uses new membranes that enable small molecules to be sorted from one another, by playing on both their size and electrical charge. For example, they enable us to separate monovalent ions (such as the chloride ion,  $\text{Cl}^-$ ) from divalent ions (such as the sulfate ion,  $\text{SO}_4^{2-}$ ) or sugars from salts. Their early applications include the simultaneous concentration and demineralization of milk to make yoghurt.

The principle of *electrodialysis* is based on the combination of membranes semipermeable to anions or cations subjected to an electric field. These membranes contain organic polymers comprising fixed groups and groups little related with the previous groups, which can move under the influence of an electric field and can be replaced with other groups. On the basis of the cationic or anionic nature of the mobile groups, the membrane lets the anions or the cations pass through it. A setup combining these two types of membranes can deionize a solution.

This technique is also one of the means to distinguish fresh water from salt water. The various techniques listed here: evaporation, reverse osmosis, and electro dialysis, are often used together to improve the competitiveness of the process.

#### **4.7. Separation processes: process engineering and the new challenges for life sciences**

The life science industries witnessed a true revolution at the beginning of the 21st Century: transformation of the pharmaceutical industry toward biomolecules, changes in the agri-food industry toward the development of more specific natural substances, and so on.

To illustrate these developments, let us consider two examples that play a prominent role. We can first quote the concept of biorefinery, born in the 1980s, and which is giving rise to growing interests. By analogy with oil refinery, it consists of developing all or part of plant fractions. Owing to the complexity of the media obtained at the end of extraction processes, the purification strategy proves to play a vital role. The same holds true in the case of biodrugs, designed and produced from living matter, and which are taking an active role in therapeutic innovation. The target molecules are thus extracted from extremely complex media, where they can be highly diluted. In both the cases, these molecules can be fragile, heat sensitive, and so on.

Given the complexity of the media considered, an initial feature of the purification processes is often the large number of unit operations required to isolate the relevant molecules. This finding leads to the first challenge: the need to implement processes with a reduced number of steps. For example, to develop purification methods that allow us to dispense with too many pretreatment steps. As an example, in ion exchange processes in a fluidized bed or expanded bed, the fermentation broth is injected directly into a column. The relevant molecules are retained on the resins, thereby avoiding a preliminary separation.

The concept of integrated process then calls for a global reflection on the entire process. An interesting illustration of this approach is the conversion of organic acid salts produced by fermentation. Indeed, during the fermentations, a base is used for pH control. The relevant form being the acid form, it was traditionally obtained by adding an acid. These processes led to the consumption of a base for the fermentation stage and an acid for the conversion stage, and to the generation of effluents. The use of electrodialysis with bipolar membranes (EDBM) can simultaneously convert salt in acid form and recycle the base for the fermentation stage. By considering the process as a whole, EDBM can help to limit the consumption of reactants and generation of effluents.

Many hybrid processes, bringing together the combination of several unit operations are presented in the literature. The idea is not just to juxtapose two operations, but to perform a coupling that contributes to raising the deadlocks of at least one of these operations. Membrane bioreactors, which allow a reaction with an integrated purification step, thus present a special advantage when a reaction inhibitor can be removed as and when it is produced.

Finally, various studies aim at designing separation processes that combine several types of driving forces, such as voltage, a difference in concentration, and so on. These processes simultaneously make use of multiple separation criteria such as differences in charge, size etc. New electro-membrane hybrid processes are thus the object of scientific publications. They particularly highlight the potential of electrodeionization (EDI) and electrodialysis combined with the use of ultrafiltration membranes (ED/UF).

This list is not exhaustive, of course: the potential pool of unit operations to be coupled offers vast possibilities to the imagination of researchers!

Let us now consider the impact of the large number of purification steps on solvent consumption. Indeed, crystallization, liquid–liquid or liquid–solid extraction, preparative chromatography, and so on, are all associated with the use of solvents. A strategy on the choice of solvents and optimization of their use thus proves to be a key element. To address this challenge, several approaches are used.

The first way is to set up a means for recycling the solvent, which is already quite a common practice in preparative chromatography. The quality control of the recycled solvent plays an essential role.

The problems associated with the consumption of solvent can also guide the selection process in advance. The resurgence of supercritical fluid chromatography (SFC), using a supercritical fluid as the mobile phase, is certainly related to its performance due to the low viscosity and high diffusivity of these media, but it is certainly also due to the ease of recycling this solvent. The development of crystallization processes, where supercritical CO<sub>2</sub> is used as an anti-solvent (SAS), helps, in addition to obtaining interesting properties of use, facilitates the removal of residual solvents. Similarly, extraction by supercritical CO<sub>2</sub> has the advantage of resulting in a spontaneous separation of substances extracted by simple depressurization.



**Figure 4.16.** *Picture of an installation of continuous separation by chromatography; this installation is used in the pharmaceutical industry to purify active ingredients, typically optical enantiomers. In the background, the installation for solvent recycling. Photo credit: NovaSep*

Finally, a third approach aiming to reduce the environmental impact of solvents is the use of solvents from “green” chemistry and to minimize their consumption by increasing, for example, the extraction using microwave heating, ultrasound heating, and so on.

Now let us consider the impact of the dilution of relevant molecules in a complex medium that includes many molecules with properties similar to that of the

target molecule, that is, the molecule that one wishes to extract. The challenge related to the selectivity of the separation step comes up here. For chromatography, a challenge is to synthesize phases that have specific affinities for the considered molecules and to select the best adsorbent/eluent couple in terms of selectivity and solubility. The development of such phases plays a vital role in the purification of monoclonal antibodies. Materials and processes should complement each other. Owing to the cost of phases involved, the choice of method should help to optimize the productivity, which is relative to the immobilized phase quantity. It is this objective that the development of continuous and sequential multicolumn processes is trying to achieve.

The performance evaluation of the processes implemented leads to another challenge: the development of analytical techniques. In fact, the analytical tests are essential to knowing the quality of the product obtained. To illustrate this key role, we can cite many analytical tests in the chromatographic operations of fractionation of blood plasma proteins. Analysis, however, is usually a major problem since the composition of matrices is unknown. In the case for example, of the purification of a molecule derived from a juice obtained from the leaves of a plant, the nature and concentration of other species present in the medium may not always be known and may vary from one crop to another. The components of these media are also not always available in pure form. It is therefore necessary, in each case, to develop methods that enable the detection and quantification of the relevant molecules. Moreover, the lack of sensors to perform online analyses can be an additional difficulty for process control because of the delay between the sampling and obtaining the test results.

All these evolutions happen in a binding regulatory context. In order to more effectively control the risks of cross contamination, there is a rise of single-use technologies.

Therefore, the mutations involved in life sciences have an impact on the manner of developing and industrializing the processes. A knowledge base in the domain of biological sciences is required to address these issues. The tools of process engineering can then respond to these new needs.

#### **4.8. Acknowledgments**

This chapter is largely inspired by the article “Génie Chimique génie des procédés” published by Editions Clartés<sup>1</sup> in 2002. It was written by Alain Storck, Jean-Jacques Bimbenet, Michel Auroy and coordinated by Jean-Pierre Dal Pont.

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<sup>1</sup> These items are available for reference exclusively at the *Bibliothèque nationale de France*.

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## Chapter 5

# Foundations of Process Industrialization

### 5.1. Introduction

Process development aims to transpose an idea, resulting from research conducted mostly in a laboratory, into an industrial innovation, which consists of a new reliable process, economically profitable and having an environmental impact as low as possible. Process development is based on multidisciplinary scientific skills, several scientific and technological barriers will be removed during this phase, and it usually takes several years. Any process development is associated with a risk of failure, which must be integrated into the development strategy.

The transition from laboratory experimentation to industrial implementation is a fundamental step in the development of a technology or a product. This step determines the value and industrial credibility of an innovation.

The industrialization process of a method can be divided into two phases: a “study” phase followed by an “engineering” phase.

The first phase consists of carrying out studies (development phase) such as: laboratory research, pre-study of the possible variants of the process, selection of process flow diagrams to develop, acquiring basic data through development of experimental tools, technologies, simulation steps of the process units, and simulation and optimization of a typical scheme of the process. This phase leads to the development of a process file, which contains all of the scientific bases (design criteria, models, etc.), which will enable industrialization, that is to say, the sizing of an industrial unit.

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Chapter written by Jean-François JOLY.

The second phase includes engineering studies: process engineering (editing the process book), basic engineering (development of FEED (Front End Engineering Design) which assesses the investments precisely), and detailed engineering after an investment decision is made. After this phase, the production unit is built on the industrial site and can be commissioned.

This chapter deals with the first phase, that is to say, process development: the foundations of industrialization.

Three main objectives are pursued in this first phase of studies leading to the basic process guidelines:

- feasibility: imagine, build, and develop experimental tools to acquire the basic data that are necessary for the development process;
- reliability: ensure that the process can continue in the long-term (even in the case of fits and starts or incidents caused) without irretrievable drift or loss of control, and without major degradation of product quality while maintaining the profitability of production;
- extrapolability: ensure the conversion of research results to an industrial scale.

Methodologies of process development have evolved over time, with the aim of improving the process to minimize the development time and associated costs, while maintaining a very good management of risks related to extrapolation.

## **5.2. The various stages of process development: from research to the foundations of industrialization**

The creation of the process guidelines containing the basics for the industrialization of a process can be divided into three stages, whose relative importance depends on the degree of innovation: a significant improvement of existing technology or development of a new technology, even a break away from the existing technology.

The three major phases that structure the development of a process are as follows:

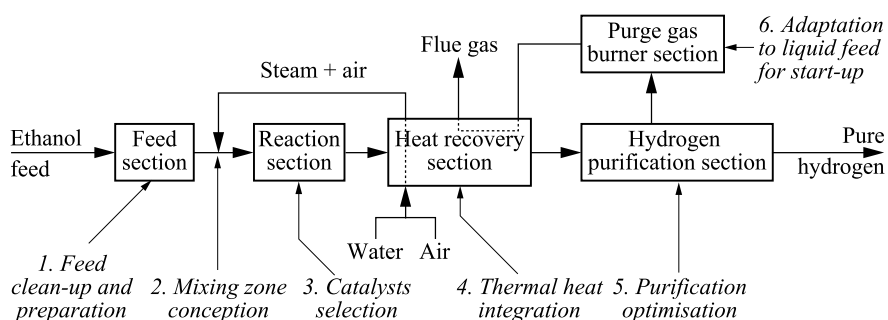
- the pre-study (or pre-development) of the process is the first step which is based on the results of the laboratory research (new reaction, new catalyst);
- the developmental stage leading to the process guidelines containing the basics of industrialization;
- the establishment of process guidelines, foundations of industrialization, which brings together all the elements relating to the process guidelines.



### 5.3. The pre-study (or pre-development process)

The preliminary study builds a consistent and rigorous development approach. It also acts as a support tool for decision-making. Indeed, process development starts with the analysis of the potentials and techno-economic feasibilities of the idea resulting from the research work. So, depending on the increase in level of difficulty of the scientific and technical barriers and on the potential market of the process, it is decided whether to continue the development process that will implement the idea on an industrial scale or not. This comprehensive approach of pre-study alone helps in judging the value of a new idea at a given time.

The process begins with the first design of a process flow diagram of the new concept (a simplified illustration is given in Figure 5.1), starting from a limited amount of data from the first laboratory tests, the first calculations, or using data from literature in order to identify the key points and any other possible barriers to be removed later in the development.



**Figure 5.1.** Example of a process flow diagram established in a preliminary study of a process for hydrogen production (source: IFP energies nouvelles)

Finally, we must estimate the technical and economic performances of the process: this study is made from strong hypotheses, especially by assuming the removal of technological barriers identified in the design of the diagram. This pre-estimation will enable us, by comparing the expected performance of the process with respect to the performance target related to the setting up of the marketing process, to validate or not the viability of the concept and, if necessary, switch to the development phase of the process if the research and development effort assessed is consistent with the issue.

In parallel, an analysis of the patent literature is required to stand out from the competition and to ensure the freedom to operate. This analysis aims to establish an industrial property: protecting innovative diagrams from the beginning by acquiring the data necessary for patent drafting.

In general, the completion of technical and economic preliminary studies also requires making strong hypotheses, as it is necessary to develop the methodologies that help to make these preliminary studies reliable.

The design and development of a process are primarily based on the material and energy assessments obtained by simulation. However, environmental constraints (resource use, environmental pollution) are increasingly present and do not appear directly in this analysis, because the pollutants are, in general, several orders of magnitude below the primary products, hence they are not taken into consideration in the simulations. Currently, we must also add the environmental impact of processes at the pre-development phase. The technical and economic preliminary studies have become technical, economic and environmental preliminary studies [POR 10]. Integrating the environment when the technical possibilities are at maximum, is the whole point of the eco-design process.

However, there is no guarantee that the process developed from just the material and energy assessments will be economically viable. The integration of economic and energy constraints has led to the birth of a new method: thermo-economic analysis [TOC 10]. This method integrates both the operational and economic aspects of the process and even seems to be able to guide the design and optimization of complex systems.

The first design of a process flow diagram is an opportunity to highlight the technical difficulties and possible barriers that will have to be removed later in the development of the process.

Barriers are the key points of the process, which, if not removed can lead to the discontinuation of the project; for example, barriers can include:

- unknown effect of recycling (accumulation of impurities in trace amounts and having a strong impact on the catalytic performances);
- need to develop a new piece of technological equipment, whose extrapolation rules are unknown;
- need for a catalyst whose shaping is not controlled, for example, in some cases it can be very difficult to produce a catalyst in the form of beads of high mechanical resistance;
- the cost of separation steps;
- dealing with any process discharges.

Various configurations are studied and assessed at this stage on a technical, economic and environmental basis: different types of reactors, defining a first fractionation flow diagram of effluents, identification of possible recycling, and so on. This pre-development approach can also specify the additional experimental data

that are required. These data will be acquired on dedicated experimental tools (studies of chemical reactions, acquiring thermodynamic data, and study of transport phenomena). This study will also be fueled by the results of the study of process modeling which is carried out in parallel, in order to optimize the pre-development process.

Once a process flow diagram is selected, the new data and models developed will be integrated throughout the development phase of the process, in order to update it based on the technical, economic, and environmental simulation and evaluation.

Beyond the technical and economic preliminary studies conducted within the boundaries of a process, it is interesting from the pre-development phase to study its impact on the performance of the industrial site in which it operates. This can be achieved by using linear programming. Linear programming is a methodology to find an optimum (maximum or minimum) by considering a certain number of constraints (material balances, quality and composition of a mixture, maximum capacity of a plant, demand for a particular product, etc.). This tool is used in operational research (deciding making) and in various fields such as air transport (rotation of crews), petroleum refining (procurement, manufacturing, and distribution), the food industry (defining mixtures), the metal industry (definition of alloys), and so on.

Tools and methodologies used in pre-development are as follows:

- process schemes are studied using commercial simulation software. These tools perform the calculations of thermodynamic equilibrium but can be enriched with kinetic models of varying complexity for the reactive sections of the process;

- optimization of heat integration can be achieved, for example, by using the pinch method which determines the objectives of consumption of utilities, calculates the pinch temperature of the process and estimates the quality of the commodities required (low steam, medium or high pressure, cold boxes, etc.). This method provides evidence that can guide the process engineer in the design of heat integration and locate the places where heat is exchanged inefficiently in terms of energy. Then it is up to the developer to accept these inefficiencies, justified by other reasons (constraints on loss of load, start up constraint, flexibility or security constraints) or to rectify them;

- tools for sizing major equipment (pumps, compressors, heat exchangers, reactors, etc.);

- different methods of technical and economic evaluation can be used, among them we will discuss the method developed by A. Chauvel [CHA 01] at IFP Energies nouvelles;

– experimental tools to acquire kinetic data, which help us to develop a simplified kinetic model of the reactions;

– reactor modeling tools (kinetic modeling, modeling of mass and heat transfer phenomena), based on the kinetic data acquired to develop the first performance models that are included in the overall process flow diagram.



**Figure 5.2.** *Example of a reactor using a heterogeneous catalyst in a fixed bed for the hydrogenation of fuels © IFPEN*

At this stage of development, it is often necessary to define the technology of the reactor, which is one of the key pieces of equipment of the process; Figures 5.2 and 5.3 are illustrations of industrial reactors using a fixed bed of catalyst within a large volume reactor (Figure 5.2), and a moving bed of catalyst within several reactors in series (Figure 5.3).

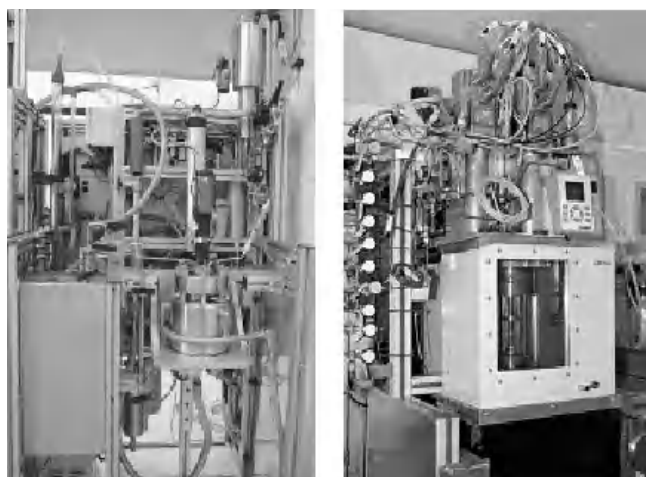


**Figure 5.3.** *Reactors of the catalytic reforming process for light fuels, radial bed technology © IFPEN*

### 5.3.1. Experimental tools for acquiring kinetic data

In the pre-study phase, it is necessary to acquire the experimental data when they are not available in the literature. It is absolutely necessary to have experimental equipment that helps us to acquire the required information in a reasonably short time (e.g. a few months). These data are used first through kinetic models that will make it possible, through reactor designs, to assess the possible choices for reactor technology, and also to set the targets in terms of performance for the development of the catalyst.

The goal is not to cover the whole field of operation of the process envisaged, but to target the minimum data necessary to develop the first model that will enable us to choose the technology of the reactor (fixed bed, fluidized bed, circulating bed, etc.).

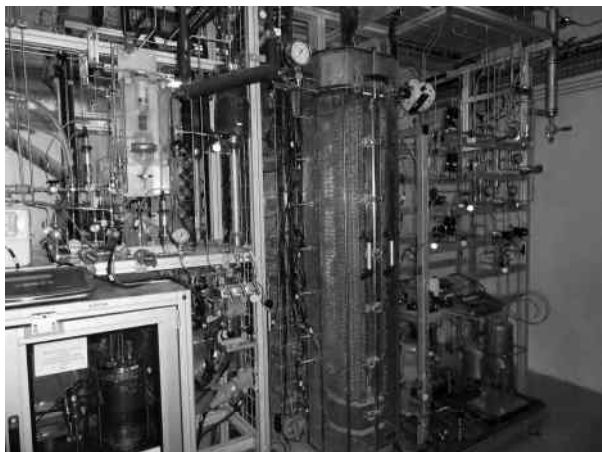


**Figure 5.4.** Pilot plants with a perfectly stirred reactor used to acquire kinetic data in the pre-development process © IFPEN, © P. Chevrolat

Acquiring kinetic data can be done on a pilot plant, operated continuously or discontinuously, in a fixed bed or in a perfectly stirred reactor, and whose configuration is not necessarily indicative of what the reactor(s) of the industrial unit will be. Taking into consideration the small volume of this type of reactor, in general from 50 cm<sup>3</sup> to 500 cm<sup>3</sup> of reactive volume (Figures 5.4 and 5.5), the isothermal conditions are met.

To determine the intrinsic kinetics, it is necessary to model the reactor, taking into account the transport transfer, and diffusion phenomena that can alter the performance of the catalytic system.

In the case where the catalyst is solid and the reactants and reactive products are in gaseous form, the flow of the gaseous phase within the reactor can be described by a piston dispersion model to consider the non-ideality of flow via an axial dispersion coefficient characterizing the degree of retro-mixing.



**Figure 5.5.** *Pilot plant with a fixed bed reactor used to acquire kinetic data in the pre-development process © IFPEN, © P. Chevrolat*

The external gas/solid transfer will be taken into account by writing a material balance at the level of laminar film of catalyst external transfer. The transfer coefficient of gas/solid will be determined by correlation. A model of particles in spherically or cylindrically coordinates, including the diffusion (characterized by an effective diffusion coefficient depending on the porosity and tortuosity of the particle), adsorption and reaction, will also be implemented to consider the possible diffusional limitations.

The coupling of flow models, external transfer, and diffusion in the particles enables us to determine the intrinsic kinetic parameters of the reactions.

Only this kinetics is directly extrapolable to other types of reactors because it depends only on the nature of the support and the active phase of the catalyst. Considering the physical and chemical phenomena is required in the pre-development phase in small pilots, so as to ensure high reliability in the scale-up studies in this pre-development phase.

Knowledge of the kinetic data intrinsic to the reactive system, coupled with the knowledge of transfer phenomena, helps us to choose the most suitable reactor technology; the first technical and economic evaluations are thus based on this reactor technology.

The choice of reactor technology also includes a first assessment of the stability of the catalytic system. Indeed, if a heterogeneous catalyst is used, then the choice of reactor technology will be directly related to the rate of deactivation, that is to say, the loss of catalyst activity over time.

This loss of activity may be due to several phenomena, including:

- the presence of impurities in the feedstocks (inhibiting or poisonous effect);
- an inhibiting effect of one of the products of the reaction;
- the loss of active sites (extraction of the active site in operating conditions of the reaction), or degradation of the catalyst support;
- build up of polymers or coke on the catalyst surface.

This knowledge is based on bibliographic studies in relation to similar reactive systems, and dedicated experimental tests aimed at identifying the main causes of deactivation of the system studied. To do this, we may, for example, harden the operating conditions to accelerate deactivation phenomena, for example by using higher reactor temperatures in order to accelerate the rate of coke building up. An initial deactivation model is then developed.

In the event that the main cause of deactivation is related to the presence of impurities in the products to be processed, it can be done using a purification section (e.g. mass capture to remove metals such as mercury and arsenic), special washing, or even dedicated reactors for purification by selective hydrogenation, for example, if these polyunsaturated components present may lead to polymers building up in the main reactor.

In the case where the cause of deactivation is related to a secondary reaction, and it is not possible to change the operating conditions to minimize such a reaction, the reactor technology proposed must consider this parameter, and this must be integrated into the preliminary technical and economic evaluation. There is not always only one technological solution to solve the phenomenon of rapid deactivation. Indeed, within the framework of a chemical transformation performed in the presence of a heterogeneous catalyst and whose deactivation rate is about 24 hours, two solutions are possible:

- the use of multiple reactors operated in “swing” mode, one of the reactors is in production, and the other reactor is in regeneration (or rejuvenation) mode. A periodic swing from one reactor to another is performed in order to maintain continuous production;
- the use of a single reactor, with a continuous or discontinuous flow of the catalyst within it, a regeneration zone being located in immediate proximity of the

reactor and the catalyst circulating between these two zones to be regenerated continuously (Figure 5.6). Such a mode of operation may appear to be more complex, however, it ensures a constant quality of the final product, and manages transitional situations that generate fits and starts of deactivation by accelerating the rate of the catalyst circulation in a more flexible manner.



**Figure 5.6.** *Industrial unit using a technology of continuous regeneration of the catalyst (catalytic reforming process by moving radial bed for production of base fuels with a high octane number) © IFPEN*

These technological choices are to be carried out at the pre-development stage, in order to clearly identify the scientific and technical barriers so that development will rise, such as the development of a catalyst adapted to the conditions and constraints of its implementation in the industrial unit: mechanical resistance (during the transport phases), catalyst shape (to minimize the process drops), accessibility of the active phase, and so on.

In the fields of chemistry, and the petrochemical and oil refining industries, chemical transformations are often carried out in large capacity reactors (a few cubic meters to 100 cubic meters). The reactions carried out can be highly exothermic, and the elimination of the heat of reaction is an important criterion to be considered, at least to preserve the quality of the manufactured products, the stability of the catalyst system, and especially to ensure safe operation of the industrial plant.



The inclusion of this criterion in the first stage of the process development is part of the pre-development phase, because it also guides us toward the choice of technologies related to the elimination of the reaction heat (exchanger reactors, using quench boxes, recycling the reaction products to limit the temperature increase by dilution of reactants, partial vaporization of the products within the reactor, etc.).

The pre-development phase also addresses the management of products and, in particular, the by-products and possible discharges of the process. These can be of various kinds, gaseous for example, if nitrogen oxides are formed, liquid or even solid.

At the end of the pre-development stage, teams responsible for the development of the process have the elements necessary for “Go/Don’t Go” decision-making to launch the development phase of the process. The development phase of the process is detailed in section 5.4.

## **5.4. Development stage of the process**

### **5.4.1. Introduction**

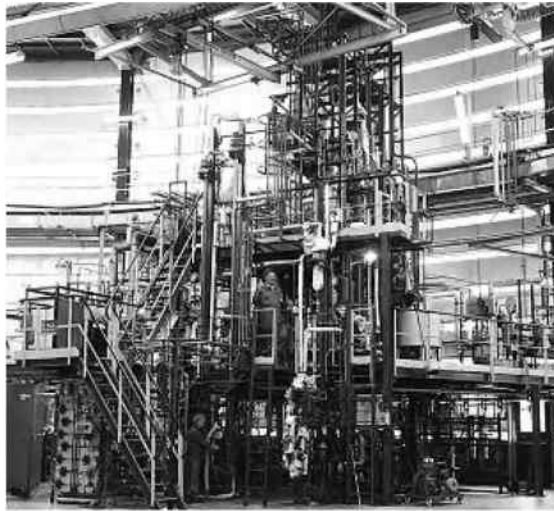
Process development aims to establish the basic data necessary for industrialization, that is to say all the necessary scientific data (models, design criteria, catalysts, optimized process flow diagram, etc.). It is executed around the technological barriers identified during the pre-studies carried out in the pre-development phase.

As the research progresses on these critical points, the engineers update the technical and economic studies and possibly redirect the studies.

The development phase is also an opportunity to protect the concepts via the patenting of process flow diagrams, formulation of catalysts, or technological solutions.

This is a complex process whose success is largely connected to the control of project management methods by the project manager, who is responsible for this development.

Scale-up factors between the tools used to acquire the basic data of the process and the industrial unit are often very high, as is illustrated in Figures 5.7 and 5.8. The quality of the experimental data, which constitute the basic data of the process, as well as models developed will guarantee the reliability of scaling up.



**Figure 5.7.** *Pilot plant used in developing a process for hydrotreating petroleum with a fixed catalyst bed* © IFPEN, © P. Chevrolat



**Figure 5.8.** *Industrial unit for hydrotreating petroleum in a fixed catalyst bed* © M. Roussel, ScOpimag

#### **5.4.2. Data acquisition process**

The team responsible for developing the process develops a strategy to acquire the experimental data required for the scale-up of the process; these data are used to develop a set of models which enables scale-up: choosing the best technology for

the reactive section, sizing key equipment, and selection of the process flow diagram, optimization, and heat integration. There are many books that deal with the design of chemical reactors, and readers can refer to [LIE 98, SCH 01, TRA 02, VII 93] for more information.

The main data to be acquired in this step are as follows:

- kinetic measurements, thermicity of the reaction (amount of heat exchanged with the reactor);
- measures in relation to the mass and heat transport phenomena;
- thermodynamic data;
- data related to the product quality obtained;
- impact of impurities on the deactivation of the catalyst(s);
- regeneration conditions.

The main deliverables of this stage of development are as follows:

- the reactor models which enable scale-up (prediction of performance of beginning of the cycle and deactivation);
- criteria for sizing key technological equipment;
- thermodynamic models that enable sizing the separation equipment (distillation, decantation, etc.), compression equipment, and heat exchange equipment (heat exchangers and furnaces).

Different experimental tools are used at this stage of process development: pilot plants to acquire data in representative reaction conditions and mock-ups to study the transport phenomena of mass and the technologies (filtration, gas/solid separation, fluid distribution, etc.).

The pilot plant is an experimental device that helps us to ensure the transformation from a feedstock into its desired product(s) and continuously over time.

The experimental conditions to be studied are set at the end of the pre-developmental stage. The pilot plant operates mostly on a continuous basis over time (24h/24h) and for periods up to several months in order to be able to quantify the stability and reliability of the process, to determine the lifetime of the catalyst, and also to produce sufficient quantities of finished product to verify the quality. The size of a pilot plant is significantly greater than that of the laboratory equipment; it is usually located in dedicated areas equipped with all the safety measures required.

A cold mock-up is a piece of equipment used for the study of technologies and is considered to be “cold” to the extent that there is no chemical transformation in it. Mock-ups help us to test the possibility of certain functions. They are usually operated in the absence of reaction and the presence of simple fluids (nitrogen, water, air, etc.); they help to test different technologies, to validate or calibrate models, such as the one developed by CFD (Computational Fluid Dynamics) which the study of fluid dynamics by the numerical solution of the equations responding to it [WIL 05].

#### 5.4.2.1. *Experimental acquirement of chemical kinetic data*

Acquisition of chemical kinetic data is a key step, because it determines the choice of reactor technology to be kept, as well as the main variables related to its size (volume, temperature, pressure, residence time, etc.).

In the preliminary study, a first simplified kinetic model has been developed based on the main reaction mechanisms involved. In the development phase, a comprehensive kinetic model will be developed, which will integrate a complete set of reactions and will cover a domain of operating conditions wider than that covered by the simplified model. The methodology of acquisition of intrinsic kinetic data is however similar to that used in the pre-study.

Data acquisition of reaction kinetics requires the availability of experimental tools whose hydrodynamics is well characterized so that we can separate the mass transport phenomena, and therefore access the intrinsic reaction kinetics of the system considered. Once the intrinsic kinetic data is acquired and mass transport phenomena are known, different reactor configurations can be calculated using models, their performance can therefore be compared, and hence the choice of the best technology will be established.

In general, kinetic models are established in operating conditions corresponding to regimes of stable operation of the catalyst, that is to say, without significant change in catalytic activity and selectivity with the time stream of the catalyst. The kinetic model developed is then a *Start Of Run* model, the engineer must develop in parallel by means of dedicated experimental data related to the stability of the catalyst in the case of a heterogeneous catalytic system, or with the consumption of catalyst in the case of a homogeneous or heterogeneous catalyst system in specific cases.

This approach is not always possible because some catalytic systems have a high or even very high deactivation rate. The catalytic activity therefore changes rapidly with time, the loss of activity could be complete within a few hours or a few days. A deactivation kinetic model of the catalyst must be developed to account for all observed phenomena. This model will help us to choose the best reactor technology

to be used to compensate for this loss of activity over time and thus ensure a constant production over time.

To acquire kinetic experimental data, continuously functioning pilot plants are most often used.

The pilot plant is not usually a small scale representation of the industrial reactor; however, the key operating conditions of process will be replicated.

Intrinsic kinetic data are directly accessible when the unit is operating under chemical kinetics conditions; in other cases, we use a model of the reactor of the pilot plant to extract from it the intrinsic kinetic data that will be used to develop the reactor models for scale-up.

#### 5.4.2.1.1. The sizing of catalytic reactors for pilot plants

The sizing of pilot plants units has been discussed in many publications. For example, Sie and Krishna have reviewed the methodology that is used to intrapolate and extrapolate fixed bed reactors by demonstrating the limitations on the use of small size fixed bed reactors [EIS 98].

Two criteria must be considered to size a laboratory reactor:

- conservation of surface velocities of fluids with respect to those of the industrial reactor considered (speed of fluid flow in m/s within the reactor);
- conservation of the hourly space velocity of reagents injected into the reactor (flow rate of reagent in m<sup>3</sup>/h by reactor volume in m<sup>3</sup> and by unit of time).

The first criterion helps us to ensure that the fluid dynamics is substantially identical between the reactor of the pilot plant and the future industrial reactor. This criterion is often difficult to achieve because in practice, the fluid velocities are lower at the scale of pilot unit reactors.

This reduction in fluid velocities can lead to the existence of external diffusional limitations to catalyst particles, due to too low mass transport outside the catalyst particles. This should be taken into account when using the experimental data to determine the intrinsic kinetic constants that will be used to select and size the industrial reactor.

In the second criterion, conversion of reagents and product selectivity is potentially the same, provided there are no mass transfer limitations.

Another important effect in the reduction of scale of a reactor is the effect of the reactor walls. Near the walls of the reactor, the particle distribution is different from that inside the bed. The average porosity near the walls being greater than the porosity within the bed, a radial velocity profile appears in the catalytic bed. This effect is negligible for industrial-scale reactors but grows when the diameter of the reactor is reduced: the deviation from ideal plug flow increases due to a disparity in the local velocities. In addition, the existence of preferential passages is probable.

Finally, because of very low flow rates, the wetting of the particles may not be uniform during downward flow of fluids. Currently, a frequently applied solution that helps us to improve the wetting, is to increase the local velocities of fluid and therefore to improve the mass and heat transfer. For this, we proceed to fill the bed with small particles to increase its porosity.

The use of these particles also reduces the axial dispersion, by limiting the preferential passages, and helps to dissipate heat, by reducing the radial temperature profiles using inert particles having a coefficient of high thermal conductivity.

For highly exothermic and very fast reactions, as for example, selective hydrogenation, a good thermal control becomes very difficult and limitations to external mass transfers are more important and can become insurmountable to evaluate the catalytic performances on pilot unit reactors with fixed beds. These problems are worsened with the development of new generations of more active catalysts.

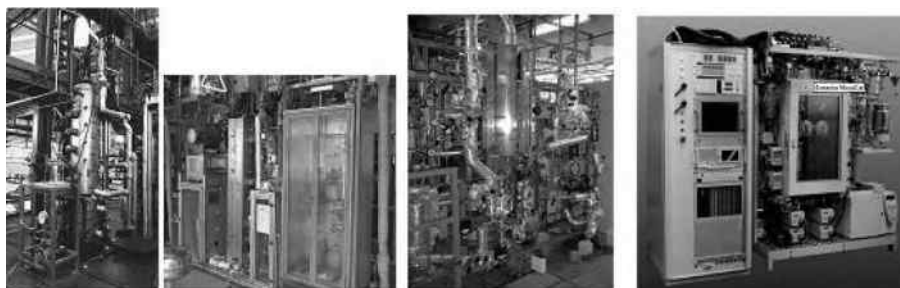
As a conclusion, various effects influence hydrodynamics and external mass transfers during the scale reduction of a reactor. By filling the porosity of a pilot reactor with small inert particles, we can improve the wetting, local velocities, mass and heat transfers, and axial dispersion.

Technologies implemented within the pilot plants have evolved over the past 20 years, with the following objectives: reducing the cost of data acquisition, reducing development time, and obtaining more accurate measures. The development of advanced analytical techniques was carried out in parallel with the development of online analysis (analyzers being an integral part of the pilot plant), and online microanalyzers to obtain the analytical information with low quantities of products.

Progress achieved on analytical methods helped to provide more detailed information on the products, due to better identification of the set of molecules, which enabled the development of more detailed kinetic models and therefore more representative of reality and consequently safer extrapolation models.

In the field of oil refining and the petrochemical industries, studies on size reduction of pilot plants have helped to move from reactor volumes close to 1 liter to

a few cubic centimeters, while preserving the quality of results (Figure 5.9). This has the advantage of requiring smaller amounts of catalyst, and having facilities equipped with several reactors in parallel, in order to multiply the number of experimental points in the same duration, which helps us to reduce the cost and duration of this phase of the development process.

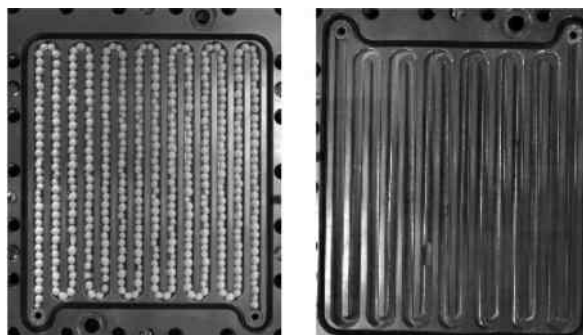


**Figure 5.9.** Pilot units equipped with fixed bed reactor with volume decreasing from left to right (1,000, 200, 50, and 5 cm<sup>3</sup>) used to acquire data on a process for hydrotreating petroleum fractions © IFPEN, © P. Chevrolat

The most frequently chosen criterion in downscaling is the preservation of the hourly space velocity (HSV). The maintenance of HSV in conventional pilot units is often accompanied by low-velocity flows of fluids. Indeed, the height/diameter ratio of reactors of pilot units is generally lower than that in the industrial reactors.

At these velocities, external mass transfer to particles can become limited with respect of reaction rates, especially for fast reactions like hydrogenation.

In this context, a new geometry of the reactor has been developed to intensify the mass and heat transfer and to increase the velocity of fluid flow: the “string” reactor (Figure 5.10). This is a reactor with a diameter equal to or close to that of the catalyst particles with a very high height (or length) to diameter ratio, which increases the fluid velocities by a factor of 10–100 compared to the conventional reactors. It is expected that the flow of fluids in the reactor allows a very good gas/liquid mass transfer. As the diameter of the reactor is very small, the ratio of external surface/volume is more considerable and thermal control is better. Another advantage of this type of reactor is to allow testing with catalyst particles similar to the commercial catalysts (extruded or beads), which helps us to represent the internal potential limitations existing in the operation of a commercial reactor.



**Figure 5.10.** Reaction section of a string reactor: catalyst-filled on the left and empty on the right © IFPEN, © P. Chevrolat

		Industrial reactor	Traditional pilot reactor	Wired reactor
Reactor diameter (mm)		1,500–8,000	10–20	2–4
Height (mm)		1,500–15,000	100–500	4,000–10,000
P (bar)		20–150		
T (°C)		30–300		
Liquid	VVH ( $\text{h}^{-1}$ )	1–20		
	$\rho_L$ ( $\text{kg}/\text{m}^3$ )	600–800		
	$\mu_L$ (cP)	0.1–2		
	$u_{Ls}$ (mm/s)	1–100	0.03–3	1–50
Gas	$\rho_G$ ( $\text{kg}/\text{m}^3$ )	15–30		
	$\mu_G$ (cP)	0.02		
	$u_{Gs}$ (mm/s)	10–200	0.5–10	10–200

**Table 5.1.** Operating conditions of typical industrial reactors in the petroleum and chemical industry, of conventional pilot plants and wired reactor

#### 5.4.2.2. Development of kinetic models

Kinetic modeling is based on theoretical tools to describe the phenomena from what is available. This description constitutes the model.

A model includes a number of variables including parameters that are necessary to estimate from experimental or measured data [CON 10]. The model with its set of



parameters enables us to generate the data that are to be compared with available experimental data (all or part). To estimate the set of parameters that will best describe the reality, a quantification of the adequacy of the model is necessary. This quantification is a criterion which is expressed mathematically by an objective function to be optimized (usually minimized).

The acquisition of experimental data, parameter estimation, and the analysis of results obtained are the stages of the modeling process and implement methods whose effectiveness we have to be aware of and manage.

In the context of developing a kinetic model, which will be integrated within a reactor model, the initial phase of developing specifications is essential.

The specifications are a document prepared in collaboration between an engineer in charge of developing the model and the project manager who makes it possible to specify the performance and goals of the model:

- definition of values to be predicted, application domain (reactants, operating conditions, performance, product quality, etc.), and accuracy of the model;
- defining the conditions for validation of the model.

The objectives of a model are thus clearly defined and collected in the specifications written in collaboration between the members in charge of developing the model of the reactor and the project manager who is responsible for coordinating the various tasks that are necessary for the development of the process. It is very much apparent that an engineer in charge of developing the model has to analyze whether the goals set are achievable, for example, in terms of the model development time or adequacy of the information required about the model predictions and information available during the acquisition phase of the experimental data.

The system that we need to model can be approached in two ways. Either by including the available knowledge based on chemistry and physics, which will build a phenomenological model, also called a knowledge model (e.g. material balance, energy balance, momentum balance, etc.), or by considering only the input–output behavior without worrying about the “reality” of the model which helps us to build a behavioral model, also called as representation model (e.g. correlations).

A basic classification of models can be made by taking into account the qualitative properties of descriptions [WAL 94]. These classification criteria, often dichotomous, correspond to a classification of resolution methods, so it is useful to specify the type of concerned or desired models, for example:

- phenomenological or behavioral;
- linear or non-linear;

- continuous time or discrete time;
- deterministic or stochastic.

#### 5.4.2.2.1. Phenomenological or behavioral

The phenomenological models have a concrete meaning that enable us to interpret them as the variables and parameters. They take a long time to implement because they require an understanding of the phenomena hence a certain expertise in system to be modeled. The computing time can be long or even prohibitive for certain applications. However, they are more reliable, especially in extrapolation.

Behavioral models are often based on a mathematical technique available *a priori*, independent of the application domain of the model. They are fairly easy to implement, they can be very effective in interpolation and low computing time, but have many drawbacks: low predictability outside the domain of validity, sensitivity to parameters, which, in general, we prefer among the phenomenological models when they are available.

#### 5.4.2.2.2. Linear or non-linear

Dependence of models on the parameters is a very important point in the classification of models. The chemical models are often non-linear, through the intervention of the activation energy of the reaction (denoted by  $E_a$ ) in an exponential in the expression of the rate constant ( $k = k_0 e^{-E_a/RT}$ ). However, we must first ensure that the model dealt with is non-linear because, on the contrary, linear models benefit from the existence of powerful mathematical tools and are accurate for both the offline and online identifications. In particular, the calculation of the gradient during the optimization and the calculations of uncertainty about the parameters (confidence intervals) can be done at low cost and accurately.

#### 5.4.2.2.3. Continuous time or discrete time

The equations of the model can be formulated as continuous equations with respect to independent (differential equations) or discrete variables (equations with differences). This is a classification of equations independent of the resolution type (numerical, analytical, etc.).

In the context of ordinary differential equations encountered in most cases, the continuous formulation is used, whereas in the case of differential equations with partial derivatives or boundary conditions, discretization (orthogonal collocations on finite elements) is preferred. In the latter case, we can find a hybrid form with the method of lines found in discretizing with respect to one of the variables and can be continuous with respect to the other (e.g. a discrete on space variable and a continuous time variable).

#### 5.4.2.2.4. Deterministic or stochastic

Most models are deterministic: the same inputs lead to the same outputs. Stochastic models [JAV 08] can, however, be used in many cases to:

- model an unmeasured interference (analysis error, etc.);
- simulate a system of differential equations;
- describe a distribution.

The first point is very useful for the study of uncertainty and discrimination of models. The second is more anecdotal in nature; the deterministic methods of differential integration have proved it. As for the third, it is especially used in the load reconstruction algorithms.

#### 5.4.2.2.5. Kinetics

The main objective of this section is not to present the way of establishing the equations that govern kinetics, but to put forward some concepts. Readers may refer to works cited in [LIE 98, SCH 01, TRA 02, VII 93] for more details.

#### 5.4.2.2.6. Rate of reaction

The rate of a chemical reaction is defined as the amount of material processed per unit of time and per unit of extensity which depends on the volume set: volume, mass, surface, and so on. Rate therefore measures of a specific rate of chemical transformation [VII 93].

In a control volume, it demonstrates an accumulation of product that has no place in the steady-state applications and for which there is still a chemical reaction. This notation can be confusing and therefore we prefer to take  $r$  as the rate of chemical reaction, whereas the concept of speed is not related to a temporal evolution.

#### 5.4.2.2.7. Reaction mechanisms

Let us take a set of  $N$  chemical reactions of index  $i$ , described by the following equation:

$$\sum_j \nu_{ij} A_j = 0 \quad [5.1]$$

where  $\nu_{ij}$  are the stoichiometric coefficients of the reaction (positive for a product and negative for a reagent) and  $A_j$  are the numbers of moles of each  $i$  species.

The net flow of formation of component  $j$ ,  $R_j$ , is given by the following equation:

$$R_j = \sum_i \nu_{ij} r_i \quad [5.2]$$

where  $r_i$  is the rate of reaction  $i$ .

#### 5.4.2.2.8. Approximation of quasi-stationary states and reduction of mechanisms

In the case of complex mechanisms, the number of equations can become very important.

In order to simplify the equations, we often carry out a reduction of the mechanism that does not show the intermediate species.

The reduction of a kinetic diagram often involves one of the following two principles:

- approximation of quasi-stationary states;
- approximation of the limiting step.

The approximation of quasi-stationary states is the most rigorous step. Its application involves the intermediate species and requires:

- the existence of intermediate species whose formation rates are almost zero;
- intermediate species in a negligible amount.

The approximation of the limiting step is to identify the slowest rates of reaction, which govern the overall kinetics and assume the other invariants in time. The rate of evolution of each of the reagents is then expressed as the amount of rate limits to which they are connected by the kinetic network.

The approximation of quasi-stationary states is considered to be a special case of approximation of the limiting step.

#### 5.4.2.2.9. Intra- and extra-particle diffusion

So far, it has been considered that the concentration of reagents inside and outside the catalyst particle was the same. This is not always the case and we may observe external and/or internal diffusional limitations.

There are various mathematical and experimental criteria to ensure the domain in which there may be the presence or absence of diffusion.

In the case where we cannot experimentally escape diffusional limitations, they must be taken into account in the model. In addition to mass transfer, they can also affect the heat transfer, that should also be considered.

The development process of kinetic models has undergone many changes since the 1960s. Thus, there is generally a continuous increase in complexity over time resulting from the development of new analytical tools providing access to more detailed information at the molecular compositions level as well as to improving the understanding of the physicochemical phenomena observed.

In fact, one of the major difficulties encountered during the construction of a model is the representation of the inlet and outlet flow of the material(s). Usually, these flows are described by their molecular composition, that is to say by the relative quantification of different chemical species that constitute them. In the oil domain, the flows are mixtures that are too complex to be represented in this way. For example, a commercial diesel can have up to several million different components.

Historically, the difficulty was circumvented by grouping the components with similar properties shared by a common family based on the type of process being studied: these are called lumping models. In the field of non-reactive thermodynamics, as oil components have a low polarity, they are grouped by family of increasing volatility called pseudo-components. With a description of the oil flows and with the help of a dozen pseudo-components and an appropriate thermodynamic model, it is possible to develop reliable models for a multistage distillation, a process of heat exchange, and so on.

In the field of reactive (and often catalytic) process models, the family lumping remains an art that depends on analytical techniques and the computing power of computers available at the time of development of the model. For example, models of catalytic cracking of petroleum residues have changed from a description in the form of 3 lumps of molecules in 1970 to 10 lumps in 1976, and to 18 in 1994. Once the lumps are defined, a kinetic network helps to show the relations of different families among them.

The models are then based on a kinetic module that helps to track the changes in the quantity of different families either over time if the reactor is agitated and closed, or along the reactor if it is open. The advantage of these models is in their ease of development and use. Their main disadvantage is that they are often dependent on the type of feedstock (mixing formed by the reactants and recycled products feeding the reactor) used in the process and the type of catalyst used if it is a catalytic process. The second drawback is that the number of parameters of the models increases, at least, in proportion to the number of lumps describing the flow.

On the contrary, other models have been developed from a molecular description of reactive flows and a network of basic steps. Several teams have worked on this type of approach: the team of M.T. Klein [KLE 91, KOR 94] based on the kinetic theory LFER (*Linear Free Energy Relationships*) and teams of G. Froment and

G. Marin that worked on the theory of single events [VYN 91]. Reconstruction methods have been developed so that they can generate a mixture of molecules (100–10,000 molecules) whose composition is optimized in such a way that the overall properties of the mixture obtained will be identical to those accessible by the analytical techniques [HUD 04, PYL 09, VAN 07, VER 10].

The advantage of mechanistic models is that the number of parameters of the model is relatively low and the parameter values are independent of the type of feedstock. Their main disadvantage is that it is necessary to have access to the molecular details of the feedstock which is possible only on the mixtures of molecules that are clearly identified, either on petrochemical feedstock or on light fuel-type petroleum fractions. For heavier petroleum fractions, it is necessary to use the “posterior lumping” to get to a level of analytical detail. A second problem concerns the reactive network whose size increases exponentially with the number of components present in the flow.

Theoretically, prediction models of processes should be mechanistic models based on fundamental kinetic theory. In practice, the difficulties in characterizing the feedstock associated with management difficulties regarding the size of the reaction networks lead to the consequence that the models usually remain combination models, even if they become more complex with an increasing number of groupings. The models then introduce an increasing number of parameters and the experimentation required for their optimization finally becomes more restrictive.

#### 5.4.2.3. *Data acquisition for the sizing of technological equipment*

The objective is to measure, understand, and describe the hydrodynamics and transfers (mass, momentum balance, and heat) in the common operations of process development and to establish the scale-up rules of technological equipment.

The necessary experimental tools are as follows:

- cold mock-ups;
- instrumentation for the acquisition of comprehensive measures: concentration measurements of liquid/solid transfer (denoted by L/S) and gas/liquid transfer (denoted by G/L), and local measures, such as determining local *hold-up* L/G/S by gamma tomography;
- imaging techniques (colorimetry, MRI, etc.).

Modeling of phenomena at different scales is used in addition to the acquisition of experimental data:

- dimensional models: these are “conventional” models of the discipline, such as the development of hydrodynamic models of pressure drop and hold-up;
- multidimensional models: modeling based on the CFD (Computational Fluid Dynamics) which enables us to design technological equipment.

The data obtained as well as the transfer models developed help to extrapolate by predicting the performance of the industrial system and by coupling of thermodynamics, intrinsic kinetics, hydrodynamics, and heat and mass transfer through a reactor model. This reactor model (or a simplified version) will be then introduced into a process simulator to study the overall performance of the system.

The experimental tools used for this data acquisition can be large pieces of equipment, and the acquired data can then be used with great reliability during the scale-up process.

Two illustrations of mock-ups are shown in Figure 5.11.

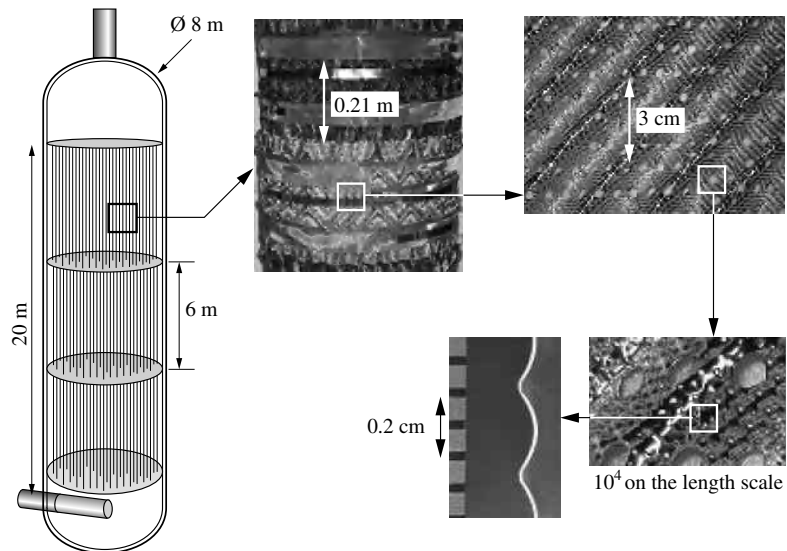


**Figure 5.11.** Examples of mock-ups used to study reactors using heterogeneous catalysts: fixed bed (left) and moving bed (right) © IFPEN, © P. Chevrolat

#### 5.4.2.3.1. Modeling of hydrodynamic phenomena

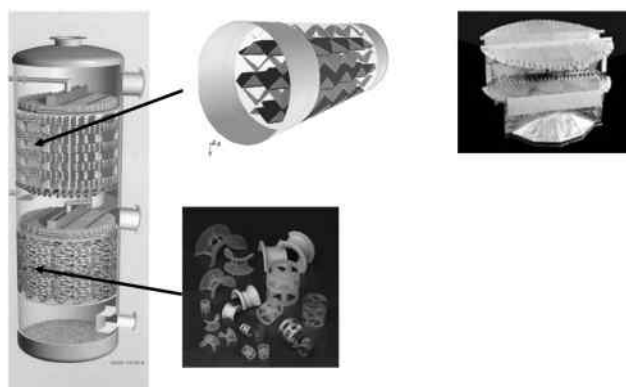
Considering the phenomena at different scales is necessary to have a better understanding of the phenomena and to help ensure safety with scale-ups.

Figure 5.12 shows, in the case of a gas/liquid contactor which aimed to maximize the efficiency of mass transfer of gas to the liquid, the different scales to be considered [RAY 07].



**Figure 5.12.** Study of a gas/liquid contactor, illustrating the different scales to be studied © IFPEN

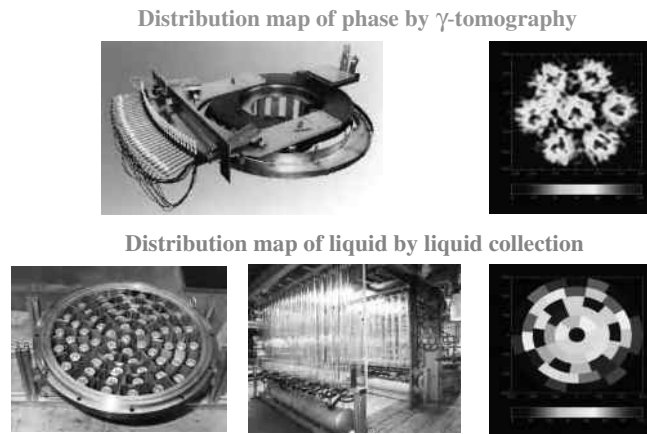
Figure 5.13 illustrates in the case of a gas/liquid contactor, different types of reactor internals to be characterized in order to obtain the sizing criteria and selection of the best reactor internal geometry to maximize the performance.



**Figure 5.13.** Different types of internals of gas/liquid contactor © IFPEN

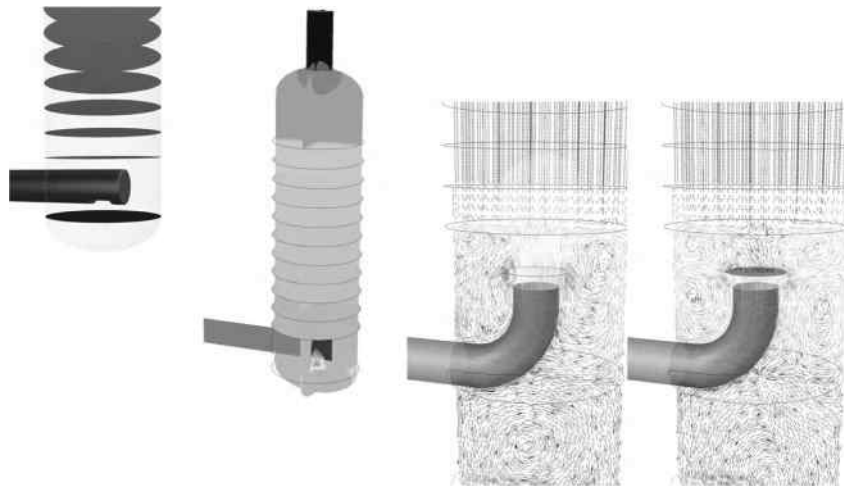


Figure 5.14 illustrates some experimental tools that are used to determine the impact of different trays or distributors on the quality of fluid distribution in an adsorber.



**Figure 5.14.** Tools used to describe the quality of a gas/liquid flow in a reactor © IFPEN

The CFD helps in better sizing of some critical technological equipment, such as the geometry of the gas distribution at the bottom of the absorption column in the case of gas/liquid contactors (Figure 5.15) [RAY 10].



**Figure 5.15.** Usage of CFD to determine the geometry of the gas injection system at the bottom of an absorption column

The review of the use of CFD over recent years reveals some strong tendencies, related either to the availability of certain physical models in commercial codes (especially two-phase models), or to the improvement of computer calculations. These tendencies can also be projected on the future uses of CFD in the forthcoming years. We can cite the modeling of unsteady flows (local fluctuations of flow rates, fluid velocities, ratio of liquid and gas in case of gas/liquid system) and characterization of small-scale physical phenomena.

#### 5.4.2.3.2. Unsteady flows

Many chemical reactors work with several phases: liquid/gas, gas/solid, for example. Modeling their behavior using simulation is a very complex domain, because these flows can show a highly unsteady nature at large scale (e.g. bubble columns, presence of low frequency oscillations). In recent years, the trend that has emerged is to resort to unsteady 3D models, which requires a lot of computing resources, but gives better results. This is particularly true in the case of dense flows of the gas/solid fluidized bed or dense bubble flow type, where the interactions between inclusions and with the flow of the continuous phase are very strong.

It is the same, but on a different scale, for the modeling of single-phase turbulent flows. The classical approach by RANS (Reynolds Averaged Navier Stokes) model is being progressively replaced by the models describing the unsteadiness caused by the turbulence, either by a direct approach (DNS *Direct Numerical Simulation*) and resolution of all scales of turbulence, or by a LES-type (Large-Eddy Simulation) approach, where only large scales are resolved. This type of tool is mainly used when the hydrodynamics and micro-mixture have a significant impact on reactive performance, that is to say, in the case of very fast kinetics.

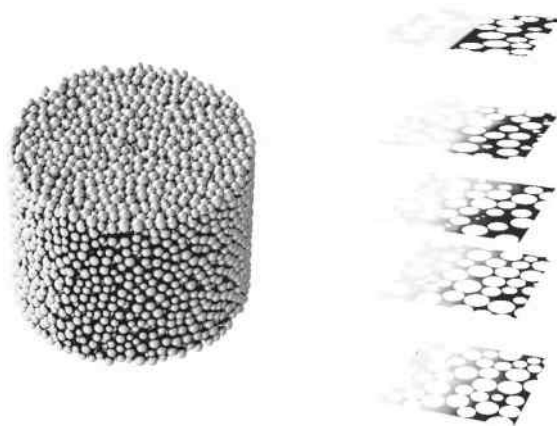
The use of LES modeling is also relevant in the case of low or non-isotropic turbulence (e.g. modeling of flows in structured packings).

#### 5.4.2.3.3. Characterization of small-scale physical phenomena

The CFD is increasingly used to characterize certain physical phenomena that are difficult to observe experimentally. Thus, some simulations on a very small scale (a few particles of catalyst, a periodic packing element, etc.) are made in order to quantify some local phenomena such as wetting of the catalyst or the gas/liquid transfer of structured packing in [AUG 10a, AUG 10b]. These results can then be applied to other models, multidimensional or not, thereby describing the overall functioning of the unitary operations. This is thus called the multiscale approach, an approach that tends to spread and shows that CFD can be used at several levels and with distinct purposes.

Figure 5.16 shows a typical example of the use of CFD as a tool to acquire local data. 3D simulations were conducted to calculate the coefficients of radial dispersion

in stacks of catalyst particles. The model solves the flow in the space between the grains and the transport of passive tracers in the flow. Post-processing of simulations, similar to that applied in the experimental data, helps us to trace the desired size.



**Figure 5.16.** *Example of simulation of the dispersion of chemical species in a fixed bed of catalyst. a) Computational domain, b) dispersion of the tracer (gray) in the transverse direction*

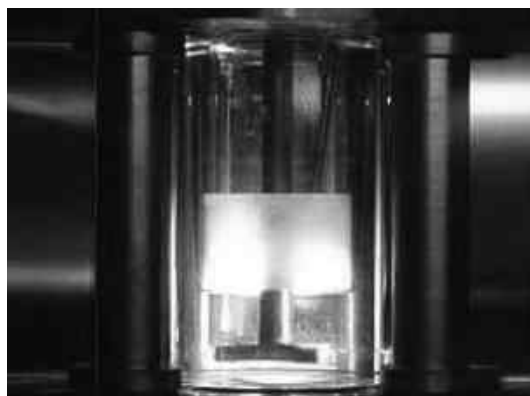
#### 5.4.2.4. Acquisition of thermodynamic data

Thermodynamics is a fundamental science. In most cases, it deals with the study of equilibria of liquid–vapor, liquid–solid, or liquid–liquid phases, and the properties of mixtures.

To deal with problems now considered to be relatively simple, such as equilibria of phases of hydrocarbons, for example, models of classical thermodynamics (cubic equation of state) coupled with a heavy experimentation but still achievable in a laboratory, helps to meet the demand.

The development and implementation of thermodynamic models require data on pure substances and their mixtures and then on real mixtures. These data should be somewhat similar to those seen in the process.

The experimental equipment used (Figure 5.17) helps to measure the equilibria and properties of phases in equilibrium, sampling systems also allow us to perform the analysis of phases. The pressure and temperature conditions signify that the technological challenges are significant and the implementations of these pieces of equipment are often long. In parallel with data acquisition, the databases are used.



**Figure 5.17.** Cell allowing us to study the vapor–liquid equilibria © IFPEN

The domains currently being addressed require more accuracy. That means operating in high pressure and temperature domains, and with very different compositions. This is one of the reasons that led to the development of molecular simulation (prediction of physicochemical properties of fluids from the knowledge of intermolecular interactions), molecular dynamics, and quantum simulations.

The acquisition of fundamental thermodynamic data is therefore based on three tools: experiments, theoretical models (including equations of state), and molecular modeling.

The selection and development of the thermodynamic model are essential. This model will be chosen according to the characteristics of the process (aqueous phase, hydrocarbon phase, and the presence of ionic species). Once selected, the model should be adjusted for the process, according to the products used and their concentration, temperature, and pressure.

For example, in the case of the development of the CO<sub>2</sub> capture process, we use an aqueous solvent containing ionic species. A possible choice for the equilibrium model of phase, enthalpy and entropy, is a NRTL (Non-Random Two-Liquid) type model. Measurements of equilibria isotherms at high concentrations have been made to make up for the lack of data available in this area of the process. Then the data acquired in the laboratory and from the literature were compiled to obtain the coefficients of interaction between the components of the process. This model enables us to know the exact composition of liquid and gaseous phases based on the components present and the temperature and pressure conditions.

Another part of the model with regard to what is commonly called transport properties, are properties such as viscosity (gas and liquid), density (gas and liquid), and surface tension. They vary depending on the composition of the phases and the temperature and pressure conditions. They are the subject of studies to achieve either the parameters of a model or a correlation representing the domain of operation of the process. They will be required to precisely calculate equipment such as pumps or heat exchangers.

#### 5.4.2.5. *Modeling of reactors*

The reactor model is used for scaling up; it helps us to define the type of industrial reactor best suited, and to specify the sizes for a target quantity of finished products to be produced.

Models of reactors, integrate kinetic model (s), hydrodynamic models and thermodynamic models.

The reactor models will predict the performance of a reactor for a given reactor technology, and they can also be integrated into a model of advanced control methods.

##### 5.4.2.5.1. Establishment of the equations of reactor model

This section briefly explains the outline which led to the writing of equations.

The writing of equations must involve the following steps:

- defining a control volume;
- list of hypotheses expressed to write the model;
- list of variables used to describe the system;
- writing the equations relating the variables to each other;
- analysis of degrees of freedom.

Writing equations of a model usually starts from the writing of conservation balances of three values:

- material balance;
- energy balance;
- balance of momentum.

##### 5.4.2.5.2. Definition of control volume

The control volume is the basic volume in which the equations are valid. In general, we choose the largest volume in which the variables are uniform. This

volume may be macroscopic (whole reactor if the variables are independent of the position in the reactor) or microscopic (if the variables depend on the position in the reactor). The control volume is characterized not only by its own volume but also by the surface that defines it which will be called as surface control.

Do not confuse control volume and reactor volume. These only fit in a very small number of cases.

#### 5.4.2.5.3. Model hypotheses

Writing the equations involves a number of simplifying hypotheses that enable us to approach the reality through a mathematical description. Failure to comply with these hypotheses can lead to very large errors on the values predicted by the model.

#### 5.4.2.5.4. Set of variables used

The set of variables used includes:

- the symbolic description used in writing equations (e.g. C, m, etc.);
- the definition of the value associated with the variable (e.g. concentration, mass, etc.);
- the unit of measure (e.g. kmole/m<sup>3</sup>, kg, etc.).

#### 5.4.2.5.5. Writing of equations

The writing of equations is done by establishing the conservation balance on the control volume and surface by using the hypotheses of the model and variables listed.

The units of each term involved in the balances should be checked routinely.

#### 5.4.2.5.6. Analysis of degrees of liberty

The analysis of degrees of liberty amounts to verifying whether the knowledge of the inputs of the system allows us to reconstruct the entire state of the system as well as its outputs.

This analysis is based on:

- the number of variables that are used to describe the system;
- the number of independent equations that describe the system.

To be able to predict the state and the outputs of the system, it is necessary to have at least as many independent equations as variables.

#### 5.4.2.5.7. Conservation equations

Whatever it is, to describe the mass conservation, energy, or momentum balance, the conservation equations describe a summary of input/output and production in the control volume per unit of time.

The following three sections describe the balance applied to the simple control volumes on which the variable values are uniform and the inputs and outputs are clearly identified. A more mathematical formulation, which enables us to describe the macroscopic balances through a divergence theorem (Gauss/Ostrogradski), is better known as the theorem of flows. The use of these theorems is more difficult but enables us to write simply the same equations for any geometry of control volume.

#### 5.4.2.5.8. Mass balances

The mass balance is written as:

$$\left[ \begin{array}{c} \text{Accumulation} \\ \text{rate of the species } i \\ \text{in the system} \end{array} \right] = \left[ \begin{array}{c} \text{Input stream} \\ \text{of the species } i \\ \text{in the system} \end{array} \right] - \left[ \begin{array}{c} \text{Output stream} \\ \text{of the species } i \\ \text{in the system} \end{array} \right] + \left[ \begin{array}{c} \text{Net rate of formation} \\ \text{of the species } i \\ \text{in the system} \end{array} \right]$$

where the net rate of formation takes into account the rates of formation (transformation of species  $j$  into species  $i$ ) and rate of disappearance (transformation of species  $i$  into species  $k$ ).

#### 5.4.2.5.9. Heat balances

The expression of the first law of thermodynamics applied to an open system is written as:

$$\left[ \begin{array}{c} \text{Rate of accumulation} \\ \text{of energy} \\ \text{in the system} \end{array} \right] = \left[ \begin{array}{c} \text{Input stream} \\ \text{of energy from/to the} \\ \text{stream of matter} \\ \text{in the system} \end{array} \right] - \left[ \begin{array}{c} \text{Output stream} \\ \text{of energy from/to the} \\ \text{stream of matter} \\ \text{in the system} \end{array} \right] + \dots$$

$$\dots + \left[ \begin{array}{c} \text{Thermal balance} \\ \text{by addition} \\ \text{of heat} \end{array} \right] + \left[ \begin{array}{c} \text{Thermal balance} \\ \text{brought in by the} \\ \text{environment} \end{array} \right]$$

## 5.4.2.5.10. Momentum balances

By applying the fundamental principle of dynamics:

$$\left[ \begin{array}{c} \text{Rate of accumulation} \\ \text{of momentum} \\ \text{in the system} \end{array} \right] = \left[ \begin{array}{c} \text{Input stream} \\ \text{of momentum} \\ \text{in the system} \end{array} \right] - \left[ \begin{array}{c} \text{Output stream} \\ \text{of momentum} \\ \text{in the system} \end{array} \right] + \dots$$

$$\dots + \left[ \begin{array}{c} \text{Balance of forces} \\ \text{applied} \\ \text{to the system} \end{array} \right]$$

## 5.4.2.5.11. Analysis of thermal stability in chemical reactors

Safety is a priority for the chemical industry as it is necessary to minimize the frequency and severity of accidents, while maintaining the productivity and quality of products obtained. The processes that implement the reactions that may undergo a thermal runaway are at high risk of an accident.

The detailed study of highly reactive reaction systems is imperative to ensure optimal and safe operation of existing processes and to develop new processes that are inherently safe.

In the domain of refining, petrochemistry, and chemistry, the risk of thermal runaway is a real phenomenon that has been observed on an industrial scale. Examples of processes that are affected by the risks of runaway include: selective hydrogenation, Fischer-Tropsch synthesis, hydroconversion of the residue in an ebullated bed, and hydrocracking. The consequences of thermal runaway may be premature coking of the catalyst the loss of operability of the plant and very rarely explosion of the compound. Obviously, there are security measures to avoid reaching the conditions of danger of explosion. These measures are as follows: the introduction of advanced control in the plant, setting alarm thresholds, installing exhaust valves and rupture discs, among others.

However, in the refining, petrochemical, and chemical industries, the alarm thresholds are set rather on experience and not on a scientific basis. Therefore, it is necessary to establish a rigorous field of safe operating conditions for processes.

The methodology for the study of stability of the reactors allows us to determine the operating conditions of the unit operation. This methodology must be valid for the reactors at the laboratory, pilot, and industrial scale, implementing simple and complex reaction systems.

The methodology consists of two main steps:

- study of the thermal stability in steady state: according to the Van Heerden criterion [VAN 53] and parametric sensitivity studies;
- study of the thermal stability in dynamic state: perturbation theory.



These studies are conducted based on a dynamic model of the reactive system to be developed, fitted, and validated upstream of stability studies.

This approach is one of the factors that led to the design of safer and more environmentally friendly processes.

#### **5.4.3. Process schemes, simulation, and optimization of the process as a whole**

This last phase of development is based on the set of data acquired (in the laboratory and development phase). It concerns the development of the complete process scheme with its list of necessary equipment to perform the optimization and heat integration and to quantify the investment and operating cost for the given production capacity.

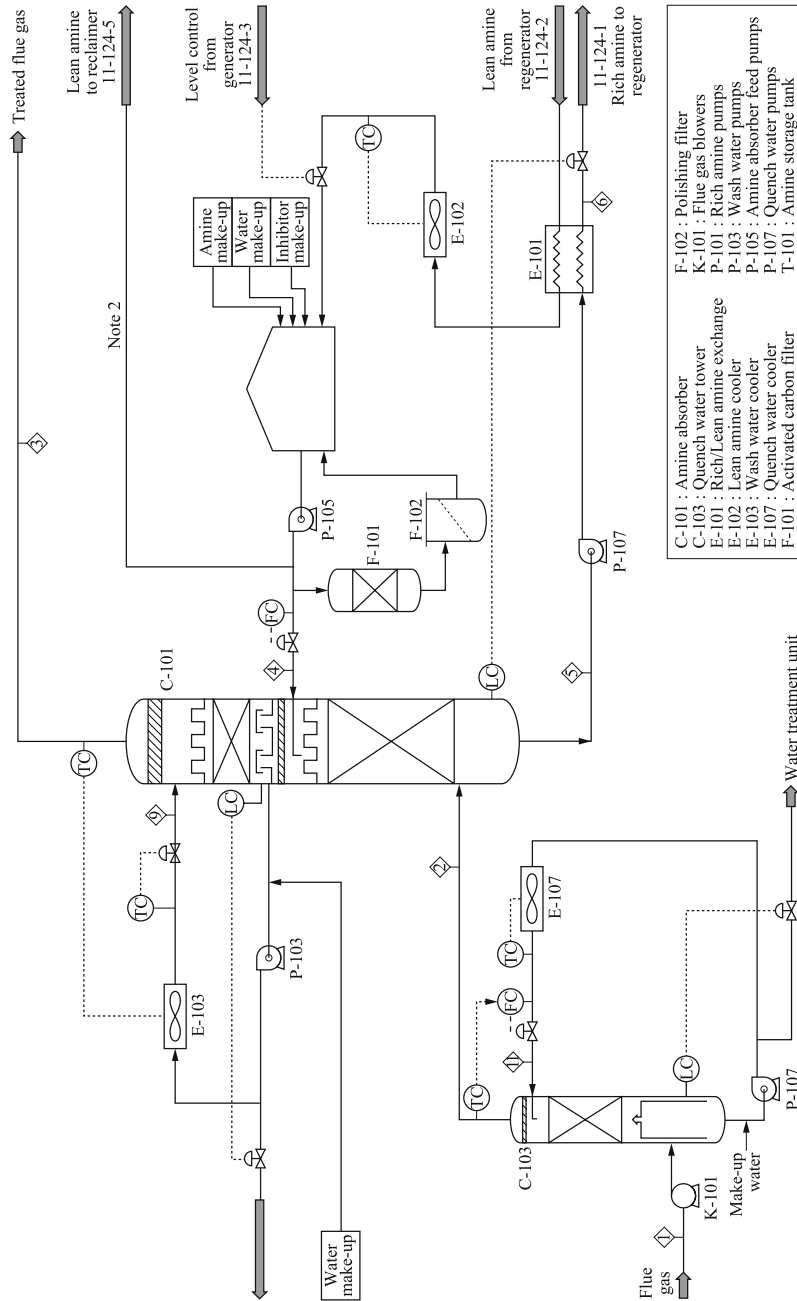
As we progress in the research on the critical points of the process, the teams responsible for the processing update the technical and economic studies and possibly redirect the study of acquisition of basic data. These teams play the role of an integrator through the collection of basic data (kinetic data, thermodynamic data, hydrodynamic and transfer data, corrosion, aging of the catalysts, and separation agents) and, from these data, define the best process flow diagrams on technical, economic, and industrial development criteria.

The development phase is also an opportunity to protect the concepts being developed through the patent of innovative process schemes and to define the process guidelines.

The technical and economic evaluation of a process requires us to determine the mass and energy balances from which the main equipment will be designed and valued as well as consumption of utilities (cooling water, electricity, cold, low pressure steam, medium pressure and high pressure coolant) and estimated chemicals (catalysts, adsorbents, solvents, etc.).

The evaluation aims to determine the investment and operating costs of the process. The investment costs include fixed capital (material investment, cost of studies, and licenses), the depreciable capital (fixed capital and initial charges), as well as working capital. The operating cost includes expenses (i.e. expenses for the operation of the plant: labor, utilities, raw materials, labor, etc.), and fixed costs (costs related to the unit itself: depreciation investments, maintenance, interest, taxes, etc.). On the basis of these cost components, we can determine the cost of the finished product, the time of return on investment, and the internal rate of profitability. These elements can be used to compare the process economically studied with variants or other existing processes.

As for the simulation and optimization of process flow diagrams, various commercial tools are available. An example of a process flow diagram is shown in Figure 5.18.



**Figure 5.18.** Example of a process flow diagram of gas treatment  
(only part of the diagram is shown in the figure)

The sizing of the equipment is established not only from the software developed by the teams which are responsible for the process but also through commercial software. For specific equipment, consultation with equipment manufacturers is carried out (e.g. gas turbine).

#### **5.4.4. End of the development process, the foundations of industrialization**

At the end of the development process, the project team is able to develop an executive summary “process guidelines for industrialization”; this document contains all the elements that are necessary to elaborate a process book and then engineering studies; the most important are listed below.

Specific considerations to the chemistry of the process:

- raw materials and their specifications (origin, impurities, etc.), and chemicals required (solvents, neutralizing agents of the catalyst, etc.);
- the products obtained at the output of the plant: specification of the desired product, by-products, waste and their management;
- the catalyst(s) required for processing;
- description of the chemical reactions involved (reaction mechanisms) and the corresponding kinetic models;
- models of chemical reactor and the optimum operating conditions, life of the catalyst, regeneration conditions;
- set of thermodynamic data (reactive and separating sections).

Considerations specific to the equipment of the process:

- sizing rules of the main technological equipment (reactor and its internals and other equipment such as: decanter, separation zones of liquid/gas, liquid/solid, etc.);
- recommendations on the choice of materials (corrosion, refractory, insulation, etc.).

Process flow and simulation diagrams as a whole:

- process flow diagram;
- list of major equipment needed.

Environmental balances:

- balance of greenhouse gas emissions.

Process control:

- recommendations for control;
- recommendations for instrumentation;
- recommendations for analysis.

Operating instructions:

- recommendations for the operation of the process;
- recommendations for starting and stopping of the process.

Industrial property:

- patents;
- freedom of use.

Once the process guidelines have been developed, the last step is the validation of the choices made. In this step, depending on the nature of the process developed, specific studies will be launched, aiming at developing prototypes:

- the development of industrial production methods of the catalysts necessary to process and validation of the performance of prototypes representing future industrial production;

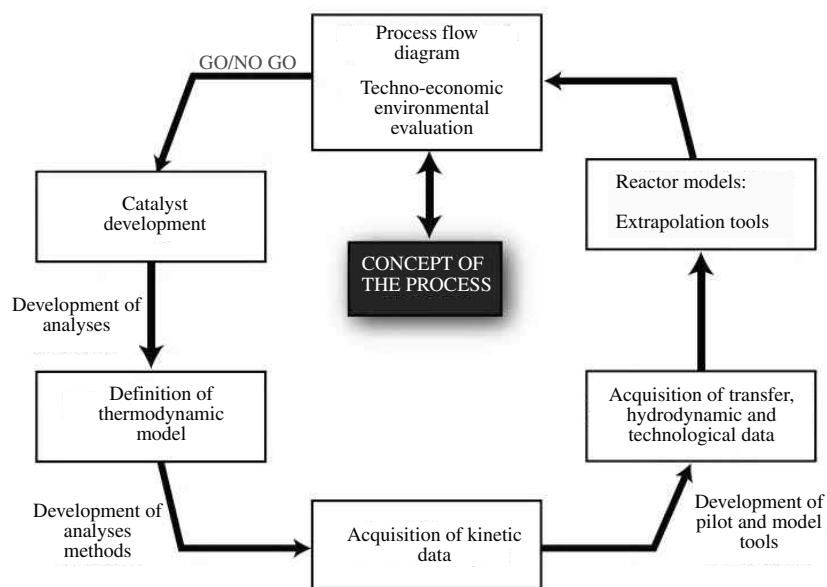
- a complete simulation of the process allowing an extrapolation on paper, and obtaining a prototype process book;

- in some cases, for processes involving breakthrough technologies, an experimental prototype may be necessary.

### **5.5. General conclusion**

The development process aims to transform an idea resulting from research conducted most often at a laboratory into an industrial innovation made up of a new reliable process, that is cost-effective with the smallest ecological footprint possible.

This chapter has served to illustrate the major stages of process development, until obtaining the foundations of industrialization, and to highlight the benefits of an “integrated” approach to the development process as well as the predominant place of modeling, at different stages of the development process. This methodological approach enables faster developments of processes, that are safer in terms of scale-up, the costs of the development phase being reduced. Figure 5.19 illustrates the process that was detailed in this chapter.



**Figure 5.19.** *Process of developing a process until obtaining the entire fundamental data for industrialization*

From the pre-development phase of a process, key points as well as any appropriate science and technological barriers that are to be removed in the further development of the process are identified. Pre-estimation of technical and economic performances of the process is also established from strong hypotheses, especially by assuming the removal of technological barriers identified in the initial design of the process scheme. From this first phase, the elements of decision which enable us to validate or not the viability of the concept and, if necessary, switch to the development phase of the existing process, were obtained through a rigorous scientific approach.

During the development phase, the acquisition of the set of data essential for the development of the process is the longest phase. The basic data to be acquired are defined at the end of the pre-development phase: reaction kinetics, product quality, stability over time of performances, thermodynamic data, mass and heat transfer, and so on.

The basic data are usually acquired using experimental facilities dedicated to the data that we wish to acquire with as much accuracy as possible. The systematic use of models (kinetic, mass transfer, etc.) helps to limit the experimentation necessary and to use experimental equipment of small size, and thereby reduces the cost and

development time. Modeling enables the development of simulators of the process so that it can be scaled-up in a rigorous and flexible manner.

Modeling at different scales (Figure 5.20) is a tool essential for today's development processes, from the development of the active phase to the optimization of the complete process flow diagram [CHA 10].

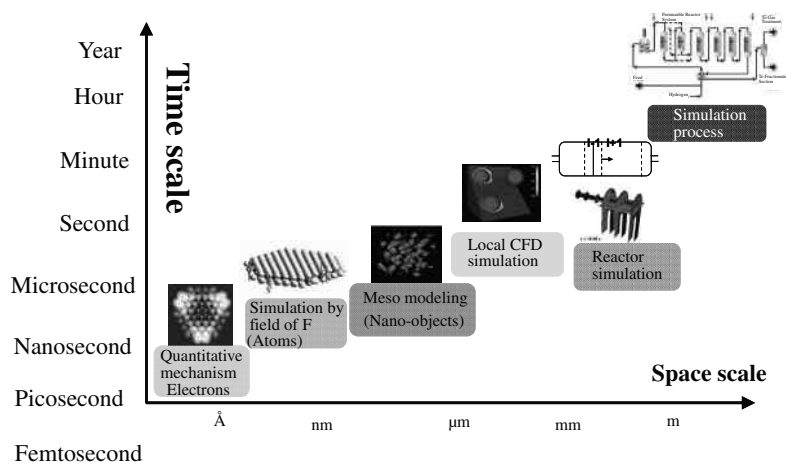


Figure 5.20. The different scales of modeling

From the complete set of experimental data available, the reactor models are developed as well as the design criteria of technological equipment, the process flow diagram is optimized on technical, economic and environmental criteria. Therefore, we have the necessary foundations for the future industrialization of the process.

Teams in charge of engineering begin to work, through the development of a process book and basic engineering studies. Once the decision on investment is made, detailed engineering will be conducted and the industrial production unit will be built and commissioned.

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### 5.7. List of acronyms

FEED: Front-End Engineering Design (basic engineering).

CFD: Computational Fluid Dynamics (CFD).

HSV: Hourly Space Velocity volume flow rate of reagent ( $\text{m}^3/\text{h}$ ) per reactor volume ( $\text{m}^3$ ) per unit time (h).

LFER: Linear Free Energy Relationships.

MRI: Magnetic Resonance Imaging.

RANS: Reynolds-Averaged Navier-Stokes equations.

DNS: Direct Numerical Simulation.

LES: Large-Eddy Simulation.

NRTL: Non-Random Two-Liquid.



## Chapter 6

# The Industrialization Process: Preliminary Projects

Industrialization can be defined as the set of processes that are required to move from research and studies, to a production system which is capable of delivering a product according to the pre-defined specifications, and responds to a business requirement, in accordance with a budget, timeline, and the ethics of the company [DAL 07].

The transition from research and studies to construction consists of steps that involve specific skills, techniques, diversified working methods, and pluridisciplinary teams.

The terminologies mostly come from the United States where they accompanied the extraordinary development of the petroleum and chemical industries in the 20th Century and the war effort necessitated by World War II.

After the development phase which is essentially a laboratory phase, the client *designs the process* in stages that take different names according to the companies: e.g. feasibility study, preliminary projects.

Depending on the case, *starting from this step*, the client can make use of what is commonly known as engineering and design departments, engineering companies in the process industries, or manufacturing engineering in the manufacturing industries (Figure 6.1).

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Chapter written by Jean-Pierre DAL PONT and Michel ROYER.

The term *process engineering* does not always have the same meaning for the client and for the engineering firm; the client looks for something “conceptual”, whereas the engineering firm needs something “concrete”.

Let us consider the example of a process for manufacturing latex, which is used for coating paper. The reactor is designed by the chemical company: the design is complex and is necessary to obtain a valuable emulsion of nanoparticles. The reactor is manufactured by a vessel manufacturer with whom the chemical company will work in order to define the best means of cooling or the most appropriate means of cleaning. The mixing system represents an important part of the know-how involved: it must take into account the design of the polymerization vessel.

This example illustrates the interdisciplinarity of knowledge and skills necessary for physical implementation and provides an initial overview of the importance of the equipment. Many tasks are outsourced to subcontractors; this is one of the roles reserved for the engineering firms to coordinate and direct.

Globalization, and the extensive use of computers beginning in the 1960s have standardized the basic concepts regarding the vocation of engineering itself, which includes *process engineering*, *basic engineering*, *detailed engineering*, and construction. We will further discuss these concepts in Chapter 9 which is dedicated to engineering.

The upstream phases, where research is still very much involved, are less codified as they are still unclear and uncertain. A lot of material facts are missing. It takes considerable flair to understand the validity of the issues: the question is whether to continue or not! The various players in the field do not proceed in the same way, do not use the same terms, and do not put the same contents into the same words! We will discuss this in more detail in what follows. The important thing is to know it!

*Initialization* is the source of the project. The company is “interested” in a concept and a vision of the future. It is followed by feasibility studies and preliminary projects to materialize into what is called “Basic Engineering”.

*Research and studies are expensive!* A well-managed project requires contemplation at the end of each step before starting the next one. This is what is called the *validation process*. This process determines the continuation, discontinuation, and reorientation of the studies. We want to move as quickly as possible “*to be first on the market*” because competition does not wait!

At each assessment process, people try to determine, as far as possible, the full manufacturing cost of the finished product, the total amount of investment needed, envisage the profitability of the project, the risks, and the chances of success. *The decision to invest is a key step.*

The company takes the risk of raising funds. There is a transition from the field of studies to completion. *Time is a terrible judge!*

Construction can take months or even years. It is during the startup phase that one will see whether the selected technical solutions are valid, whether the tool works as expected, and whether the product meets expectations.

The commercial success, however, will take time. Sales do not saturate the plant immediately. It can sometimes take months or years for the company to start making money. Construction is done for the long-term; it raises the question of what will happen to the market, if competitors are going to develop a more efficient process starting from more available and/or more “green” raw materials.

*The job of the industrialist and the entrepreneur although it may be exciting, is difficult and risky!*

Stopping a project under construction is a huge waste with heavy financial consequences and a black eye on the image of the company. It requires courage to stop a project when one has motivated teams, raised hopes, negotiated with customers, and “mediatized” the project. This decision is painful but sometimes beneficial.

Investing is a practically irreversible act, a bet on the future, particularly for projects where the cost represents a significant proportion of revenues and especially of the available funds [DAL 07].

All the functions of the company should be involved in the major projects:

- first of all, the *business* (i.e. the business including sales and marketing) has to sell the products obtained from the production facilities. This is the purpose of investment in order to generate profit to pay off the expenses incurred in the project;
- the R&D functions, industrial function, and engineering have to validate the technical solutions, working methods, choice of the project team, and the contractors, especially the contractor in charge of building the plant;
- human resources have to allocate the necessary resources to the project and accompany the changes induced by major projects in the organization;
- the finance department has to raise funds;
- logistics, purchasing, and communication;
- the production function that will inherit the investment.

The top management bears the ultimate responsibility: it is they who decide to invest, postpone or abandon the project, or reorientate in view of the information provided.

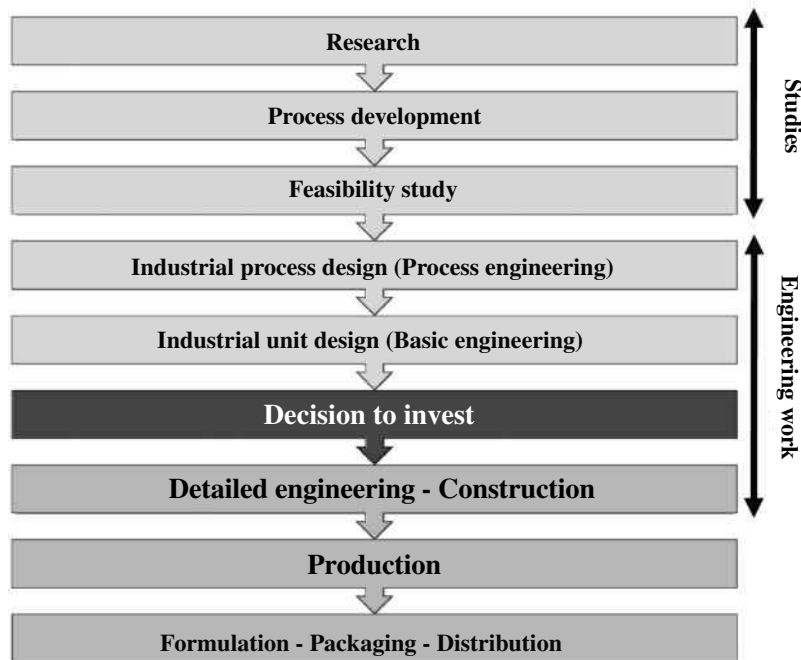
Much confusion arises due to a lack of understanding of the nature of the projects, their degree of progress, and the accuracy of costing. A management board who is told that a plant costs 10 million dollars with an accuracy ranging from  $-20\%$  to  $+40\%$  will never retain the three figures 8, 10, or 14 million dollars, but only one: 10 million dollars.

One of the major misunderstandings is the confusion between the studies and the project. From our point of view, a project suggests that the company has basically “decided to go for it”, that is the funds are at least budgeted for in principle.

We will focus on the upstream steps preceding the *process engineering* step in section 6.1, that is on the part of the industrialization process that applies to the process research and preliminary projects. “*The downstream steps of process engineering*” will be discussed in Chapter 9, which is dedicated to “Project Management Techniques: Engineering”.

### 6.1. Steps of industrialization

The main steps of the industrialization process are illustrated in Figure 6.1.



**Figure 6.1.** *The steps of the industrialization process: from the laboratory to production and distribution*

Before describing each step, industrialization includes two distinct phases separated by the decision to grant credit:

- the study phase that ends with basic engineering;
- the completion phase that begins with the detailed engineering and ends with the start up of the installation.

The following describes a complete process which starts from the research. Very often, the manufacturer improves an existing plant and the contribution of the research is then different. The manufacturer is actively involved: we are dealing with his tool! This case will be discussed in Chapter 13, which is dedicated to “Management of Change”.

## **6.2. Bases of industrialization or process development**

Chapter 5, “Foundations of process industrialization”, written by Jean-François Joly, described in detail the work done in the laboratory to learn the bases of industrialization. This step consists of the acquisition of data necessary for the definition of industrial equipment and their operation: chemical kinetics, diffusion, mass transfer, heat transfer, momentum analysis, phase diagrams, thermodynamic equilibria, and so on.

At this point, the definition of the major equipment results in a functional specification, prior to any data sheet. It also concerns mastering the break-even points, particularly those regarding the:

- product and its value of use;
- safety (deviations of reactions);
- environment (effluent toxicity, treatment, recycling, revalorization, etc.);
- capacity and yield (catalyst poisoning, clogging up of equipment, estimation of recycling, etc.).

Beyond the control of critical points, work simulation and optimization are undertaken to find a technico-economic solution and to reduce the risks.

Process and product developments are conducted in parallel. The equipment and processes used to produce the first samples and product lots for pre-commercialization purposes are not always consistent with the final industrial process. A product can be purified in batch, whereas in the industrial facility, it may be crystallized continuously. So called laboratory research studies done by chemists usually precede the process development and feasibility studies that precede the preliminary sketches of the process flow diagrams.

### 6.3. Feasibility study

Feasibility studies are aimed at defining the essential characteristics of the process in order to determine the total amount of investment and full manufacturing cost of the finished product.

It refers to selecting technology in order to meet the requirements of the *business*, making comparison tables between different solutions, assessing the technological risks, strengths and weaknesses, and assessing the *reliability* of the process and its impact on the environment in the broad sense. It includes:

- the establishment of simplified diagrams and the costing of the total amount of investment (order of magnitude);
- the validation step, the purpose of which, is to choose the process technology.

#### 6.3.1. Design of the industrial process – preliminary engineering – preliminary projects

*This is the phase where everything is at stake! It requires a lot of involvement from the client; everything else will ensue from it!*

This is the stage of preliminary projects for which the initial technology was selected; it must be reinforced by model tests, pilot tests, selecting the principal equipment, selecting a manufacturing site, and considering its advantages and constraints.

This is actually the validation step of the industrialization base, thereby ending the development phase of the process and the product, and enabling the production of samples that are provided to major customers. It includes:

- the approximate calculation of the investment and of the full manufacturing cost, the determination of the time required for project completion and the profitability study;
- the technico-economic justification of the project carried out by an *ad hoc* committee.

The expected decision consists of moving toward the basic engineering step and stopping or reorientating the studies. The client wants to know the profitability of his project as soon as possible. This profitability will depend on the production cost (dollars/kg, dollars/tonne) and the total amount of investment.

If the variable cost of the product (raw materials cost) is the first available cost, then the fixed costs or overheads will be dependent of the amount of investment that will determine the depreciation costs, maintenance and the manpower costs. This last item will largely depend on the design of the plant: its degree of automation, layout, and staff productivity.

The profitability study should be conducted right from the beginning, that is starting from the preliminary studies. The result of this study will often imply the continuation or discontinuation of the project.

The preliminary study should not be limited to one type of operation, one type of equipment, material, and so on. Instead, it must help to open up the field of optimization by selecting the most appropriate equipment and propose alternatives.

The steps of engineering as such include:

- *process engineering*;
- *basic engineering*;
- *detailed engineering*;

– the *construction* and the *start-up* steps will rely as already mentioned on the skills of specialized contractors.

They are carried out by the general contractor appointed by the client to study and eventually build the installation. We will address these questions in Chapter 9 which is dedicated to engineering.

Figure 6.2 is another representation of the industrialization process. Depending on the companies, the names used for different steps and their breakdown may vary. Here, the preliminary study is divided into a feasibility study and a preliminary project. This figure illustrates the transition from one step to the following step. The black triangles correspond to the validation processes.

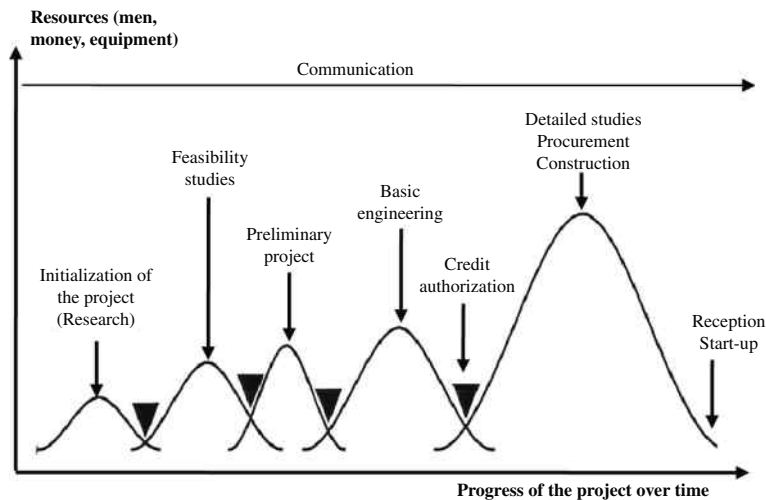
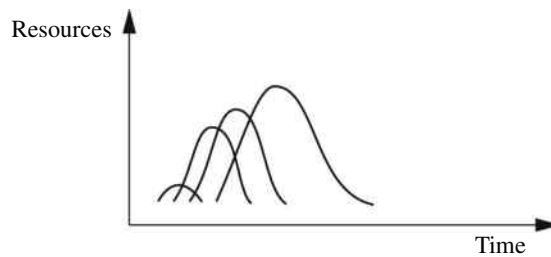


Figure 6.2. Example of an industrialization process

The area of the “bump” provides an idea about the (human and financial) resources and the time required for its achievement. Each “bump” has a leader who is the researcher at the beginning of the project, followed by the process engineer who plays a major role in the feasibility and basic engineering studies. The basic engineering step involves about 20 different engineering skills. The construction phase requires all sorts of crafts such as carpenters, pipe fitters, masons, welders, lifters, and so on.

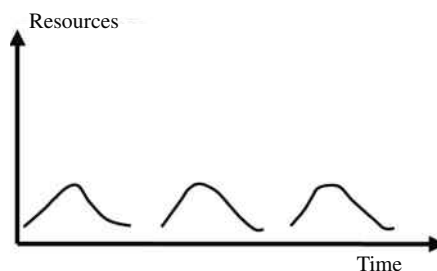
Two types of project, fast track and sea serpent, are extreme cases with respect to the smooth management as described above.

*The fast track project:* in this case, one wants, knowingly or unknowingly, “to jump the gun”. Almost everything is done at once. The project manager should be either an undisputed leader or else a dictator. “Blunders” are to be expected because the traditional systems are not respected; only one supplier is consulted or the order is placed with the one who has the shortest term.



**Figure 6.3.** *The “fast track” project with integration of the steps*

The psychological impact on the players of the project is great, sometimes with unfortunate consequences. This type of project is justified only in extreme cases where it is necessary to have an installation as quickly as possible. Such an approach is obviously expensive and risky; one has to do, undo, and consume hours of engineering!



**Figure 6.4.** *The sea serpent project*



*The sea serpent project:* on the contrary, this project shows discontinuities in the steps. The file is stored in a drawer, the project team is dispersed, and another team takes over when the project is relaunched. This type of project, synonymous with indecision and lack of discernment, does not motivate teams.

Figure 6.5 is another representation of the industrialization process. It shows the sequence of the eight steps of industrialization over time.

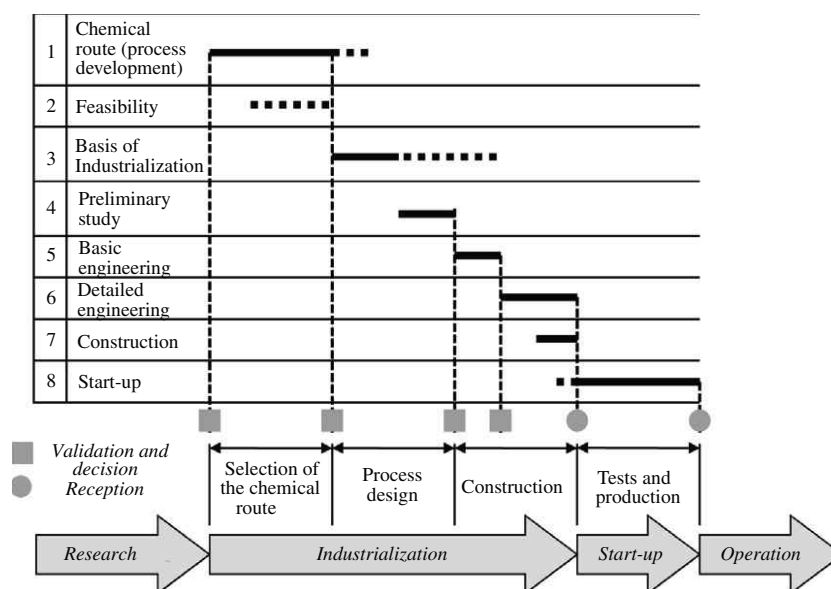


Figure 6.5. Representation of an industrialization process

One condition for success is continuity in communication between the different parties involved. The steps must overlap partially. As we move toward downstream, the more different skills the project needs. The core knowledge of the company is mostly concentrated toward upstream in its research centers and engineering departments.

The research chemist in charge of the process will probably be assigned to other research activities at the time of construction that can last for several years. It is important, however, that he keeps an eye on his “work” and takes part in start-up to avoid deviations in design. He can be called on sometimes to redo a few additional verification and optimization tests.

Along the same lines, the operator must be assigned to the project early enough so that he can share his experience with the engineering and design department in order to avoid questioning the technical solutions that would have been implemented without his knowledge.

There is a difficulty at the company level here, where the company has a tendency to “diminish” the resources allocated to the project manager in order to reduce its costs. All these difficulties are intensified during the transfer of technologies abroad.

#### 6.4. Cost and typical duration of industrialization studies

Table 6.1 shows the orders of magnitude on the typical costs of industrialization steps of a large organic chemistry plant. The costs are provided based on the probable final cost (PFC) of the installation. This cost will be known only when the project is completed and possible changes are made to the installation so that the specified performance is obtained. Normally, an allocation called “contingencies costs” included in the PFC, typically a few percent of the PFC, is included in the installation cost.

Steps	Accuracy of the estimate	Cost of studies in % of the PFC	Objective of the step	Documents needed	Comments
Order of magnitude	± 50%	Variable	Orientation/ Selection Continuation/ Discontinuation of R & D.	Simple description of the process. Preliminary outline. Material approached.	“Back-of-the-envelope” estimate or better “grocery” calculations.
Feasibility	-20% + 40%	Variable	Check if the process is viable.	Process flow diagrams. Equipment list. The site is retained.	Helps detect what remains to be done, therefore to orient the “process development” phase.
Preliminary project	± 20%	0.5% to 1%	Check if the basic engineering is justified.	In addition to the above the edition of process and instrument diagrams (PID). Layout. Specifications of the main equipment.	The site is defined. There is “philosophy” of Buildings. Instrumentation. Electric network.
Basic engineering	± 10%	3% to 7%	Request for credit authorization.	In addition to the above and “frozen” PID plans. Main equipment defined	This file accompanies market studies, risk assessments, and audits.

**Table 6.1.** Typical costs of the steps of industrialization and related documents (large chemical plant, for information only)

We note that the cost of studies increases rapidly with the desired accuracy for the PFC. Let us consider a process unit of a PFC of 100 million dollars; the study may cost from 500,000 dollars to 1 million dollars for the preliminary project and from 3 million dollars to 7 million dollars for the basic engineering study! The need for validation steps is better understood! Major projects that are aborted weigh heavily on corporate resources.

The more progress in the industrialization process, the more accuracy is required and the greater the need to involve additional specialists and crafts. Engineering companies have references, but in important cases the estimate requires a specific job.

Let us consider the case of a very important piece of equipment such as a stainless steel distillation column several meters in diameter and several dozen meters in length, which works under pressure. The assessment of its cost may require the development of a specification sheet by a project engineer and a call for tenders from boiler makers; all these have a cost! *Accuracy is expensive!*

#### **6.5. Content of an industrialization project – conceptual engineering**

A key aspect of the project is to define its content (*project scope*). The accuracy of costing is mainly based on the fact that *nothing* has been forgotten rather than the accuracy of costing of individual elements.

The industrial function of the company is to materialize the ideas of the *business* and R&D upstream. Its first task is to find process units that can meet the requirements. These units may exist within the company or can be found outside from subcontractors. They may need an adaptation called *revamping*.

If these units have to be created, which means investment, it is essential to implement *conceptual engineering*. Right from the beginning of the study, this visualizes the installation type and defines its key features.

A project, sometimes a simple idea at first, needs to mature and take shape. It often takes time and, sometimes, a lot of work to get the project accepted at the company level. *A large distance separated the announcement of the Apollo program by President J.F. Kennedy and the landing of Eagle on the Sea of Tranquility on July 20th 1969!*

*Technology forms the basis of everything. It will give the essential characteristics to the project.*

In chemical synthesis, the chemical route, that is the base reaction, will generate a different process unit if the reaction occurs in vapor phase at 200°C in a fixed bed reactor or in liquid phase at 100°C.

The origin of technology, be it from research, existing in an operating plant or purchased from a licensor, will strongly influence the work to be done downstream.

In general, a project can be broken down into several parts, some are easy to define like the tank farm, while others require in-depth studies. It is important to manage what is defined and what is not separately, and not to waste resources to looking for illusory clarification. To do this, a few principles are set:

- dividing the project into technically homogeneous sections, for example, a crystallization plant which is necessarily followed by a means of solid/liquid separation and a dryer;
- a tank farm normally easy to define;
- highlighting the high-impact “shadow zones”, either in terms of investment, or in terms of operating costs;
- defining the essential elements of the full manufacturing cost: a single raw material may represent the first 80% of proportional costs and 50% of manufacturing cost;
- defining the key elements of the total amount of investment; the distillation column mentioned above can itself represent a significant percentage of the total amount of investment;
- establishing a list of major technical difficulties.

Figure 6.6 shows an example of the breakdown of an industrialization project.

<b>Unknown:</b> Waste water treatment
<b>Vague:</b> Efficiency of a chemical reaction
<b>Known:</b> Tank farm

**Figure 6.6.** Breakdown of a project: from the known to unknown

This approach goes hand in hand with the search for human resources and skills, thus the setting up of teams whose role and composition vary greatly during the course of the project.

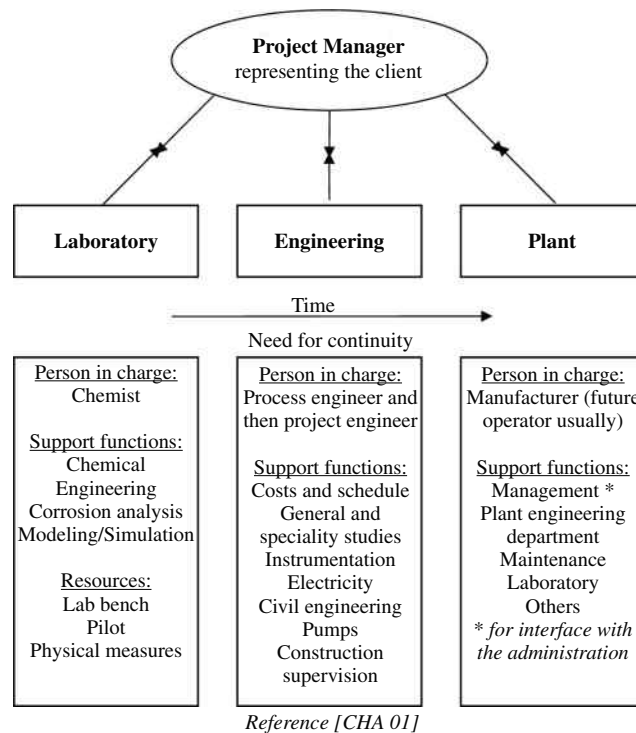
*The project will take shape based on the interaction between: business, research, engineering, and production.*

*Generally unclear at first, the project will become consistent and materialize. The first assessment of the cost and total amount of investment, hence the first assessment of the profitability, will have an immediate impact on the development of the business. It can be decided whether to stop or continue the business by changing the objectives, i.e. its scope.*

### 6.6. Typical organization of an industrialization project

*The project is said to be initialized if it is recognized at the company level. The company then plans to dedicate resources and to place the project in a multiyear plan.*

When the project enters the primary step, which is costly and decisive for the future, the company (client) must set up an appropriate structure of the type shown in Figure 6.7, which will be confirmed after credit authorization. Other types of organization are also possible.



**Figure 6.7.** Typical organization of an industrialization project

In this type of organization, a project manager is assigned to a project. This means that he has been freed from other activities and signs on to the project! It is very important that the project manager is appointed at the preliminary stage even if he is not allocated to provide 100% effort to the project; *this is the step where major decisions will be taken that will impact the future.*

The reconsiderations are expensive in terms of time and money which amounts to the same thing: *time is money!* This also means that the company confirms the importance that it gives to the project and allocates resources to it!

Figure 6.7 shows that the project manager takes over from the research manager to the extent that he will “appropriate the laboratory studies”, check their validity, finance other studies when needed, and ensure that the handover is carried out under good laboratory conditions to the process engineer(s) in charge of the process development phase and subsequently the *process engineering*.

The project manager representing the company (client) is the person with whom the engineering design department or the contracting engineering firm prefers to deal with. He will oversee *all* the project activities including the stages of study and implementation.

As pointed out already, the manufacturer, who will be in charge of the installation, must be involved early enough in the project and must be in agreement with the solutions adopted. If the future manufacturer is the project manager, then the issue is resolved *ipso facto*.

Under each essential stage of the project, we have included the typical skills required.

At the “laboratory” stage, the person in charge is often a chemist. He will be assisted by experts in modeling/process simulation, and catalysis and corrosion. We can refer to Chapter 5 written by Jean-François Joly for more detail.

As stated earlier, engineering by itself includes about 20 skills or crafts: process engineer, project engineer, cost engineer, instrumentation engineer, control engineers, experts in vessel construction, piping, and so on [CHA 01].

When the project enters a concrete phase, it is important that future operators such as those responsible for maintenance or instrumentation take part in some meetings including validation meetings, especially if the installation is expected to be set up in an existing site. This will avoid unwanted reconsiderations thereafter.

### **6.7. Business/industrial interface**

We have mentioned that studies are expensive. Normally, it is the business unit that will ultimately pay for the costs associated with the studies. It is therefore

important to explain the mechanisms brought into play by industrialization, to evaluate and announce the costs and deadlines. It is necessary to decide along *with* the business, whether to go forward, knowing that discontinuation will demobilize and disperse the teams (sea serpent).

#### **6.7.1. *The questions posed by the business to the industrial function***

Gradually, as development takes place, the *business* needs to know the evolution of the following elements:

- the full manufacturing cost;
- the total amount of investment;
- the period of availability (which can vary considerably depending on the size of the project);
- the chances of success of the operation and its risks.

*What the business looks for is gains and customer satisfaction; the two are interrelated.*

The industrial project or preliminary project rarely has only one technical component. Apart from the problems related to safety, the environment, and marketing constraints (like registrations, permits, and so on), the overall success may be dependent on the success of operations conducted in parallel, such as:

- contract to supply a strategic raw material;
- selection of an industrial site.

One of the key functions of the project manager is to maintain consistency and cohesion of the project by taking into account all the socio-economic constraints.

#### **6.7.2. *The questions posed by the industrial function to the business***

Gradually, as development takes place, the industrial function needs to know about any changes to the following elements:

- the quantities to be manufactured (volumes, tonnages) over time;
- the average selling price: adequacy between volumes and selling prices;
- the specifications of the finished product;
- the lifetime of the product (accumulated turnover).

The forecast tonnage and the number of manufacturing steps will strongly influence the characteristics of the production facility and therefore the strategy to be implemented.

We can move either from a pilot plant to one or a series of multipurpose plants, to a dedicated installation, or from a batch process unit to a continuous process unit.

Quality in the broad sense (performance) is a permanent concern, firstly because it should be achieved during the start-up, and secondly because any change may alter the process and thus the installation.

Problems as mundane as bulk or drum shipment alone can weigh down heavily on the total amount of investment if it becomes necessary to add a packaging line, a warehouse, or storage bins or silos.

## **6.8. Typology of industrialization projects**

Industrial projects differ by their technical characteristics, the total amount of investment, the host site, financing packages, and the type of the client company (in partnership or not) to name a few critical aspects.

Many projects are actually prototypes. A nuclear power plant, a steam cracker, a thermal power plant, a cement factory, a multipurpose fine chemicals plant, a tank farm, or an air compressor with a flow of 50,000 m<sup>3</sup>/h at 6 bars, will have completely different technical characteristics, and will require different competencies, expertise, and working methods.

The client, with the help of his project manager, must identify the techniques to be implemented from the beginning, which will lead to the selection of appropriate engineers and experts. Real-life experience in similar cases plays a major role.

### **6.8.1. Parallel projects**

While the main project proceeds, the other projects, known or unknown by the project manager for confidentiality reasons, may have a life of their own. It may involve deals at the highest level between the client company and a potential partner to establish a *joint venture*, where the partner will provide the capital. This may be a contract related to the supply of an essential raw material, negotiating with a foreign government for funding assistance, and so on.

The decision to invest may depend on the authorization for the release of the product when it comes to drugs or products for plant protection. It is very difficult for a project manager, from a managerial and psychological point of view, to lead



his project knowing that other battles are taking place where, in most cases, he is not involved. This is what we call parallel projects.

### **6.8.2. *Small scale projects***

In the above sections, we deliberately focused on “big projects” – to make things precise – greater than 30 million dollars with regard to the great organic chemistry. These projects need to be highly structured.

Small projects are often difficult to manage; they are often the “nemesis” of engineering firms because they cannot be staffed like large projects with their numerous experts, whereas the *duties to be performed are the same!* They need to be managed by versatile and resourceful professionals, who have no fear of taking risks and are looking some form of independence.

There is a whole domain dedicated to small companies that specialize in “technological niches” and operate close to their bases. The management principles remain the same, again it is necessary to implement them!

### **6.9. The industrial preliminary projects**

The preliminary projects or preliminary studies constitute a stage in the process of deciding the future of the project: to continue, stop, or continue differently. The preliminary project must:

- throw light on the future;
- propose alternatives to the question(s) posed;
- be consistent;
- highlight the risks and difficulties;
- reflect the consensus of the project team.

It is expected that the preliminary project gives:

- the total amount of investment, whether to manufacture a new product, modify an existing process, ensure compliance of an existing unit with regulations, and so on;
- the full manufacturing cost of the new or improved product;
- profitability or justification of the capital expense.

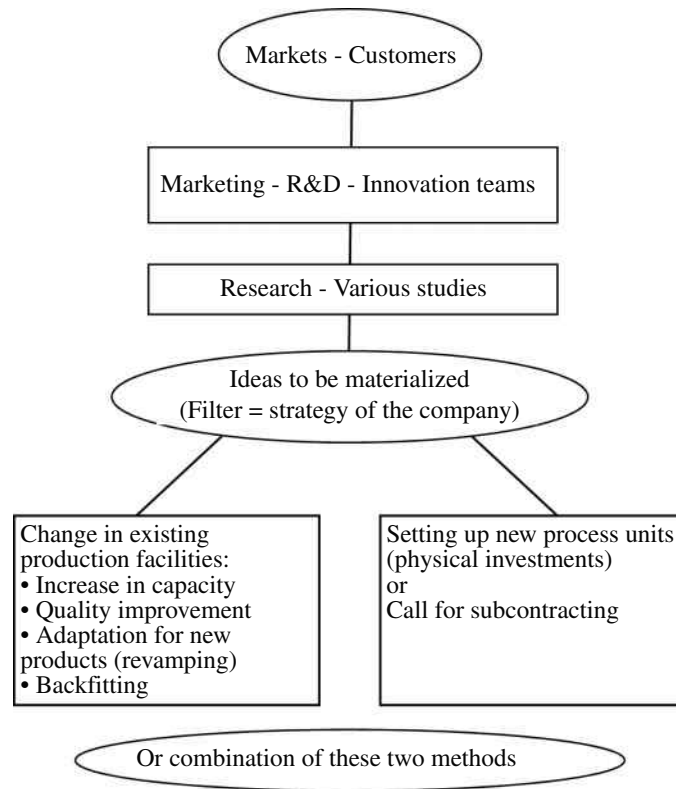
In all cases, an idea must be given or the completion deadlines, the means to implement, not to mention the risks (that are feared) and opportunities (that are hoped for), must be specified.

The technical (industrial) preliminary project is only an (essential) element in the decision process: the sales representatives and finance people have their say.

**6.9.1. Origin of industrial preliminary projects**

*This section is especially for students who have to work on preliminary projects as a part of their curriculum.*

In the industrial world, these are, traditionally, marketing and the R&D and innovation teams that are always ready to listen to customers and search for new markets for existing products, or detect the need for new products, who are at the beginning of the preliminary projects.



**Figure 6.8.** *Origin of industrial preliminary projects related to business*

The field of demand may go from a change of packaging, for example, moving from a 200 liter drum to a 5 liter can (which will perhaps require the investment of a

new filling station), to developing an entirely new product which will require research and engineering studies and major investment.

*The following questions have to be answered: manufacturing cost, total amount of investment, deadlines, time limits, risks, and so on.*

**6.9.2. Perception of a preliminary project by the various players in the company**

A preliminary project may be perceived very differently by the stakeholders of the company. It is important that the person in charge of the preliminary project takes into account the different approaches at risk of creating malfunctions with heavy consequences within the organization. We all know them “*I said it, they did not listen to me, this was to be expected ...*”.

*Case study:* let us consider the real example of a preliminary project of industrial rationalization. A plant has 5 outdated and little instrumented process units; an engineer is asked to study the grouping of 5 control rooms into one.

Before	After
5 process units	5 process units
5 control rooms	Only 1 control room
2 control room attendants per control room	3 control room attendants
$2 \times 5 \times 6$ (shifts) = 60 people	$3 \times 6 = 18$ people

**Table 6.2.** *Example of an industrial rationalization preliminary project*

Before rationalization, there were two control room attendants (operators in control rooms) working  $4 \times 8$  for each control room, that is a total of 60 people. Rationalization would lead to a lay off of 42 people.

The annual savings in manpower is about 1.5 million dollars per year, for an investment of 4.6 million dollars (order of magnitude). The *pay-back* takes about 3–4 years.

NOTE.— *The pay-back represents, in a simplified manner, the number of years required to recoup its money; the expenditure is divided by the annual gain.*

The project has two essential elements: a physical investment based here on the instrumentation (sensors, data processing, hardware, software), but the project also requires human consideration to define the new jobs, the training of personnel reclassification, updating operating instructions, internal and external information, legal aspects, and so on.

The different players in the project may have the attitudes summarized in Table 6.3.

Features	View points and questionings
Finance Department	Return on investment: – 3 years <i>pay-back</i> ? – profitable project? Should money be granted to this project? Would it not be better to invest the money elsewhere?
HRD	Human and labor issues; social unrest due to downsizing.
Planning and Strategy Management	Future of the plant if project is not implemented.
Plant Manager	Strongly for or strongly against or in between; future of the plant versus social unrest and lay off of excess staff.
Technical Department (Industrial)	Outdated equipment, lack of reliability, safety, preparing for the future, brand image.
Business	Pros: – the plant will be more “open for viewing”; – showcase for customers; – products of better quality. Cons: – risk of being out of stock in case of human and/or technical problems; – increase in full manufacturing costs (financial depreciation is more adequate).
Top Management	Must examine this project and decide ...

**Table 6.3.** *Role of different players in the project*

What should be learned from this case study?

This project clearly has two essential components: a technical component and a strong social and human component. It is not attractive from a financial perspective as its pay-back is long. The commercial value of the products, i.e. their contribution to the profit of the company, and their impact on the business is a major deciding factor.

From a technical point of view, the question arises in keeping outdated process units “alive”. If the decision is taken to implement the project, the technical and human aspects should be managed harmoniously.

The project manager must maintain the cohesion of the project at the company level in accordance with the decisions taken at the highest level by involving the stakeholders of the project at each and every step of validation.

### 6.10. Selection of production sites

Site selection is critical, the decision is irreversible, at least for a very long period. Rolling back would lead to exorbitant costs. Some criteria may be an upfront elimination factor such as the proximity of dwellings in the case of manufacturing dangerous products.

ESSENTIAL CRITERIA FOR THE SELECTION OF A NEW SITE	
Market	Proximity to customers and the market size (customers do not buy if not local).
Access to energy	Cheap energy (if energy is an important part of the full manufacturing cost).
Land layout	Availability of cheap, readily available, flat, and remote land if it is difficult to completely eliminate the pollution specific to the industrial mode: noise, odor, dust, truck traffic, and so on; the wind rose is important.
	Possibility to create buffer zones around the site.
	Soil quality that will be determined by conducting analysis with an appropriate networking.
Water management	Availability of cooling water.
	Outlet for wastewater.
Logistics	Ease of procurement of raw materials and distribution of finished products: roads, railways, waterways ...
Financial aid	Financial support, tax abatement, contribution to staff training, other aids.
Intellectual environment	Presence of universities, training centers.
Social environment	Quality of life, education for children (crucial elements in the case of expatriation).
	Quality, stable manpower, union issues, wage levels, and so on.
Regulatory aspects	Regulatory constraints.
Miscellaneous	Protection of the know-how (can be a discriminatory factor).
	No long-term unwanted neighbors.

**Table 6.4.** *Essential criteria for selecting a new site*

The essential criteria in the case of selecting a new site (*grass root*) are proposed in Table 6.4.

In the case of installation on an existing site, other criteria to be considered are as follows:

- the host site has the required know-how, therefore the appropriate human resources, and it provides utilities and services (maintenance, fire protection) that will reduce the investment;
- the over-the-fence process units provide the raw materials or receive the finished goods *over the fence*.

An evaluation grid can be made by weighing the above criteria. It is necessary to estimate the impact of key factors on the cost of the product. A snapshot is not enough; it is necessary to look ahead and imagine the potential changes. In a city like Shanghai, if care is not taken, a plant in the open countryside today may end up in the city in 10 years!

### **6.11. The consideration of sustainability in the preliminary projects**

Chapter 8, “Methods for design and evaluation of sustainable processes and industrial systems” written by Catherine Azzaro-Pantel, also addresses sustainability aspects but focuses primarily on the process aspects. What follows is more about a systemic approach at the company level.

More and more large companies rely on outside companies to evaluate their results in terms of social and environmental responsibilities. The economic result – the profit – is no longer enough. Even though it is always essential for the company to survive, it is no longer the sole indicator of good management, or we could say good leadership; the company likes to see itself as a responsible and moral person, or a corporate citizen. This notion requires the establishment of performance indicators of sustainable development specific to the company’s business, indicators that must be known to all, accessible and verifiable.

In the United States, some consulting and management firms analyze the rate of sustainability of firms and advise their customers whether or not to buy *stocks* accordingly. Some companies go to the extent of asking their *stakeholders* to assess the validity of certain investments! The company owner has to lead the company by taking into account the return on invested capital and sustainability as well.

Table 6.5 presents the principal sustainability indicators. It is a summary of the methods developed by Hertwich *et al.* [HER 97].

Sustainability indicators	Definition
HHS <i>Health Hazard Scoring System</i>	Assessment of the toxic effects and risks of accidents at the working places
MIPS <i>Material Input Per Service unit</i>	Sum of material flows involved in the manufacture of a product or service
SEP <i>Swiss Eco-Point</i>	Relative load of pollutants compared to an acceptable total load by taking into account a factor of environmental shortage
SPI <i>Sustainable Process Index</i>	Surface necessary for sustainable functioning of a manufacturing process
SETAC <i>Society of Environmental Toxicology and Chemistry</i>	Sum of the flow of pollutants with similar impacts, expressed as a potential equivalence
EPS <i>Environment Priority System</i>	Damages caused to the environment expressed in monetary terms

**Table 6.5.** *Principal sustainability indicators*

### 6.11.1. HHS indicator

*Objective:* to reduce health risks and accidents in the workplace, which can lead to injuries or pollution.

*Principle:* the classification of risks associated with a chemical product present at a given site according to the quantified criteria of toxicity (HP) and estimated site characteristics (F):

$$HHS = HP \times F \quad [6.1]$$

– *HP* is a number, the product of the chemical risk *H* by the nature of the phase *P* (liquid, gas, or solid);

– *H* is a number between 0 and 9, the product of the effect (lethality, minor effect, etc.) by the dose causing the effect;

– *F* is a number based on the judgment of an expert.

*Scope of application:* assessment limited to only the potential impacts associated with the production site, excluding the upstream (production of raw materials) and downstream (waste treatment).

*Categories of risks:* there are seven categories (toxicity by oral means and by inhalation, irritation of the skin and eyes, carcinogenicity, flammability, and reactivity), which are organized into a hierarchy according to a method of decisional analysis (AHP) developed by the EPA.

*Advantages:* simplicity (requires a short training course) and availability of material safety data sheets (MSDS).

*Disadvantages:* purely qualitative and dedicated to a specific site.

### 6.11.2. MIPS indicator

*Objective:* reduction of mass flows used in the manufacture of a product.

*Principle:* measure of the total mass flow required for the production over the entire cycle of the product or a service.

*Field of application:* basis for LCA and *eco-labeling*, the MIPS is for sustainable operations (remanufacturing, recycling, and material flow optimization).

*Application examples:* services, catalytic converters, yogurt, and regional economies.

*Advantages:* simplicity (material balances), expression in quantified form (mass), extension to the entire lifecycle, specific or not to a site, a good educational tool.

*Disadvantages:* demanding in data (LCA), implicit non-consideration of effects on health (toxicity) and the environment (GHG) with a risk of pernicious results. Thus, the method will involve the replacement of a significant amount of non-toxic product by a small amount of highly toxic product!

*Examples of deliverables:* 1 kg of paper consumes 65 kg of water, 30 kg of air, and 3 kg of wood and chemical products.

### 6.11.3. SEP indicator

*Objective:* to reduce emissions of specific pollutants by dilution and to reach acceptable levels in a given region.

*Principle:* assessment of the polluting load based on the contribution of each source to an acceptable total load and a scarcity factor (critical polluting load):

$$SEP = [\text{relative emissions}] \times [\text{environmental factor}] \quad [6.2]$$



– relative emissions: ratio of the emission flux of pollutant of a process to the absorption capacity of an environmental compartment for this pollutant (acceptable load);

– scarcity factor: ratio of the total pollution load irrespective of the process or the product studied in the given environmental compartment, to the absorption capacity of the latter for the pollutant in question.

*Example:* for a target of 20% reduction in CO<sub>2</sub> emissions at the national level in 8 years, the scarcity factor is:

$$100/(100 - 20) = 100/80 = 1.25 \quad [6.3]$$

*Advantage:* introduction of the scarcity factor.

*Disadvantages:* identical assessment of various pollutants, and difficulty in determining the acceptable load.

#### 6.11.4. *SPI indicator*

*Objective:* to define processes integrating them into the ecosphere on a sustainable basis.

*Principle:* to determine the area required for a process to be sustainable based on the generation of renewable resources and the degradation of effluents in compliance with all forms of life. The choice of the “area” factor is based on its relationship with solar and sustainable energy.

*Advantages:* simplicity, use of data that is available very early in the development of process, quantitative results are expressed in unit of area.

*Disadvantages:* lack of consistency since the data include not only the environmental hazards but also economical, technological, and political risks.

*Examples:* assessment of technologies on renewable materials, and selection of process improvement in the electronics industry.

*Application:* calculation of the SPI based on the production of 10 kt beet ethanol:

For comparison purposes, the SPI for 10 kt of fossil oil (expressed as carbon) would be about 4,000 km<sup>2</sup>/year, which is 30 times more.

– <b>Consumption of raw materials:</b> 151 kt sugar beet obtained with a yield of 4.9 kg/m <sup>2</sup> site coverage:	$S_1 = 31 \text{ km}^2/\text{year}$
– <b>Consumption of energy assumed to be renewable:</b> steam (14 GWh/year) and electricity (50 MWh/year) site coverage:	$S_2 = 3.8 \text{ km}^2/\text{year}$
– <b>Manpower:</b> 12 people to be provided with clothes, fed, and sheltered site coverage:	$S_3 = 0.2 \text{ km}^2/\text{year}$
– <b>Discharged effluent:</b> COD of 694 tons/year, based on rainfall of 1m/year and an average oxygen content. The dissipation of 1 kg of COD requires 140 m <sup>2</sup> /year site coverage:	$S_4 = 97 \text{ km}^2/\text{year}$
Hence $SPI = S_1 + S_2 + S_3 + S_4 =$	<b>97 km<sup>2</sup>/year</b> for 10 kt of ethanol

**Table 6.6.** SPI indicator in the case of production of 10,000 tons of beet ethanol

#### 6.11.5. SETAC indicator

*Objective:* reduction of all environmental impacts in the broad sense (production, transportation, usage, end of life).

*Principle:* three-step process:

– step 1 - classification: identification of impacts generated by the pollution and depletion of resources by *stressor categories*: greenhouse gases, acidification, human toxicity, and so on;

– step 2 - characterization: determination of the intensity of the impact of the above *stressors* on the environment, human health, and resource depletion;

– step 3 - assessment: balancing and summation of the impacts into a unique index based on judgment by experts.

*Advantages:* rigorous, extensive, and in-depth analysis with a final quantified result.

*Disadvantages:* extremely demanding in terms of data and therefore expensive with the risk of having only very vague data in the case of data shortage (use of hypotheses).

#### 6.11.6. EPS indicator

*Objective:* determination and quantification of the impacts on five *safeguard subjects*.

*Principle:* definition of five safeguard subjects (human health, biodiversity, production (e.g. fertility), resources, and esthetic values) for which the cost borne by the company to avoid damage is assessed. A scale value is defined, expressed in ELU (Environmental Load Unit): 1 ELU = Euro 1 (€).

*Advantages:* quantification of damage (an advantage when compared with the SETAC method). Assessment is based on the independent analysis of local conditions.

*Disadvantages:* demanding in terms of scientific, technical, and social data.

*Scale of values:*

– human health: 1 death = 106 ELU;

– biodiversity: extinction of a species, small animal or plant = 1,015 ELU.

*Application example:* comparison of the environmental impact of two materials for the construction of an automobile (in ELU).

Material	Steel	Composite	Gain	Gain in %
Production cost of the material	9	2	7	78
Manufacturing cost	1	1	0	0
Fuel consumption	40	24	16	40
Complete automobile	50	27	23	46

**Table 6.7.** EPS indicator applied to the automobile

The environmental impact of an automobile is two times lower when steel is substituted by a composite material. The impact on fuel consumption accounts for 70% of the gain (16/23).

## 6.12. Tips for conducting preliminary projects

### 6.12.1. Capacities of the installation

The capacity is clearly an essential basic criterion. Here again, a long-term vision is necessary; lack of vision, which is sometimes unavoidable, requires precautions to be taken during the risk analysis.

A very small and hardly expandable process unit, which will quickly saturate, will result in shortfalls. The customers may tend to turn toward equivalent products.

A very big process unit will see the full manufacturing cost aggravated by fixed costs and high depreciations.

The question arises of operating the plant round the clock, 24 hours a day, 7 days a week or 2 shifts per day-5 days a week, or on a daily basis only.

Should the process unit be polyvalent (multiproducts)? Can it be reconverted for other manufacturing purposes and is it easily expandable? Fine chemical companies know how to solve these problems by installing cascades of batch reactors connected to tank farms for raw materials, working in use products and finished goods. The polyvalence in this case is part of the specifications of the project.

#### 6.12.1.1. Rated capacity

The rated capacity is the production that can be expected over a long period, expressed either in tonnes/day or in tonnes/month. This notion is sometimes the source of misunderstanding! In particular, it should not be confused with the notion of maximum capacity, which is greater than it.

It is in fact necessary to consider the production loss over a given period, due to:

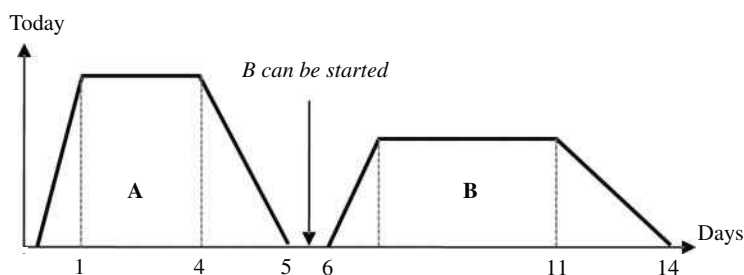
- compulsory shutdowns: maintenance and cleaning (e.g. clogging of devices in the case of polymerizers, exchangers);
- off-spec products during the phases of start-up and shutdown;
- the possibility of product degradation during operation at reduced rates due to the increase in residence time.

A coefficient called *stream factor* (SF) is also introduced:

$$\text{rated capacity} = \text{maximum capacity} \times \text{stream factor}$$

#### 6.12.1.2. Production by campaign

Example: in a process unit that operates in batches, two products A and B are manufactured successively according to the following diagram:



**Figure 6.9.** Two products manufactured by campaign

The production of A requires a certain number of days to reach the rated capacity and then a certain number of days to shutdown, clean, and prepare the installation to produce B. The capacity of the installation for A and B in tonnes/day can be different.

#### 6.12.1.3. *Multistep products with use of different process units*

In some types of discontinuous process units, the batch undergoes several transformations, by successively passing from one process unit to another. This holds true in the case of fine chemical process units where a raw material will react with other raw materials in successive reactors, for example, the oxidation process unit is followed by a nitration unit, which in turn is followed by a hydrogenation unit in a specific process unit.

The identification of limitations in the production capacity of each process unit (bottlenecks) makes it possible to define the occupation time in each process unit.

#### 6.12.2. *Description of the process and essential characteristics*

Chemists, biologists, and physico-chemists are the project managers of this first stage of the industrialization of a process that constitutes the establishment of the chemical route of the product. But process engineering must confirm and define the unit operations (reactions, separations, product engineering, recycling) of raw materials into finished products. The process engineer has questions about the:

- reaction: chemical, catalytic, electrochemical, biochemical reactions, and so on, agitation and mixing;
- separation: distillation, extraction, adsorption, absorption, membrane separation, crystallization, precipitation, decantation, filtration, dewatering, drying etc.
- product engineering: drying, granulation, atomization, extrusion, compaction, emulsification, prilling, agglomeration, coating, pelletizing, flaking, freeze-drying, micronizing, saturation, etc.
- transportation, packaging, storage.

The project engineer wonders whether this is industrially feasible, if so at what cost and whether there are any possible alternatives. This is a step of *interaction* between, on the one hand, the chemists, biologists, physico-chemists, and on the other hand, the process engineers. The description, comprehension, and modeling of phenomena, the analysis of products, their structure, and nature result in unit operations, which form the bases of the architecture of an industrially feasible process.

At this stage of industrialization, the equipment is not set, but only the functions to be carried out (reaction, separation, etc.) are defined, the nature of the input and output products, the flow rates or quantities used, the conditions in terms of temperature and pressure, and the amount of heat exchanged.

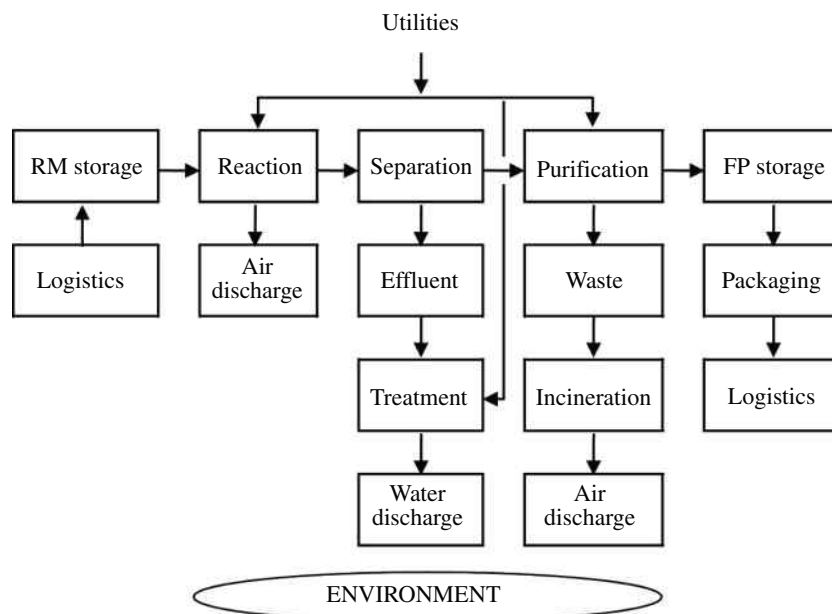
#### 6.12.2.1. Block diagrams

A block diagram is a functional diagram, and a simplified graphical representation of the process involving several units or steps, not to mention the treatment of effluents. It also enables us to carry out simple mass balances that provide general information on the consumption or production of products and energies.

It is made up of rectangular blocks connected by lines of action. The minimum information required for a block diagram is as follows:

- name of blocks;
- name of the input and output flows of the system as shown;
- direction of flow between the different blocks.

Such a diagram makes it possible to describe in one page (two if necessary) what it is about (executive summary). An example is shown in Figure 6.10.



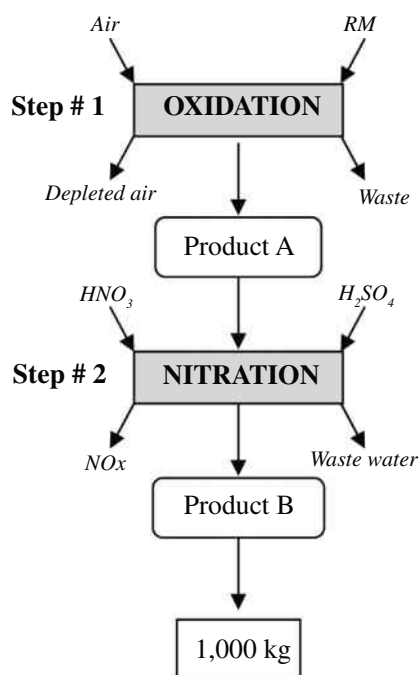
**Figure 6.10.** Example of a block diagram

The block diagram may also contain some additional information such as characteristics of the blocks, mass flow and energy flow rates, as well as the operating conditions (temperature, pressure).

#### 6.12.2.2. Simplified process flow diagram

A simplified *process flow diagram* is a diagram used in chemical engineering to describe the flow and principal chemical reactions of the process. It presents the key input and output flows with their names and flow rates, thereby making it possible to establish the material balance (reduced to 1,000 kg) and specify the yields identified by the study.

An example is shown in Figure 6.11.



**Figure 6.11.** Example of a simplified process flow diagram

#### 6.12.2.3. Summary table

At a single glance, the summary table (Table 6.8) should make it possible to:

- see the key products that are the basis for calculating the full manufacturing cost;

- have the material balance of the process unit on key products and utilities;
- know the procurement needs (e.g. number of trucks per day);
- know the load of the wastewater treatment plant (WTP).

	<b>Unit consumptions (per ton)</b>	<b>Nominal consumption (per hour)</b>
MP # 1 (kg)	890	2,500
MP # 2 (kg)	210	590
Steam utilities (t)	2.5	7.0
Electricity (kW)	3.2	9.0
Organic waste		
Wastewater		

**Table 6.8.** Summary of unit consumptions and emissions

#### 6.12.2.4. Essential features of the process

After completing the above steps, it is important to analyze, in retrospect, the process as a whole by answering the following questions:

- what are the important points?
- where does the *innovation* (if any) take place?
- are there any notable breakthroughs?
- what is that, *a priori*, does not pose any problems?
- are products that are particularly aggressive used?
- do safety and respect for the environment necessitate special precautions?
- does one know how to do it? (skills of the company?)
- how does one face *competition*?

EXAMPLES.— Reactions at very high pressure, complex chemistry, difficult separations, and devices with unusual volume (stirring power, size of graphite heat exchangers, etc.).



### 6.12.3. Risk analysis

*A risk analysis process should be implemented right from the feasibility stages, very early in the project. This is a continuous process that must accompany the project till the end.*

The management of *technical, organizational, or business* risks should lead to the following questions:

– have the risks been identified? Can they be identified? What are the methods used?

– what does the company intend to do to bring the risks to an acceptable level? What is acceptable?

EXAMPLE OF TECHNICAL RISK.— Performing tests at a larger scale or over a long duration.

Competitive risk is a major risk that is difficult to assess! *Can competitors do better? If yes, in how many years?*

### 6.12.4. Regulatory risks

Any implementation must comply with many regulations, codes and standards that vary from country to country. It is up to every trade association to comply with them.

In developed countries and in most of the developing countries, any new installation or modification of an existing installation requires a study of the impact on the environment and the procurement of a construction permit and production license, without which, it is illegal to lay the foundation stone.

These constraints will have, in most cases, a crucial impact on the design of the work and the deadline for completion; the construction permit, also referred to as *permitting* is very often on the critical path of the project. In China, *permitting* is something of an obstacle course; not less than 20 “offices” have to stamp all sorts of documents.

Most often, it is necessary to consider these constraints right from the beginning of the project. Licensing (in the broad sense) can be the key factor in the design, manufacturing start-up, or sales agreement stages.

Regulatory risks can be classified into three categories (Table 6.9) for which answers to the inherent questions are sought.

Regulatory risks		
A	Safety	Design of the plant?
		Proximity to dwellings?
		Working conditions?
		Maximum allowed doses (concentrations) (selective, for 8 hours etc.)
B	Environment	Effluents: treated at the plant or to be sent to the WWTU (waste water treatment unit) of the plant, to the WWTU of an industrial complex or a city
		Classification of waste (hazardous or not)?
C	Approvals/Codes	Is the license for marketing and export available?
		Are Good Manufacturing Practices (GMP) in place?
		Is it approved by the Food & Drug Administration (FDA)?

**Table 6.9.** *Table of regulatory risks by categories (indicative)*

### 6.13. Modification of the project scope

The project scope can be changed for many reasons:

- the customer still does not know what he wants: his own constraints could have changed over time;
- the costs are too high, which is a recurring phenomenon! It is necessary to cut down the “costs”.

Cutting down the “costs” may involve reducing the capacity of the installation, while providing opportunities for expansion, building the bare minimum, knowing that it will not please everyone, especially future operators.

The call for subcontracting can prove to be very useful. This may involve getting part or all of the product manufactured by companies who specialize in it. The fine chemicals industry often uses batch installations of subcontractors who have “batch” reactors, with different means of separation (distillation columns, filters, grinders) and appropriate tank farms. Distillation, grinding, crystallization, formulation, waste disposal, and packaging (putting in bags, drums) can easily be contracted out.

The question of knowing what the company wants to do by itself, what it wants to contract out, or make into a JV (joint venture) often arises due to the risks that the

company faces from competitors from developing countries. Subcontracting often involves taking the risk of compromising its independence, losing its know-how, or not achieving it.

*Everything is a matter of judgment! Life means risk!*

#### **6.14. Host site**

An industrial site may encompass a single process unit or several process units belonging to different companies that mutualize the production of utilities, the treatment of effluents and logistics. This can be a real industrial city as in the case of countries such as Germany (Ludwigshafen), Brazil (Camaçari), and China (Jiling).

An industrial *site* has *advantages*, *disadvantages*, and *constraints*. A site consists of men and their history, therefore a culture, know-how, and trades. A large petrochemical site actually has little in common with a large fine chemicals site, although both “deal with” chemistry.

In section 6.14.1, we will briefly discuss the essential characteristics of an industrial site on the assumption that a new process unit has to be established.

##### **6.14.1. Essential characteristics of an industrial site**

###### **6.14.1.1. Human aspects**

The skills of the operators, and the technologies, that they can master, are some of the most obvious characteristics of an industrial site. For example:

- *the site knows how to nitrate and hydrogenate but does not know about chlorination; there is a chlorine “culture”!*
- *the maintenance department knows how to deal with glass, graphite, and special steels equipment;*
- *service instrumentation has broader competences in automation and process control systems.*

The population pyramid of the staff, its *turn-over*, that is its replacement rate and level of training should be considered upfront.

The frequency rate of accidents, absenteeism rate, occupational illnesses, and the nature of social conflicts are all indicators of well-being or malaise and of the job atmosphere in general.

The “employer/employee” relationships, union issues, employment contracts, remuneration policies, the flexibility of operators, and the working conditions (shift work, day work) will affect the fixed costs. *In the United States, the fact that a site is union or non-union is of particular importance in the operating aspects of a plant.*

#### 6.14.1.2. Regulations

They vary greatly between countries and even between the states in the USA. Various taxes, statements of all orders, construction licenses, commissioning licenses, marketing licenses, import licenses, export licenses, and so on, are the problems that have to be faced. One cannot do without the experience of “locals”, which is indispensable to move in the impermeable administrative jungles in “foreign locations”.

#### 6.14.1.3. Master plan of the site

The master plan of an industrial site is a *long-term vision* of possible changes in the site in line with the strategy of the company [DAL 07].

The first idea is the division of the site into a checkerboard with roads that intersect at right angles. This is an arrangement which by its rationality pleases the eye.

The different units are arranged logically by taking into account:

- the functionality of each unit;
- risks, pollution, and regulatory distances;
- the flow of products, fluids, and people;
- safety issues, the impact of the units on each other (Domino effect), the possibility of evacuation, fire fighting, and so on;
- the need for shelter zones;
- the creation of buffer zones: remoteness of hazardous or polluting process units from dwellings and thoroughfares;
- presence of flames (kilns, flares, dryers, boilers, etc.);
- development plan for future process units.

#### 6.14.1.4. Support functions

There are many support functions including:

- administration: management, payroll, accounting, external relations, and so on;
- safety service (risk management), fire protection, and protection of property (security);

- infirmary and first aid center;
- changing rooms;
- maintenance, undoubtedly one of the most important technical functions, whether subcontracted or not.

Others include:

- electrical services, instrumentation, and automatisms sometimes grouped under the same umbrella in small organizations;
- inspection;
- analytical and application laboratories (customer service);
- IT department;
- logistics (shipping and receiving) including material handling equipment, hoisting, and warehouses;
- WWTU (wastewater treatment unit);
- means of incineration of hazardous products;
- approved landfills.

#### 6.14.1.5. *Utilities*

The utilities include:

- electricity (voltage);
- emergency power supply;
- steam (high, medium, and low pressure);
- energy sources: coal, gas, fuel oil, hydrogen, others (wood, hydropower etc.);
- water (cooling towers, ground water, chilled water, deionized water, etc.);
- brine (temperature level);
- air (instrument, service, and respiratory);
- nitrogen;
- hot oil (temperature, vapor/liquid phase).

An unreliable supply of utilities can severely impact an installation, namely:

- the process safety in the case of exothermic reactions that can lead to runaway reactions;
- the product quality in the case of heat sensitive products like fermentation products.

#### 6.14.1.6. *Basic chemicals*

Chlorine, hydrogen, carbon monoxide, carbon dioxide, oxygen, and various solvents (valid for large sites or sites near large industrial complexes).

#### **6.14.2. *Impact of a new process unit on an existing site***

As already mentioned, the implemented technology is the essential characteristic of a means of production. Technology here means pieces of equipment and their operating conditions.

There may be synergy between the new process unit and the host site. Without repeating the “identification” of a site as stated above, the new process unit can make use of the experience of the host site and its infrastructure taken in the broadest sense. In contrast, the new installation may generate additional risks and create disruptions in the working conditions.

For example, the new process unit operates round the clock 7 days a week, whereas the plant works in “2 × 8” shifts only.

*EXAMPLE.– The maintenance personnel of a plant in the Grenoble region are accustomed to using graphite material. A new installation uses glass material which is admired by the visitors; the products circulate. But glass is fragile! It cannot withstand rough handling! The glass material is gradually replaced with a graphite material. Culture is difficult to change!*

##### 6.14.2.1. *Particular case of human resources*

The layout of a new process unit in an existing site generally requires additional human resources, hence the creation of new fixed costs called direct fixed costs and absorption of existing fixed costs. Please refer to Chapter 2, which is dedicated to “The Two Modes of Operation of the Company – Operational and Entrepreneurial” for more details on this.

Needless to say, any new installation is generally very well regarded and sites will fight among themselves to take advantage of what can be considered as an opportunity.

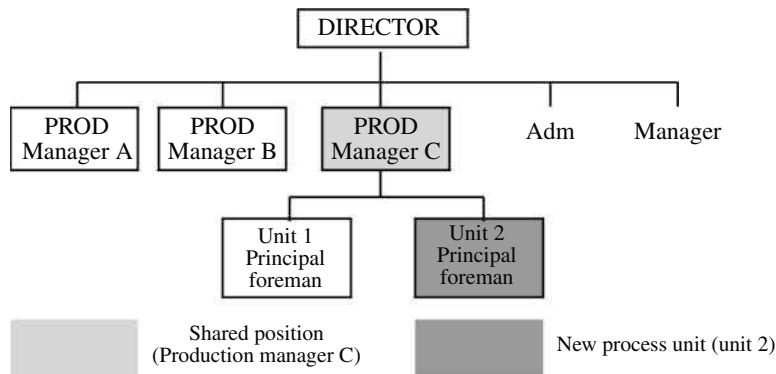
The project manager in charge of the new process unit should establish the fixed costs involved in the full manufacturing cost. In order to do this, he must define his needs in manpower in terms of quantity and quality, which is more difficult than it first seems! It is in fact with the receiving plant management and more particularly, the future manufacturer that he has to work. If this work is not complete before the decision to invest, unpleasant surprises are to be feared!

In order to acquire the necessary new human resources, the site has to plan for hiring and training, which leads to additional costs.

We recommend the establishment of predictive organization charts which include new and shared positions. A new process unit does not usually require a new plant director, but some of the costs of site management will be “allocated” to the newcomer. It is also necessary to know what this represents!

*Case study*

Let us consider the impact of a new process unit on an existing site in terms of organization of manpower. To make things clear, let us draw an organization chart (Figure 6.12) including a new process unit denoted by “unit 2” which is annexed to the production manager “C” who already manages a process unit called “unit 1”.



**Figure 6.12.** Organization chart including the impact of a new process unit

Additional needs in “unit 2” production amount to 35 persons as follows:

- supervisors: 1 principal foreman and 2 day first-line supervisors;
- workers: 5 shift operators × 6 = 30 shift and 2 day workers.

The additional non-manufacturing needs, amount to 12 people as follows:

- laboratory: 1 shift technician × 6 = 6 shift positions;
- maintenance: 2 mechanics;
- electricity: 1 day electrician;
- instrumentation: 1 day control room attendant;
- logistics: 2 forklift truck operators.

The total additional needs amount to 47 people.

The layout of a new process unit has the following consequences:

- creating jobs;
- improving the site balance by sharing the post of the process unit manager with the two process units 1 and 2.

#### 6.14.2.2. *Other impacts: waste, effluents, and utilities*

Any installation generates all sorts of effluents. The host site must manage this installation physically and *administratively* (environmental studies, various permits); it also requires utilities.

*Waste*: the consideration of the future of wastes is an integral part of the process approach. The points that have to be addressed are the following:

- the physico-chemical characteristics, dangerousness;
- process treatment;
- internal destruction (incineration);
- external destruction (price, accountability).

*Effluents*: as in the case of waste, effluent treatment is a part of the process. The following questions require a suitable response:

- is (are) specific treatment(s) necessary?
- can the existing treatment plant “take over” the new process unit?
- is it necessary to:
  - separate the process water from cooling water?
  - install a storm water basin? Water storage in case of severe contamination? Including fire water?

*Utilities*: everything mentioned above obviously applies to the utilities. It is very unpleasant to be told, when one least expects it, that one must invest in a new boiler. A new installation may receive low pressure steam that may be of no use to it. It may also require new energy balances to be found. Each scenario is a particular case.

### **6.15. Reporting**

The project manager needs to inform the stakeholders of the project, the level of progress of the project under his responsibility. This is what we call reporting, which



has a broader meaning than just a report. Reporting not only informs, but also raises questions, which involve the project players, thereby giving rise to comments, and looks into the future.

Reporting throws light on the future (to use a nice expression). It announces what will be done and requires a tacit or *formal* agreement of this work from recipients on the decisions to be taken.

It highlights the difficulties and opportunities. Reporting *is an essential tool of project management*.

In the following two tables, we include many items to be considered: these are in fact *checklists*.

The first *checklist* (Table 6.10) has a strong technical nature and is primarily used in the development phase (see Chapter 5 by J.F. Joly).

The second (Table 6.11) has a more industrial connotation, which is the phase of “Feasibility study, site search, and production aspects”.

*The content obviously depends on the level of progress! There may be umpteen reports! All the sections are not required to be included! All do not have the same importance.*

#### **6.15.1. Technical checklist**

The technical specifications must be very detailed and must not leave out any information. It is based on the four main characteristics.

#### **6.15.2. Executive summary**

*Executive summary* has a broader sense than just a summary. *The executive summary encompasses, in one page, what each “stakeholder” of the project must know and understand, whether he/she is a technician or not.*

Thus, in the example provided in section 6.9.2, the people involved in HR affairs must be informed of the progress of the technical project.

*A trader does not have to know the type of catalyst that can improve the efficiency of the reaction but that a breakthrough may be the cause of improving the full manufacturing cost of the product for which he is responsible.*

Composition of the technical specifications (process development phase)		
A	Bases of the study	
	Information sources	Laboratory reports
		Literature, patents
		Plant tests
		Technology purchase
		Similar experiences
	Technical bases	Is it time to move to the pilot scale?
		Is it possible to conduct large-scale tests?
		Scale-up factors?
		Has the stationary state been reached during tests?
		Lifetime of the catalysts (is the study long enough)?
		Effect of recycling (accumulation of impurities)
		Corrosion tests to be pursued
B	Raw materials (RM)	Are they properly characterized and defined?
		Have the tests been carried using “real” RM?
		What are the analytical methods used?
		Safety and security of RM procurement?
C	Specifications of the Finished product (FP)	Are they properly characterized and defined?
		What are the analytical methods? (caution with the Performance Products for which the product qualities of the product can be difficult to assess)
		What are the tests involved?
		Solid products: Is the sample representative (particle size, caking, etc.)?
		Product stability ( <i>shelf life</i> )?
D	Residues, Intermediate products, Waste and Effluents Specifications	Quantity, Quantities?
		Toxicity? (attention, the toxicity of an intermediate product (cancer) can result in the termination of the study: Ethics of the Society)
		Feasibilities of treatment and elimination?

**Table 6.10.** Checklist of project/specifications

Typical plan of a “reporting” (Feasibility Study Phase)		
1	Executive Summary	
2	Technical specifications	Technical basis
		Raw materials
		Finished Product Specifications
		Residues, waste, intermediate products, and effluents specifications
3	Installation capacity	Rated capacity
		Duration of campaigns in case of multipurpose units
4	Description of the process and essential characteristics	“Block” Diagram
		Simplified Process Flow Diagram
		List of the main RM
		Essential characteristics of the process
5	Technical risks	
6	Regulatory risks	HSE
		Registrations, Regulations
7	Project scope modification	
8	The co-products	
9	Host site	Constraints and opportunities of the host site
		General characteristics of the structure
		Layout
		Organization of work/manpower/jobs of the site and its culture
		Utilities
		Waste
		Effluents

**Table 6.11.** *Typical reporting plan*

The *executive summary* may include the following items, given for guidance:

- A: recall of the initial project scope;
- B: update on the project;

- C: technical data;
- D: industrial feasibility;
- E: risks and opportunities. Hard spots:
  - technical,
  - regulatory (construction permits, regulations, etc.).
- F: HSE aspects;
- G: full manufacturing cost, total amount of investment, profitability;
- H: Follow-up:
  - continue as planned, reorientate,
  - short- and long-term essential activities; deadlines of major decisions.

The industrialization process is complex given the amount and variety of criteria and parameters to be taken into account.

It is a process that greatly affects the future of the corporation; too many projects neglect it! They want to move quickly, too quickly, to the completion stage. Knowing how to find the best compromise is an art. Professionals should consider gaining experience in manufacturing! It will help them greatly should they move to corporate positions later in their career.

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## Chapter 7

# Lifecycle Analysis and Eco-Design: Innovation Tools for Sustainable Industrial Chemistry

### 7.1. Contextual elements

#### 7.1.1. *The lessons of Easter Island*

The dramatic story of the Easter Islanders is, now more topical than ever and a lesson to remember for the sustainable development of our civilization. On Easter Sunday in 1722, the fleet of the Dutch admiral Jacob Roggeveen reaches the coast of the island Rapa Nui, “the great distant” in Maori language. Roggeveen was therefore the first European to set foot on this island, one of the most desolate and most uninhabited places on Earth. One hundred and sixty square kilometers that stretch in the Pacific Ocean, at 3,700 km from the Chilean coast and at 2,300 km from the nearest inhabited land, Pitcairn Island. The colonization of Easter Island belongs to the last phase of the long expansion movement of men across the globe during the 5th Century AD. Initially, the first Polynesians came from Southeast Asia, reached the Tonga and Samoa islands around 1,000 BC. From there, they moved to the east of the Marquesas Islands about 300 AD then, from the 5th to 9th Century, to Easter Island in the south east, Hawaii in the north, the Society Islands and then finally New Zealand. Once this colonization was carried out, Polynesians were the people most widely spread on Earth, occupying a huge triangle from Hawaii in the north to New Zealand in the south west and the Easter Island in the south: which is twice the area nowadays of the current United States.

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Chapter written by Sylvain CAILLOL.

And when Roggeveen arrived on this island, he discovered a primitive society of some 3,000 people living in miserable reed huts or caves, in almost permanent state of war and forced to cannibalism to improve the meager available food resources. Yet, amid this misery and barbarism, the early European explorers discovered on this land the evidence of an ancient society. Indeed throughout the island lay more than 600 stone statues of at least 6 m in height. 20th Century anthropologists who have studied the history and culture of Easter islanders have established that these statues could never be the work of the destitute and primitive population discovered by the 18th Century colonists, but had been made by a once thriving and developed society.

Resulting from the about 30 Polynesians who originally colonized the island Rapa Nui in the 5th Century, the Easter Island society flourished and reached a population of over 7,000 inhabitants at the height of its civilization, in the 1500s. The Easter Islanders took most of their resources from the trees of the forests: energy for heating and cooking food, wood for building their houses, and fishing boats, for making weapons and nets for hunting and fishing, and organic enrichment of soil for agriculture. The villages were then spread all over the island in small groups of huts surrounded by cultivated fields. Social activities took place in ceremonial centers around the monuments of “ahu”, vast stone platforms similar to those found in other parts of Polynesia. They were used for burials, ancestor worship, and celebrations in the honor of the missing leaders. The Easter Island society was the most advanced Polynesian society of all and one of the most complex in the world considering the limited resources available. Islanders shared most of their time between elaborate rituals and the construction of religious monuments. Over 300 platforms were built on the island. Most of them were built according to sophisticated astronomical alignments, directed toward one of the solstices or the equinox. This is evidence of a high level of intellectual achievement. At each site there rose between 1 and 15 of the monumental stone statues that have survived today, the only vestige of the disappeared Easter Island society. They represented a male torso and a head crowned with a “bun” of red stone carved in stone quarries, weighing about 10 tons. The shape of the stones was made in various quarries on the island. The main difficulty was in transporting these monumental works across the island, and then erecting them at the top of the “ahu” (see Figure 7.1). The solution to this problem found by the islanders was also an element of ruin ... because of the absence of beasts of burden, they had to use a very large human labor to haul the statues by using tree trunks as rollers.

The rise in population led them to reduce forest areas to convert them into settlements and cultivable lands. And trees that are certainly a renewable resource, were consumed at a rate greater than their ability to renew themselves ... In a few decades, population growth was the cause of increased crop production, which led to land impoverishment and the reduction of forest area, thereby leading to soil

erosion. Forest resources became scarce. As the population increased, they had to cut down more trees to provide land for agriculture, fuel for heating and cooking, construction material for houses, canoes for fishing, and trucks to transport the statues. Very large amounts of wood were consumed, and one day, there was not enough wood anymore ... and 600 stone giants, which had required so much wood for their erection, became witnesses to the extinction of this civilization.



**Figure 7.1.** Photo: Yann Payoux, 2009

In fact, the lack of trees continued until the complete disappearance of this resource. The social and cultural impacts of deforestation were very important. The inability to erect new statues must have had a devastating effect on belief systems and social organization and challenged the many foundations on which this complex society was built. But the deforestation of the island did not only just mark the end of a sophisticated social or religious life: it also had dramatic effects on the people's daily life. Thus, the tree shortage forced many people not to build any more wooden houses, but to live in caves. When about a century later wood completely disappeared, everyone had to make do with the troglodyte caves dug into the hillsides or flimsy huts of reeds cut from the vegetation that grew along crater lakes. It was no longer possible anymore to build canoes: reed boats did not allow them to undertake long journeys. Fishing also became more difficult because the mulberry wood with which they made nets was not available any more. The loss of forest cover further impoverished the soil of the island, which was already suffering from a lack of suitable animal manure to replace the nutrients absorbed by crops. Increased

exposure to bad weather worsened erosion and made crop yields fall rapidly. Poultry became the main source of food. As their numbers increased, they had to prevent theft. But there were not enough to keep 7,000 inhabitants alive, and therefore the population declined rapidly. From 1600, the society in decline, Easter Island regressed to an even more primitive level of life. Deprived of trees and canoes, the islanders found themselves as prisoners thousands of kilometers from their native land, unable to escape from the consequences of the collapse of their environment for which they were responsible themselves: a massive degradation of the environment caused by the island deforestation.

Thus, if the first discoverers of the island in the 18th Century found it completely cleared with the exception of a few isolated trees at the bottom of the deepest crater of the island, contemporary scientific studies have proven that Rapa Nui had a thick vegetal cover in the 5th Century.

#### **7.1.2. On the carrying capacity**

This instructive historical example enables us to put the emphasis on the importance of a wise usage of our resources, whatever they are insofar as the concept of renewal capacity of any resource is intimately subjected to the rate of its consumption. This concept is developed in the concept of *carrying capacity*.

*Carrying capacity*, in agronomy, is defined as the number of animals (maximum or optimum) that a territory can tolerate without causing any damage to plant and soil resources. And we define overshoot, as the growth of a population beyond the carrying capacity of its region. These concepts are widely used in natural resource management. These fundamental concepts thus partly determine the bases for sustainable development:

- a rate of consumption of renewable resources that does not exceed their regeneration capacity;
- a rate of consumption of non-renewable resources not exceeding the development of alternative resources;
- a quantity of waste and pollution that does not exceed what can be absorbed by the environment.

Thus, life and Earth sciences and social sciences have offered various models for the study of the relationships between the population and environment, especially decomposition models (or multiplicative models). In these models, the total impacts on the environment are considered to be the product of population size, level of wealth or of consumption/production per inhabitant, and the level of environmentally harmful technologies. The empirical applications of this type of



model were used to examine the increased use of specific resources, or discharge of specific pollutants associated with the increased supply of various goods or services. The results are more heterogeneous with respect to the role of demographic factors. But these models are still well summarized by the IPAT equation [7.1] of Ehrlich and Holdren. This equation is defined as:

$$I = P \times A \times T \quad [7.1]$$

with:

- I = impacts: resource use, emissions of pollutants;
- P = population;
- A = abundance, wealth determined by GDP/person that defines the level of consumption;
- T = technology that quantifies the impacts/GDP;
- GDP: gross domestic product. It is an economic indicator that measures the production level of a country. It is defined as the total value of domestic production of goods and services in a given country during a given year by the actors residing within the country.

Population and abundance are the quantities defined, subjected, insofar as we do not seek to reduce them in our civilization. Therefore, the only factor that can allow us to reduce the *impacts I*, is the factor *T* of *technology*.

If we now introduce the concept of eco-design, it should lead us to seek the means to reduce the factor T of impacts/GDP.

## 7.2. The chemical industry mobilized against upheavals

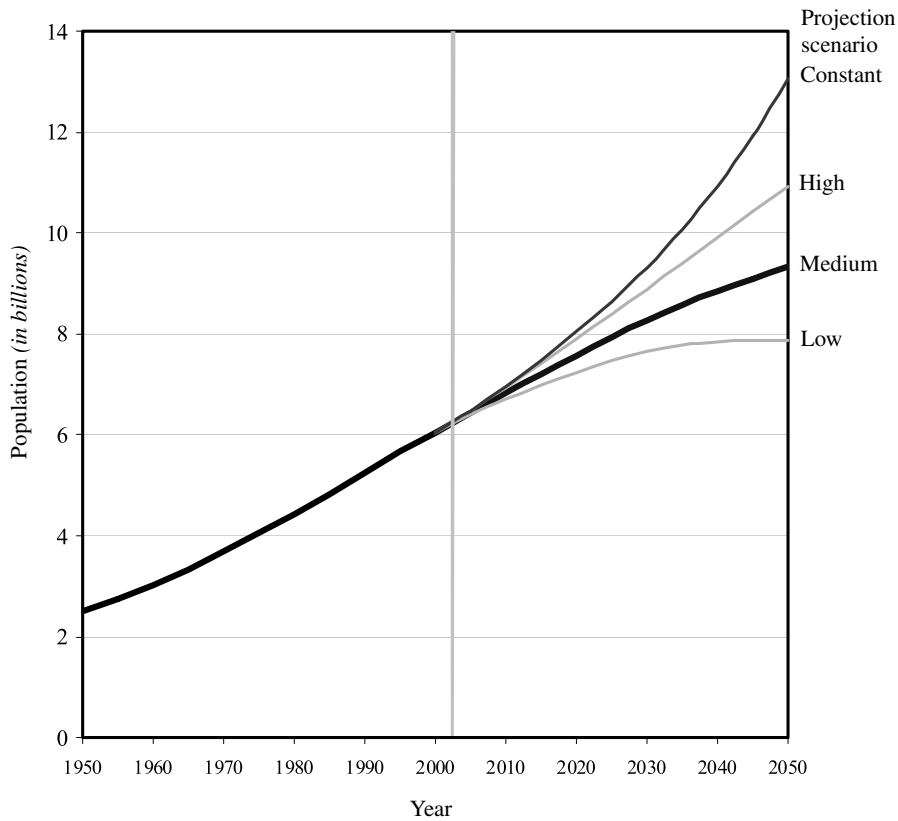
### 7.2.1. *Global turmoils*

Our company has recently become aware – on the human scale– that it was mortgaging its collective future to meet its need for individual wealth. As long as there were only a few hundred million people on Earth to share most of the wealth and generate, consequently, most of the anthropogenic pollution, the balance – questionable, certainly – was maintained – Vilfredo Pareto's laws are thus made. But with the arrival in the last decades of nearly 3 billion people, Indians, Chinese, and so on, that claim – rightfully so – a high level of consumption, and with the prospect of an increasing world population in the forthcoming years, the international community calls for sustainable development: to establish a new truly sustainable balance.

The 20th Century has thus been marked by unprecedented population growth, economic development, and environmental changes. From 1900 to 2000, the world population grew from 1.6 billion to 6.1 billion people. However, as the world's population quadrupled, the global real GDP increased 20 to 40 times, thereby allowing the world not only to support a quadrupling of the population, but also to do so with much higher living conditions. However, this population increase and rapid economic growth has been uneven across the all countries, and all regions also have not equally benefited from the economic growth. In addition, the population growth and economic development, which occurred simultaneously, led to the increasingly unsustainable use of the physical environment of the Earth.

The analysis of the interrelationships among the population, environment, and economic development is much older than Thomas Malthus (late 18th Century). Since ancient times, statesmen and philosophers gave their views on issues such as the optimum number of people and disadvantages of excessive population growth. One of the recurrent topics was the balance between population and natural resources, which are defined as livelihoods, such as food and water. The reflections and activities of the United Nations devoted to the population, environment, and development are as old as the organization itself. In the 1960s, we became more and more aware that the world population growth had reached unprecedented levels, a situation considered seriously worrying in many studies and debates. A report of the Secretary-General entitled "Problems of the human environment" mentions the "explosive growth of human populations" as one of the signs of a global crisis concerning the relationship between humans and their environment. This report was an essential milestone of the process that led the United Nations to convene the United Nations Conference on Environment held in Stockholm in June 1972. This was the first global intergovernmental conference devoted to environmental protection. The 20th Century has been marked by an extraordinary increase in the world population from 1.6 billion to 6.1 billion, an increase that occurred at a rate of 80% since 1950. And the world's population should keep on growing. On the basis of the varying fertility average, the UN expects the global population to reach 9 billion by 2043 and 9.3 billion by 2050. However, small but steady deviations of fertility rates can influence the size of the population over time. Thus, a scenario of high fertility in which the fertility rate is higher than half a child to an average fertility scenario, provides a size of 10.9 billion individuals by 2050 (see Figure 7.2).

Urbanization is also another important trend. In fact, although the world population may double in the next 40 years, the urban population, now of 3 billion people, is expected to reach 6 billion, resulting in a doubling of the urban population, with energy requirements that will also increase considerably. By 2050, among these "neo-urbans", there will be around 1 billion climate refugees, driven away by large mining and dams projects and by the effects of global warming and conflict, inherent in the generated changes.



**Figure 7.2.** World population projections under different scenarios of projection, 1950–2050 (Source: UN)

In the forthcoming years, the expected population growth will also be accompanied by an increase in consumption per person. The first item of consumption will be energy consumption. Thus, IEA estimates lead us to imagine several worrying scenarios that might arise by 2050: a doubling to tripling of energy consumption compared to 11 Gtoe consumed in 2007!

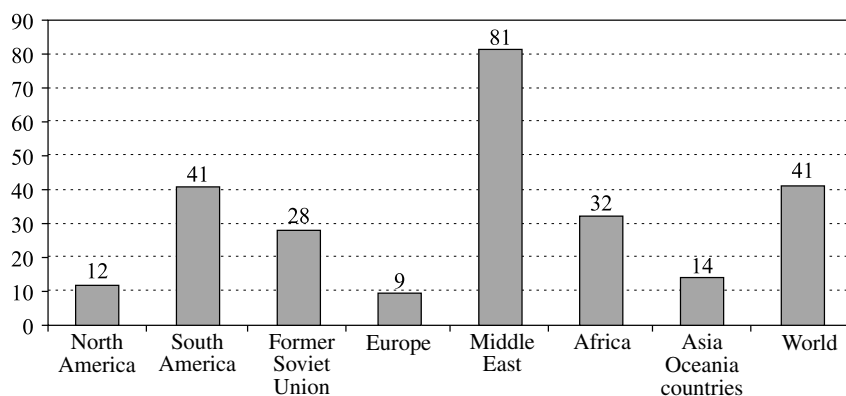
Similarly, the *Global Footprint Network* has identified the global overshoot day the 23 September 2008. This means that between January 1 and September 23, 2008, people have consumed the resources that nature can theoretically produce in a year.

Thus, from September 24, 2008, and until the end of the year, people have lived beyond their means, overexploiting the environment and undermining its capacity to regenerate. According to the calculations of the *Global Footprint Network*,

humanity's needs began to exceed the productive capacity of the Earth in 1986. Since then, as a result of the world population growth, the date when mankind has exhausted the resources theoretically produced in a year has been reached earlier and earlier. In 1996, our consumption exceeded 15% of the production capacity of the natural environment, and the "global overshoot day" fell in November. In 2007, it was October 6. In 2008, we have exploited the planet to 140%. Certainly, the accuracy of the calculations to arrive at this result can be challenged, but one thing is certain: we are in a bubble, and humanity is now living on credit.

### 7.2.2. *New constraints of industrial chemistry*

In addition, our society is currently based on the almost exclusive use of fossil fuels, especially for energy supply and consumer goods. The question is not to know whether there will be a peak production but rather *when* it will occur. In deed, almost all experts agree on the amount and duration of our global reserves of oil, coal, gas, nuclear fuel, and so on, based on our current consumption rate. Thus, at the end of this century, we will have exhausted all the land reserves that nature has taken millions of years to form. And yet this exploitation of fossil fuel resources – fossil carbon – is accompanied by a transfer of material, the transfer of carbon, which by oxidation (and *a fortiori* by combustion) will take the form of CO<sub>2</sub> in our atmosphere; accumulating and contributing to the increase in the concentration of the famous greenhouse gas emissions, which are responsible for the rise in average global temperatures.



**Figure 7.3.** Oil stocks in the world (in years of production in 2005)  
(Source: BP statistical review, 2007)

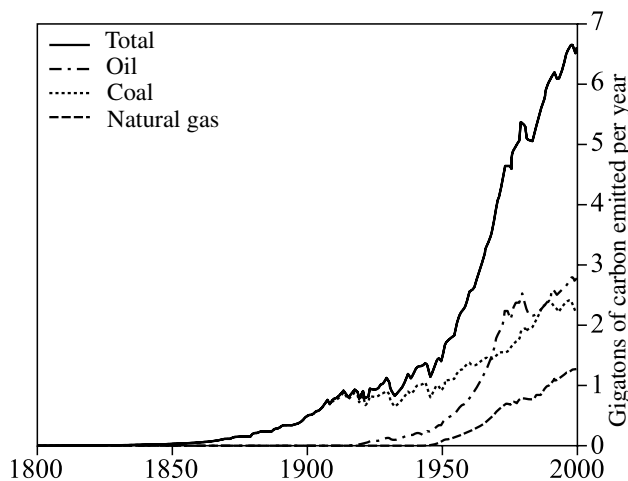
These matters are all constraints on industry and, in particular, the chemical industry – the industry of industries, since over two-thirds of its products are

intended for downstream industries. And because of these constraints, the chemical industry will undergo a revolution that is based on:

- anticipating the exhaustion of raw materials resulting from the fossil fuels with a higher price volatility. Thus, over the period of 2002–2007, the price of butadiene, a compound obtained directly by steam cracking of naphtha, has increased almost by a factor of 4. And the unequal distribution of fossil fuels, particularly oil, gives rise to significant speculations that jeopardize a stable supply (see Figure 7.3);

- an obligation to drastically reduce the polluting emissions of chemical processes and in particular the release of greenhouse gases (CO<sub>2</sub>, NO<sub>x</sub>, etc.).

The evolution and procurement level of fossil fuels have increased significantly the amounts of fossil CO<sub>2</sub> emitted into the atmosphere each year (see Figure 7.4).



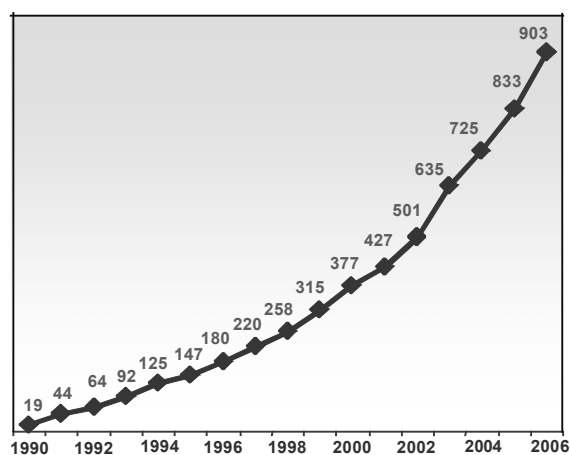
**Figure 7.4.** Emissions of fossil carbon since 1800 (Sources: G. Marland, T.A. Boden, and R.J. Andres, 2003)

The CO<sub>2</sub> cycle is in equilibrium on a global scale, with solubilization and vaporization balances at sea levels, and storage and release balances in the biomass. But this balance is challenged by anthropic activity that emits significant amounts of fossil CO<sub>2</sub> by oxidation (chemical process) and combustion (energy process) of the fossil fuels. The International Energy Agency forecasts an increase of 65% in greenhouse gas emissions by 2030, if no action is taken to reduce them. If the evolution of greenhouse gas emissions and their consequences have long been a subject of controversy, the IPCC has managed to develop a factual statement. The rise in atmospheric CO<sub>2</sub> concentration is of anthropogenic origin, and directly results in the rise of the average temperatures on Earth. Thus, the IPCC showed that an

increase in CO<sub>2</sub> emissions in the 20th Century is responsible for an average rise of temperature of 0.3°C. The current concentration of CO<sub>2</sub> in the atmosphere is 385 ppm. Several *scenarios* are imagined for the 21st Century, depending on the stabilization level of CO<sub>2</sub> concentration. In the “medium” *scenario*, the concentration would reach 700 ppm, which would cause an increase in temperature of 3°C by the end of this century, accompanied with a rise in sea levels from 25 cm to 50 cm. In addition, Nicholas Stern has tried to estimate the cost of climate change and estimated in 2006 to about 5,500 billion of dollars, the optimistic *scenario* corresponding to the consequences of a rise to 550 ppm of CO<sub>2</sub>;

– a strong regulatory pressure on toxicology and environmental toxicology related to the use of raw materials, synthetic intermediates, and products from chemical industry, with especially the REACH regulation, the Water Framework Directive WFD, but also many European directives regarding the end of life of materials (ELV directives, waste electrical and electronic equipment WEEE, directive on volatile organic compounds VOC emitted by paints, varnishes and vehicle refinishing products, etc.).

If the early regulations on industrial activities dating back to 1810 with a Napoleonic decree requiring compliance with a distance around production sites, the first European directive controlling the toxicity of chemical production was established in 1967 with the Directive 67/548/EC on the “classification, packaging, and labeling of dangerous substances”. Since then, the number of EU directives related to the environment has increased dramatically, particularly since the late 1990s with a sharp increase (see Figure 7.5). All these regulations are severe constraints for the chemical industry, but may turn out to be stepping stones for innovation.



**Figure 7.5.** Accumulation of European regulations on the environment  
(Source: Federchimica)

Therefore, covering the needs of humanity (food, energy, health care, etc.) while respecting our environment is the challenge that lies ahead and that chemistry will have to face in the forthcoming years. Chemistry has already managed to win battles in the last century – fight against epidemics, increase in agriculture, food, and industrial productivity to meet the growing demands for food and consumer goods, and so on. Currently the demand is different, but *it is chemistry that has the keys to sustainable development*.

### 7.3. The lifecycle analysis, an eco-design tool – definitions and concepts

#### 7.3.1. *Eco-design: a few definitions*

The production of goods and services is from now on under stress. It will no longer be sufficient to meet the specifications by technical means in accordance with the cost limit. Henceforth, we will have to integrate the respect for mankind and the environment, which means reducing the consumption of fossil fuels, limiting greenhouse gas emissions, comply with environmental constraints – this amounts to *limit environmental impacts*. However, taking into consideration all environmental impacts during the manufacturing process, and not only the measurement of the carbon footprint and CO<sub>2</sub> emissions amounts to integrate *eco-design* to the traditional design processes, but also consequently to the innovation process. This innovation process undergoes significant changes. We are not only waiting for a quick response, some time is taken, but to provide a comprehensive response on the environment, an eco-designed response.

In addition, eco-design is an integral part of the recommendations of the Grenelle Environment Forum held in 2007. Indeed, the Commitment no. 217 encourages analysis approaches of environmental products and eco-design “*Commitment no. 217: generalize the present environmental information about products and services: energy brand applied to all major energy consumer products, with a single reference point, development of eco-brands accompaniment of voluntary approaches to support the development of information on ecological impacts, with progressive obligation to provide these information; study of the development of the ecological price (double price to inform consumers about the environmental footprint of the goods they are buying) eventually going towards a collaborative eco-contribution*”.

Finally, eco-design is from now on a regulatory requirement with the framework directive for Ecodesign which states, for energy consuming products, that: “*The eco-design of products is an essential axis of the community strategy on the Integrated Product Policy. As a preventive approach, aimed at optimizing the environmental performance of products while maintaining their quality, it provides new and real opportunities to the manufacturer, consumer, and society as a whole*”. This directive

was reinforced by a directive laying down eco-design requirements for the following products: hot-water boilers fed with liquid or gas fuel, refrigerators, freezers and household electrical appliances, and ballasts for fluorescent lamps. Eco-design is therefore starting to become an obligation. It is also a response to consumers' expectations. In fact, the end users are now awaiting for eco-friendly products. According to the IRSN barometer, since 2006, the environmental degradation is in the top three concerns of the French. Eco-design is thus a comprehensive approach, which is focused on the product. It mainly takes into account the environmental and human criteria from the design phase of a product. These criteria generally relate to the set of phases followed by a product: production, distribution, use and end of life, namely *the lifecycle* of a product (see Figure 7.6). Eco-design is a multicriteria preventive process, which seeks to identify and reduce at the source all impacts on the environment.

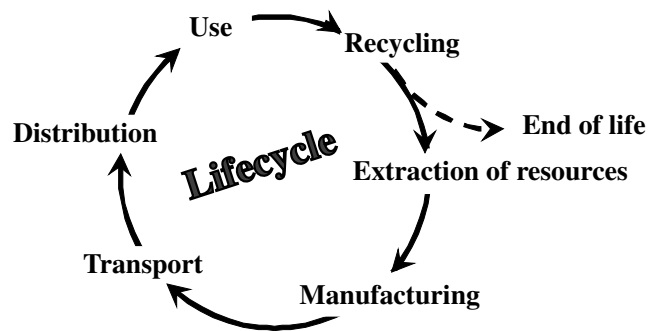


Figure 7.6. *The lifecycle*

The concept of eco-design is based on a powerful tool to identify the environmental impacts: the lifecycle assessment – LCA.

### 7.3.2. *The lifecycle assessment: history*

The lifecycle assessment, as practiced, is actually an environmental lifecycle assessment as the evaluated impacts are mainly environmental impacts (see Figure 7.7).

The “lifecycle assessment” thinking is a holistic way of thinking, which takes into account all impacts, environmental, social, and economic on the whole lifecycle of the product or service. This way of thinking should help to prevent local improvements from resulting in a transfer of problems (pollution, social conditions, etc.).



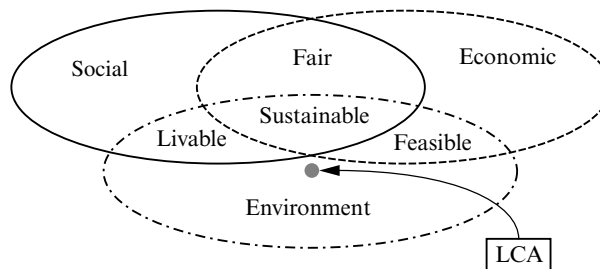


Figure 7.7. LCA lay out

LCA dates back to the late 1960s and to the early environmental assessments conducted in the United States on the REPA – Resource and Environment Profile Analysis model. These assessments intended to compare materials for packaging applications and focused on energy consumption, consumption of raw materials, natural resources, and waste production, in relation to the discussions of the moment on growth and environment (especially by the Club of Rome). In the early 1970s, following the first oil shock, industrial companies were essentially making the inventory of the energy flows consumed by their activities, under the form of analyses of environmental profiles and of use of resources, at the expense of real environmental analyses. In the late 1980s, a renewed interest emerged for environmental analyses, in relation to the issues of solid waste. Matter and energy inventories are also used for marketing purposes. The initial methods led to results that were difficult to use from one country to another, from one product to another, due to the heterogeneity of the data used and the various approaches. Industrialists and government had called for the development of a systematic, repeatable, and comparable methodology at least on regional scales. The SETAC (Society of Environmental Toxicology and Chemistry) and BUWAL (Swiss Ministry of Environment) had then responded to this call and the first Swiss method of environmental balance of BUWAL appeared in 1984.

The concept of *lifecycle assessment* appeared in reality for the first time during a seminar in Vermont (USA) of SETAC in 1990, which had put the emphasis on the need to extend the eco-balance based on material/energy balances to a real lifecycle assessment – the concept of impact assessment was established. The first lifecycle assessment was therefore performed in France on the steel packaging products of the SOLLAC company. In 1993, SETAC proposed a code of conduct that then constituted the reference frame for future developments. In 1997, the ISO – International Organization for Standardization – published the first International standard on the lifecycle assessment – ISO 14040: Environmental Management – Lifecycle assessment – Principles and framework. In 1998, the ISO published the international standard ISO 14041: Environmental management – Lifecycle assessment – Definition of the purpose and scope of study and analysis of the

inventory. In 2000, the ISO published the international standard ISO 14042: Environmental management – life cycle assessment – evaluation of impact on the lifecycle and the international standard ISO 14043: environmental management – lifecycle assessment – lifecycle interpretation. LCAs were developed in France in the 2000s with the carrying out of LCA by specialized firms and the organization in 2005 of the first symposium on eco-design and chemistry in France by the French Federation of Science for chemistry FFC and ChemSuD chair. In 2006, ISO published the standard 14044: environmental management – lifecycle assessment – requirements and guidelines and established a new version of the standard 14040. These two new standards cancelled and superseded the previous ISO standards 14040, 14041, 14042, and 14043.

### 7.3.3. Lifecycle assessment: concept and definitions

The lifecycle assessment is an analytical method, which consists of quantitatively assessing all potential environmental impacts of a product or service by considering the entire Lifecycle.

This analysis can be applied to the entire Lifecycle, in a “from cradle to grave” approach, to the extent that at each stage of the Lifecycle there is energy and resource consumption, and generation of environmental, social, and economical impacts.

The lifecycle assessment therefore consists of assessing, within a system defined by some *limits*, the impacts due to *inputs* (consumption of natural resources) and *outputs* (emissions into air, water, soil, and other pollutions (see Figure 7.8)).

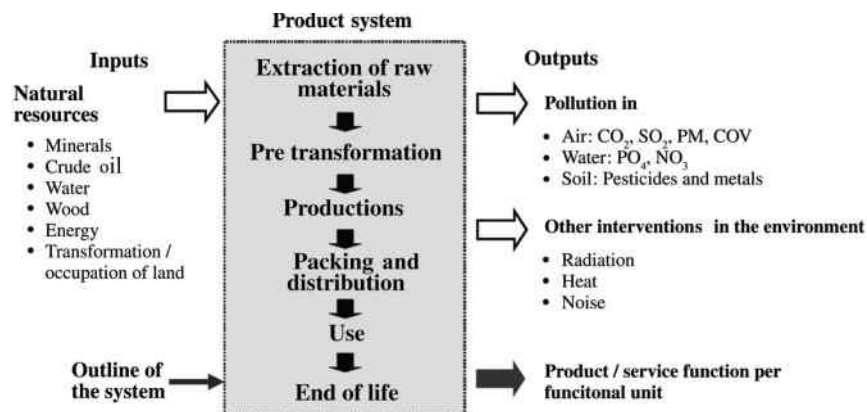


Figure 7.8. Principle of the LCA

This analysis is actually based on four really well-defined phases: *defining the objectives and framework* for the lifecycle assessment, *lifecycle inventory*, *evaluation of the impact of the lifecycle*, and finally, *interpretation* of the lifecycle. The analysis is based on a scientific methodology, which relies on computer software, supervised by the ISO standards 14040 and 14044 (see Figure 7.9).

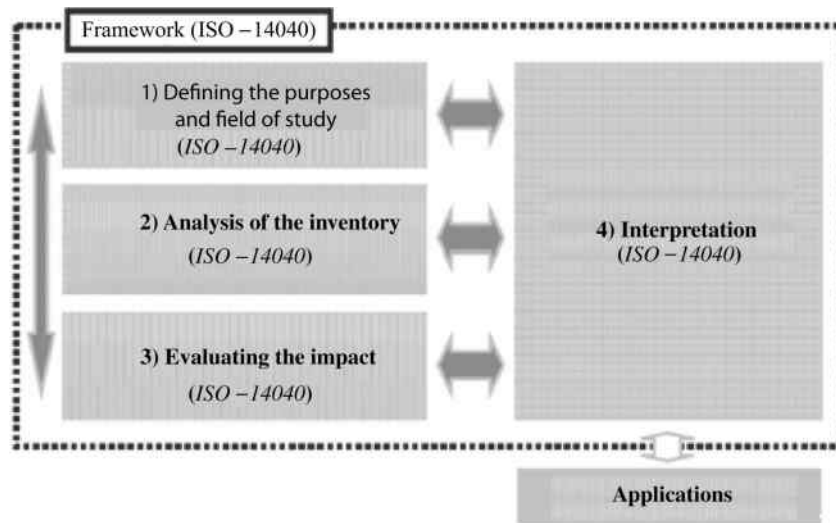


Figure 7.9. Framework of the LCA (Source: CIRAIIG)

#### 7.3.4. Defining the objectives and scope of the lifecycle assessment

Defining the objectives and scope of the lifecycle assessment is the subject of a reference document that is updated at each stage of the assessment. In general, lifecycle assessment studies are carried out in order to answer specific questions about the environmental impact by comparing different products or services. In all cases, these are comparative analyses that are *attributional*. They can be made to answer the questions related to the consequences of the massification of a process – for example, the consequences of the general implementation of a limited or localized behavior, in the case of which they are *consequential* lifecycle assessments.

To define the *objectives* of the study, we should initially specify the intended application, the reasons leading to conduct this study and the public concerned, namely those to whom it is intended to communicate the results of the study. In a second step, we should define the *scope of the study* that enables us to restrict the

study to the given *limits* and establish the limits of the system studied, and also to define the activities and impacts that are included or excluded from the study. We define the *temporal* cover (system lifespan), *geographical* cover, *technological* cover, cover of the *processes* (system boundaries), cover of *environmental interventions* (inputs and outputs), and cover of the *potential impacts*.

To determine the impacts related to the proposed project, we can rely on a list of environmental references. The study of this list will help us to eliminate unnecessary impact categories, to arrange the categories with insignificant impacts at a low level of analysis, and therefore to identify the critical impacts. This amounts to setting an *inclusion threshold* for the impacts on the lifecycle analysis.

*Inclusion threshold*: It is in fact usually impossible to consider all the compounds forming a complex product. The head of the LCA is required to set an inclusion threshold, which corresponds to the rules of *negligibility* whose principle is as follows: all components representing less than X% the total mass of the product are neglected. Secondly, we verify that the sum of what is taken into account remains above a fixed percentage, which is always close to 100% and, qualitatively, that the neglected compounds do not have particularly dangerous characteristics (e.g. toxic substances, radioactive waste, etc.) or other specific established problems (e.g. compound whose achievement is known as highly polluting and energy consumption). If not, these compounds will be reintegrated into the analysis, whatever their quantity.

The system definition also includes the definition of the *functional unit* and of the *reference flow*.

The functional unit is a quantity used to quantify the function of the studied product system and to compare different systems performing the same function.

#### EXAMPLES.—

– In the framework of an LCA to evaluate different packaging, the function studied is packaging. The functional unit to be defined is a packed volume  $V$  ( $m^3$ ) and not a packed mass (kg) or a mass of packaging materials;

– In the framework of an LCA to evaluate various means of hand drying, the function studied is drying. The functional unit is thus a  $N$  number of dry hands, and not a surface of tissue paper. We can thus compare reference flows, such as a quantity of paper or a volume of hot air;

– In the framework of an LCA to assess the environmental impacts of two mural paintings,  $P1$  and  $P2$ , the function studied is the cover of a wall surface. The functional unit to be defined is thus a painted surface  $S$  ( $m^2$ ). The Direct comparison of the impacts of a liter of paint  $P1$  to those of a liter of paint  $P2$  is meaningless and

*could even lead to completely wrong results. In fact, if per liter, the paint P1 is 30% cleaner than the paint P2, during the application, P1 requires two layers when one is enough for P2. We can thus obtain wrong results. In fact, a liter to liter comparison would lead to recommend the use of the paint P1, while it would have no interest for the environment or the user;*

*– if the analysis focuses on the comparison of processes or waste treatment process (storage, incineration, recycling), the functional unit may be, for example, the processing of one ton of waste.*

This definition phase is really crucial, as the results of LCA depend greatly on the objectives and framework that have been previously set (but usually not on the sponsor or the director). Thus, the LCA of a plastic yoghurt pot from a particular manufacturer, knowing the precise transport distance of their products as well as the composition and the different modes of production of energy that it uses, will not give the same results as the LCA of the European yogurt pot, which is made based on the average member of European production. Therefore, to avoid inaccurate interpretations or generalizations in the subsequent use of results, the objective and scope of the study should clearly explain the studied issue.

### **7.3.5. Lifecycle inventory analysis**

This phase is the one, which was the most developed at the methodological level. It benefited from the methods resulting from raw materials/energy balances of the 1970s. The definition of the Lifecycle inventory analysis according to international standards is: “Phase of lifecycle assessment involving the compilation and quantification of inputs and outputs for a given product system during its lifecycle”. The inventory is the basic objective of the LCA, as it is constituted by the basic processes obeying the physical laws of conservation of mass and energy. This type of inventory is not, however, absolute. Indeed, this approach involves a phase of data collection related to the achievement of working hypotheses. The data can indeed be collected not only on production sites but also with complete data from trade associations or organizations.

It consists here of gathering data or collecting the existing data and making calculations according to a precise sequence: flow chart, description of each basic process, data collection, and data validation. The quantitative input and output data of each elementary process calculated with respect to the reference flow are put in relation to the functional unit.

All environmental interventions (use of resources and emissions of pollutants) for product system, for each of the unitary processes at each step of the lifecycle (see Figure 7.10), are thus summarized into an inventory table and expressed with respect

to the system reference flow. At this point, during this aggregation, the spatial (place of emission) and temporal characteristics (time of emission) are generally lost. This may be harmful to the actions to be taken after a lifecycle assessment, in so far as the inventory is very spatialized in our global economy (e.g. oil production in the Middle East, refining in the U.S., production of synthesis intermediates in Europe, mineral production in Asia, etc.) and also registered in time as technologies change rapidly and thus also their environmental impacts.

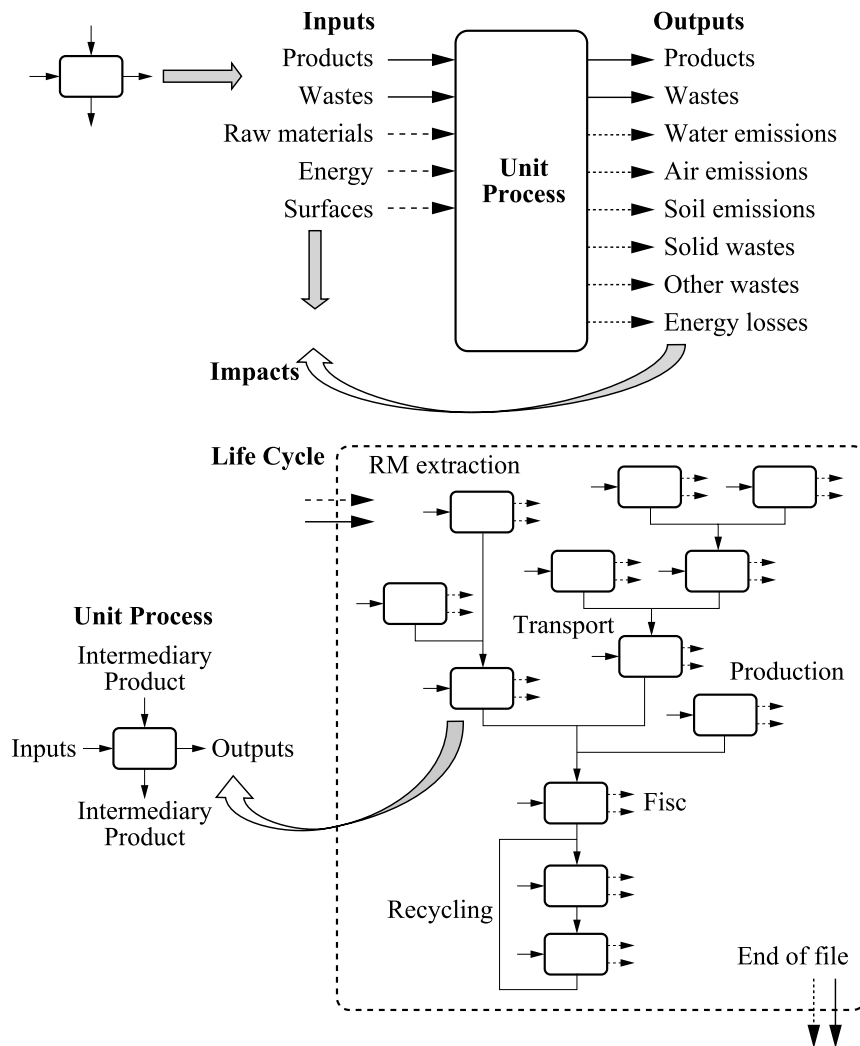


Figure 7.10. Lifecycle inventory

Inventory data are composed of material flows (mineral iron, bauxite, water, etc.) and energy (oil, gas, coal, etc.) entering the system under study and of corresponding outflows (solid waste, liquid, or gaseous emissions, etc.). There are some lifecycle inventory databases especially for common raw materials, energy, and transport. These data are accessible at low cost in the form of public or published databases (e.g. database *Ecoinvent data v2.1*).

Some groups or professional federations have also collected data on the environmental impacts of their material throughout its lifecycle or, more frequently, on the upstream part of the cycle, to make them available to the users of those materials, so that they incorporate them into their own LCA. For specific data to the study, data collection has often to be carried out on an individual basis, for a collection on industrial sites, through bibliographic researches, or through the perspective of previous studies.

Case of plastics: The APME (Association of Plastic Manufacturers in Europe) provides for free by mail and on its Website, the “Eco-profiles” of major plastics, in the form of lists of averaged inventory results, which are easily usable in spreadsheets or calculation software.

### **7.3.6. Assessing the impact of the lifecycle**

The impact assessment phase consists of explaining and interpreting the results obtained during the inventory, in terms of impacts on the environment, and in the form of an adequate summary that could be understood by a non-specialist. This phase should help to prepare the disclosure of elements related to the product environmental impact. It is particularly sensitive.

*The two previous phases – inventory and assessment – are those that are mostly related to chemistry since the entire manufacturing process is divided into material and energy balances, and deconvoluted in primary inputs: oil, gas, electricity, and so on. At each step of this process, by-products, effluents, and so on, are identified and their future is evaluated in terms of directly or indirectly possible pollution.*

To conduct the impact assessment phase, we must first select the *impact categories* to be remembered (see Figure 7.11), define the *impact indicators* and characterization models, and carry out *the allocation* of inventory results in different impact categories (*classification*).

For each indicator category, we must calculate the results (*characterization*), the amplitude of the results in comparison to reference values (*normation*), the grouping and ranking of indicators, and finally *the weighting* of indicators.

Basic impact categories	Supplementary impact categories
Depletion of abiotic resources	Loss of biodiversity
Land occupation	Ionizing irradiation impacts
Climate change	Odors
Destruction of stratospheric ozone layer	Noise
Human toxicity	Drying out
Ecotoxicity	
Formation of photo oxidant chemicals	
Acidification	
Eutrophication	

**Figure 7.11.** *Impact categories*

The impact indicators rely on various methods, which come from various sources. Thus, in general, we retain the following indicators (see Figure 7.12).

Indicator	Inventory flow	Method
Greenhouse effect ( $\text{kg}_{\text{eqCO}_2}$ )	$\text{CO}_2$ , $\text{CH}_4$ , $\text{N}_2\text{O}$ , CFC ...	Greenhouse effect 50.100 or 500 years – IPCC International Panel on Climate Change
Air acidification ( $\text{kg}_{\text{eqH}^+}$ )	$\text{NO}_x$ , $\text{SO}_x$ , HCl ...	Potential acid – Ecole Polytechnique Fédérale de Zurich
Formation of smog/of tropospheric ozone ( $\text{kg}_{\text{eqC}_2\text{H}_4}$ )	Volatile organic compounds ...	Oxidants – World Meteorological Organization (UN)
Eutrophication of water ( $\text{kg}_{\text{eqPO}_4}$ )	Chemicals demands for oxygen, $\text{NH}_3$ , $\text{NO}_3$ , $\text{PO}_4$ ...	Institute of Environmental Sciences of the University of Leiden CML

**Figure 7.12.** *Impact indicators*

EXAMPLE.– For an inventory outcome identifying the release of various components such as cadmium,  $\text{CO}_2$ ,  $\text{NO}_x$ ,  $\text{SO}_2$ , and so on, we will define acidification as one of the impact categories. In this case, the inventory outcome allocated to the selected



impact category includes acidifying emissions due to  $NO_x$  and  $SO_2$ . Modeling the indicator category is the release of  $H^+$  protons. The chosen indicator is aggregated acidification potential AP and  $SO_2eq$ . For aggregating, the weighting coefficients to be used are as follows: 1 for the emissions of  $SO_2$  and 0.7 for  $NO_x$  emissions. The category application point is composed of ecosystems such as forests, vegetation, and so on.

It is imperative that the chosen indicator provides an adequate representation, i.e. that the low indicator corresponds to a low impact and that the indicator shows a relevant environmental phenomenon.

For this, the number of indicators must be limited, indicators should be determined from the data and existing models, and the calculations should be executable in a limited time at a reasonable cost.

Category indicators actually represents the amount of potential impact. They are distinguished according to two main types, depending on their position in the causal chain between emissions and impacts (see Figure 7.13): midpoint and endpoint indicators.

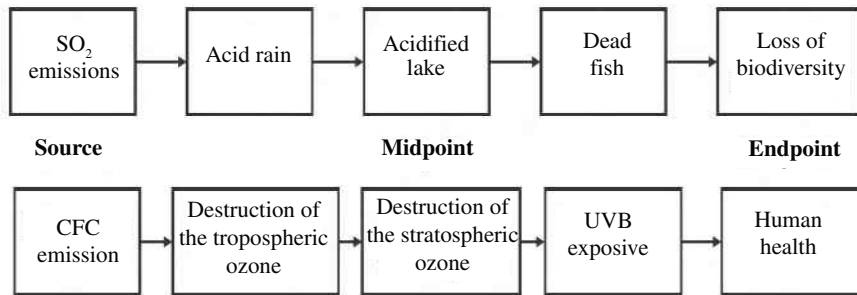


Figure 7.13. Midpoint and endpoint indicators

Midpoint indicators correspond to the aggregation by type of impact (acidification, destruction of the ozone layer, etc.). They are more easily accessible, with a limited uncertainty, but have a low environmental relevance. Endpoint indicators reflect the impact on targets (loss of biodiversity, human health, etc.). They are not easily accessible, with a high uncertainty but are of great environmental relevance.

Another way of classifying the impacts is to separate them in terms of *direct* and *indirect impacts*. Direct impacts correspond to the actions of sources on specific targets such as the depletion of natural resources by the extraction of raw materials.

Indirect impacts actually correspond to cascades of effects: the emission and dispersion of SO<sub>2</sub> cause acid rains, which will in turn lead to the acidification of soils, lakes, and air. The consequences of acidification will cause an alteration of flora, the death of fish, and human toxicity, with as the ultimate consequences the loss of biodiversity and agricultural and human productivities. The general form of an indicator is as follows [7.2]:

$$Ind_i^{cat} = coeff_i^{cat} \times pond_i^{cat} \times m_i \quad [7.2]$$

with:

- $Ind_i^{cat}$  : indicator of flow  $i$  for the impact category  $cat$ ;
- $Coeff_i^{cat}$  : coefficient of contribution of the flow  $i$  to the impact category  $cat$ ;
- $pond_i^{cat}$  : weighting of flow  $i$  for the impact category  $cat$ ;
- $m_i$  : mass of the flow  $i$ .

EXAMPLE 1.–

- *Type of impact: climatic change;*
- *Net Asset: CO<sub>2</sub>, 20 kg; CH<sub>4</sub>, 1 kg; and N<sub>2</sub>O, 0.1 kg;*
- *Characterization model: IPCC model defining the global warming potential by greenhouse gas emissions;*
- *Characterization factor: potential PR warming;*
- *PR CO<sub>2</sub> = 1 kg<sub>eqCO2</sub>;*
- *PR CH<sub>4</sub> = 21 kg<sub>eqCO2</sub>/kg CH<sub>4</sub>;*
- *PR N<sub>2</sub>O = 310 kg<sub>eqCO2</sub>/kg N<sub>2</sub>O;*
- *Indicator Outcome: Ind (PR) = 20 × 1 + 1 × 21 + 0.1 × 310 = 0.72 kg<sub>eqCO2</sub>.*

EXAMPLE 2.–

- *Type of impact: eutrophication;*
- *Net asset: 2 kg of NH<sub>3</sub>, 4 kg of NO<sub>3</sub>, and 0.2 kg of PO<sub>4</sub>;*
- *Characterization model: potential contribution to the formation of aquatic biomass of average composition (16 moles of N, 1 mole of P);*
- *Characterization factor: potential PE eutrophication;*
- *PE NH<sub>3</sub> = 0.35 kg<sub>eqPO4</sub>/kg<sub>eqNH3</sub>;*

$$- PE NO_3 = 0.1 \text{ kg}_{eq}PO_4/\text{kg}_{eq}NO_3;$$

$$- PE PO_4 = 1 \text{ kg}_{eq}PO_4;$$

$$- \text{Indicator Outcome: } Ind (PE) = 2 \times 0.35 + 4 \times 0.1 + 0.2 \times 1 = 1.3 \text{ kg}_{eq}PO_4.$$

### 7.3.7. Interpretation of the lifecycle

The two previous phases, impact inventory and assessment are the areas of expertise of the lifecycle assessment. Indeed, the approach is technical and the data are numerous. In the interpretation phase of the lifecycle assessment, users, managers, and decision makers, will use the results of the impact analysis to identify the key actions, which will have to be taken into accounts other sizes (research and development, marketing, production, financial services, etc.).

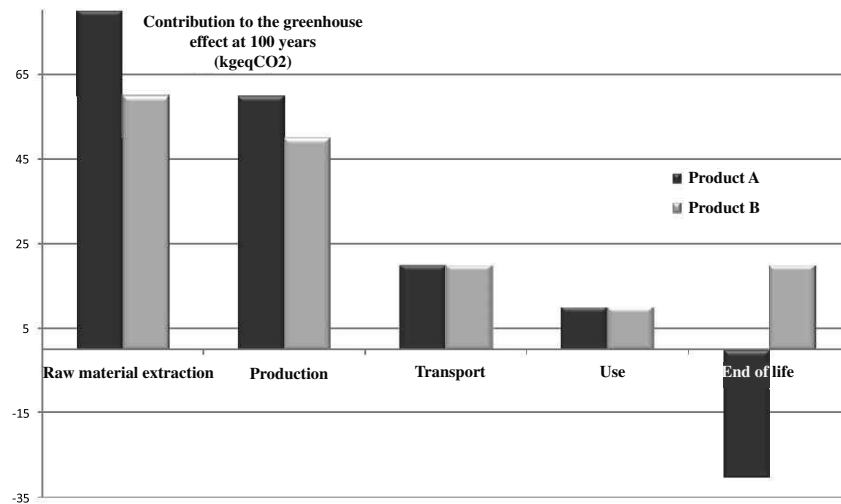
LCA results are expressed as a series of data that has both potential impacts (e.g.  $X \text{ kg}_{eq}CO_2$  for the greenhouse effect) and physical flows (e.g.  $Y \text{ MJ}$  of non-renewable energies). They are the subjects of a report and, in the case of communication, of a public summary document.

For a LCA comparing the two products A and B, the results for each impact can be expressed for each step of the lifecycle, to compare and identify the steps presenting the greatest impacts. This can also help to compare the contribution of each product at each stage of the Lifecycle. The following results (see Figure 7.14) enable us to establish that the product A contributes more to the greenhouse effect than the product B for the steps of raw materials extraction and production, but its ability to recycle at the end of life, enables it to absorb  $CO_2$ . This representation enables us to identify the steps on which efforts have to be made in order to reduce impacts.

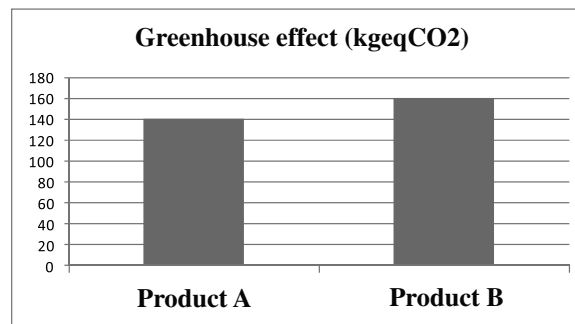
The aggregation of results for the contribution to the greenhouse effect per product enables us to identify macroscopic trends (see Figure 7.15), but annihilates the differences in the lifecycle. This representation enables us to make a global selection of the product causing the least impact.

The essential phase of interpretation is the report writing that should contain the main elements of the lifecycle assessment: a reminder of the context and objectives of the lifecycle assessment, detailed definition of the chosen functional unit, methodology of the lifecycle assessment, basic information and sources used and their limitations, encountered technical, methodological, and scientific difficulties. This report must necessarily include a critical review, i.e. the review of the study by an independent expert. This expert can act either alone or within a critical review committee involving experts of the studied field and key stakeholders: the key is to ensure the impartiality of the experts regarding the LCA in the studied domain.

Comments and responses to recommendations resulting from the critical review should be included in the summary report.



**Figure 7.14.** Contribution to the greenhouse effect of the lifecycle of products A and B



**Figure 7.15.** Aggregation of the “greenhouse effect” impact

The results of an LCA can also be conveyed as an environmental statement, and are then called “Type III environmental declaration”, or *eco-profile*, which can be printed on the product. This is the international ISO standard 14025, published in 2006, which establishes the principles and procedures for developing Type III environmental declarations and the use of the ISO 14040 series of standards for developing Type III environmental declarations. Type III environmental declarations described by ISO 14025 are mainly intended for inter-company communication, but

their use for the communication between a company and private individuals under certain conditions is not ruled out. The search for improvements is the component of the lifecycle assessment, in which the options to reduce environmental impacts of the system are identified and assessed. This stage includes the identification, assessment, and selection of options for the improvement of the environmental load of products or processes.

Currently, lifecycle assessments are most of the time used to meet certain requirements, such as the environmental performance of an industrial process, the environmental sales pitch, the comparison of environmental impacts of two products (or more), and the calculation of environmental balances.

In addition, the initial characteristics of the product generally determine the possibilities of valorization at the end of life. Finally, this approach shows a strategic advantage in terms of communication. Indeed, the results obtained in this type of approach may be shared with customers and bring about a competitive advantage that differentiates the product from its competitors.

### 7.3.8. LCA software

There are now dozens of software for analyzing the lifecycle assessment. Initially, the first software that emerged in the 1990s that have replaced the spreadsheet programs of 1980s, have been developed by consultants, at first for their own needs and then for their customers. We can thus name some early versions of *TEAM d'Ecobilan*, *Sima Pro*, *PRé Consultants*, etc. These various types of software were designed as sophisticated spreadsheets adjusted to the calculations of inventory and have provided with their different versions, more extensive features in terms of input and modification of models, display and print of the results as tables and graphs. The following versions have integrated various methods of assessment, based on the structure of LCA defined by the SETAC also with sensitivity analyses.

The latest generation of LCA tools is derived from the previous software, to which were added a user interface and a database specific to a type of use, such as product design (*Eco-It* derived from *Sima Pro*). Other types of software are dedicated to a specific industry, such as *EIME* for French electrical, electronic, and communication industries or *WISARD* for household waste management; both of them are derived from *TEAM*.

Suppliers of LCA software, who usually have initially developed the software for their own use, are now divided into three categories:

- public research institutes;
- environmental consulting offices, especially in LCA;

– industrialists, who, after having developed a software for their own needs in the early 1990s without marketing it, now often associate with consultants or research institutes to develop a new software.

#### 7.4. Innovation through eco-design

LCA does not provide solutions to design products or processes of low environmental impact but is a guide to select which stages to improve. The LCA is thus a tool that helps to make choices and to guide researches to foster innovation. In fact, the results of the lifecycle of a given initial product (see Figure 7.16) help us to identify that the highest  $X$  impact is related to the production stages of raw materials. Therefore, the research should be conducted on this stage in order to identify access channels or raw materials of lesser impact to develop a *eco-designed* new product. It is in this research process that innovation is found, and it is in this sense that eco-design is a real innovation tool.

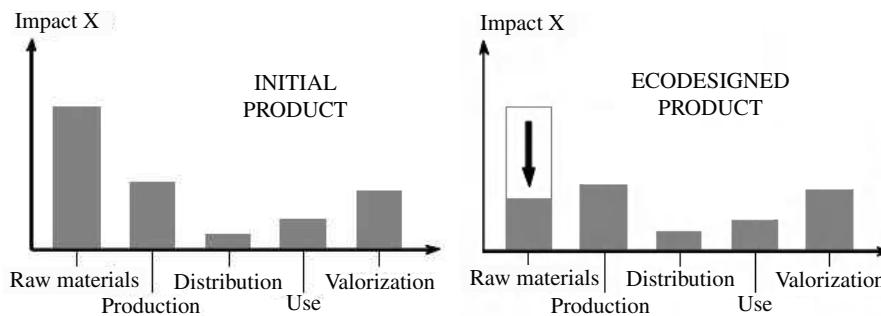


Figure 7.16. Innovation process

We propose to study the examples of case studies to detail the whole process applied to industrial products and processes.

##### 7.4.1. Example: LCA of supermarket shopping bags

The example of the comparative lifecycle assessment of the shopping bags distributed in supermarkets is very informative. This study was conducted in 2004 by an expert office in LCA, for a distribution company. It was completed by a critical review organized by ADEME. This study aimed at quantifying and comparing the environmental impacts of four types of shopping bags available to customers in supermarkets: a disposable polyethylene (PE) bag, a reusable shopping bag made of soft polyethylene, a disposable paper bag, and a single-use biodegradable bag. The

*inventory* was conducted by using data collected by the bag suppliers of the distribution company and completed by the Ecobilan database.

Eight *indicators* were selected for this study:

- consumption of non-renewable energy resources;
- water consumption;
- greenhouse gas emissions;
- atmospheric acidification;
- the formation of photochemical oxidants (smog);
- contribution to the eutrophication of aquatic ecosystems;
- production of solid residual waste;
- the relative risk of disposal of bags in the environment.

The *functional unit* defined for this study corresponds to the service rendered by the bags, i.e. packing the purchases made by customer in stores. The *hypotheses* defined in the framework of this study report 45 visits per year per customer on average in the stores, with 200 L of purchase by visiting (a cart filled to 80%), corresponding to 9,000 L of goods per year. The functional unit selected is thus “*packing 9,000 goods in the shops of the group*”. Bags compared within the framework of this study have the following characteristics (see Figure 7.17).

	PE Bag	PE Soft bags	Paper bags	Biodegradable bags
Material	Virgin HDPE	Virgin LDPE	Recycled paper	50% amidon/50% polycaprolactone
Volume (L)	14	37	20.5	25
Mass (g)	6.04	44	52	17
Use	One time	Reusable	One time	One time
<i>Nb of bags for UF</i>	643	<i>Case 1 use: 243</i> <i>Case 3 uses: 83</i> <i>Case 20 uses: 12</i>	439	360

**Figure 7.17.** Characteristics of shopping bags

The *boundaries* of the system take into account the production and transportation of materials for bags, the manufacturing and printing of bags, transport of bags,

phase of usage, and various end of life possibilities. The *inclusion threshold* defined is 5%: this means that the sum of the *inputs* whose production is not included in the system represents less than 5% of the total mass of the system inputs. Some *processes* are also *excluded* from the lifecycle. Thus, the study does not include the assessment of impacts related to the construction of buildings for industrial sites, or to the manufacturing of machine tools or delivery trucks. In fact, in a steady state of stabilized operation, the amortization of all this equipment is carried on throughout their whole lifespan, and then becomes negligible in the studied lifecycle. The study does not address the transport of full bags to shoppers' homes.

In calculating the impacts identified in this study, the *reference flows* identified are as follows:

- natural resources: consumption of oil, coal, natural gas, uranium, and water;
- air pollution: CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub>, SO<sub>x</sub>, and COV;
- water pollution: discharges of nitrogen, phosphorus, and oxidizable substances (COD);
- total waste production.

The impact of relative risk by disposal, was evaluated using the following parameters:

- volume of bags used to be processed: this volume is directly correlated to the number of bags that are disposed off;
- probability of disposal: this probability depends on the mode of acquisition, it is low when the bag is purchased, strong when it is free;
- probability of flying off: this probability depends on the density of the bag, it is strong if the bag is “light”, weak if it is “heavy”;
- persistence of the bags in the environment: this parameter depends on whether the material of the bag is biodegradable or not.

The LCA has focused on the *lifecycles* of the four types of bags being considered. For example, the lifecycle of the disposable HDPE bag (see Figure 7.18) first takes into account the use and refining of oil for the synthesis of ethylene, the polymerization of ethylene by Ziegler Natta catalyst, production of HDPE pellets, and their transport. These data are resulting from the inventory databases of 1999 of APME (average on 24 European sites producing LDPE 3.87 Mt/year or 89.7% of the production of Western Europe). The lifecycle also takes into account the production of titanium dioxide (data from a production site – 1992), calcium carbonate (data from the Swiss Ministry of Environment), and linear PE with low density (averages of the APME), which are the loads in the bag. The production of glue and ink is also taken into account.



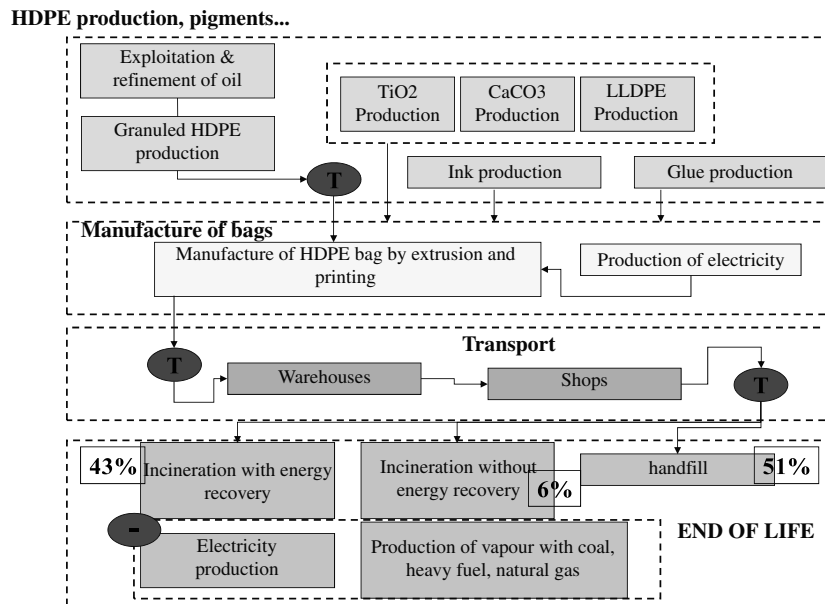


Figure 7.18. Lifecycle of disposable HDPE bags

In these lifecycles, energy production is modeled based on the energy ratios of electricity production of countries producing bags, namely France, Italy, Spain, and Malaysia. The differences are particularly significant for the impacts concerning the consumption of natural resources and the production of greenhouse gas emissions. Thus, the electricity in France is 75% of nuclear origin, whereas the electricity in Malaysia is 75% produced by the combustion of hydrocarbons. In addition, the calculations made to assess the impacts related to transport stages are based on the fuel consumption by trucks. The model takes into account the average consumption of a truck with full load (38 L/100 km) weighted by one-third the mass of the load, including the influence of *empty* return. The equation is therefore as follows:

$$\text{Actual consumption (L)} = \text{number of kilometers traveled} \times 38/100 \times (2/3 + 1/3 \times \text{real load/ payload} + \text{empty return rate} \times 2/3) \quad [7.3]$$

Finally, the end of life stage was modeled using data from ADEME for household waste. Thus, 51% of waste are brought to landfills and 49% are incinerated. And 88% of incinerated waste are recycled to produce energy, 5% is exhausted as vapor and 22% is generated as electricity.

The *impacts* of this lifecycle assessment are presented in two forms: for each stage of the lifecycle of each bag being considered (see Figure 7.19), or

agglomerated for each bag by considering the number of reuses of soft bags (see Figure 7.20).

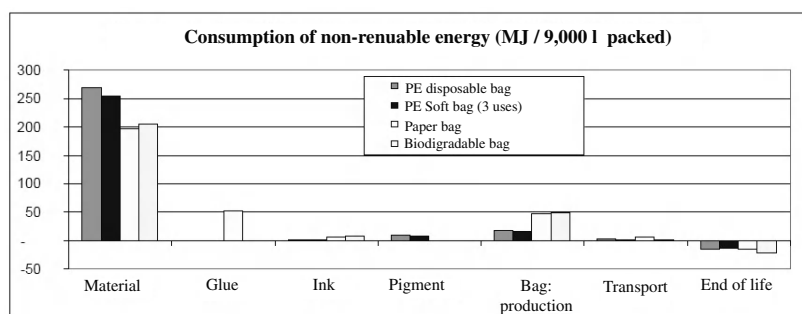


Figure 7.19. Non-renewable energy consumption

The interpretation of the results of impacts enable us to identify the following trends:

– consumption of renewable energy, greenhouse gas emissions, and formation of smog are impacts that are due to the phases of material production (see Figures 7.19 and 7.22);

– paper bags are the highest water consumers, due to the paper recycling process (see Figure 7.21);

– paper and biodegradable bags are the source of the impacts of eutrophication, due to the paper recycling process or the use of fertilizer for corn crop from which we get starch (see Figure 7.24);

– phases of material and bag production are the strongest contributions to atmospheric acidification (see Figure 7.23);

– the formation of solid waste is the end of life stage, which is the largest contributor to this impact;

– for the set of relevant impacts, soft bags show impacts: higher than other types of bags meant for a single reuse; equivalent from three uses; and lower than a number of reuses higher than three;

– The relative risk presented by disposal is very high for disposable PE bags, and low in all other cases.

The broad guidelines of the findings are also that the reduction of the mass of the bag and reuse of the bag are two major factors that reduce the impacts on the environment. The conclusions of this study are therefore strongly favorable to the use of soft LDPE bags – with the assumption of reuse of these bags for at least three times.

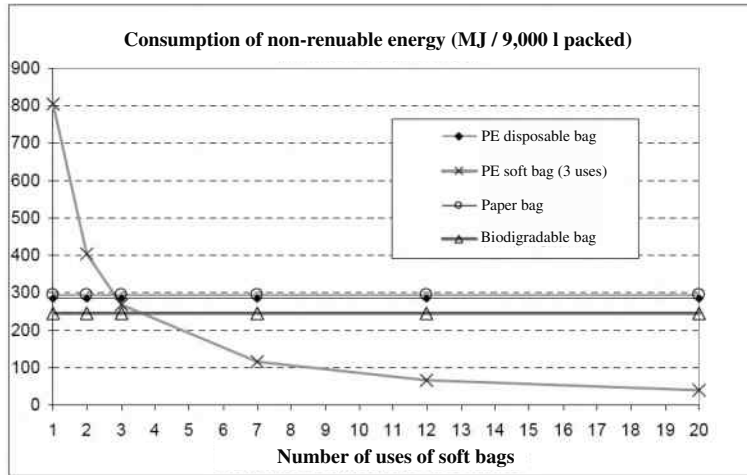


Figure 7.20. Consumption of renewable energy for N uses of soft bags

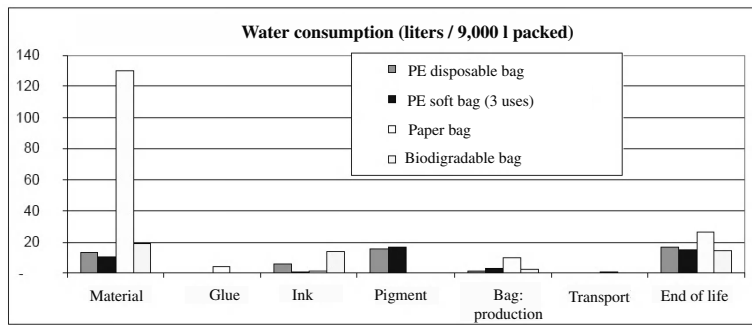


Figure 7.21. Water consumption

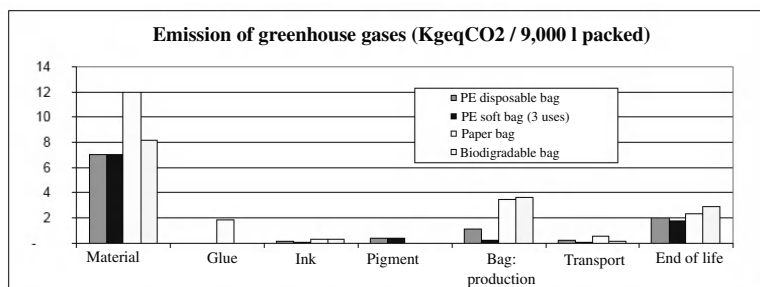


Figure 7.22. Emission of greenhouse gases

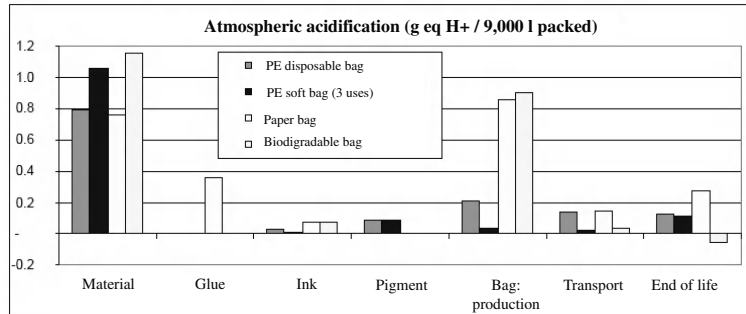


Figure 7.23. Atmospheric acidification

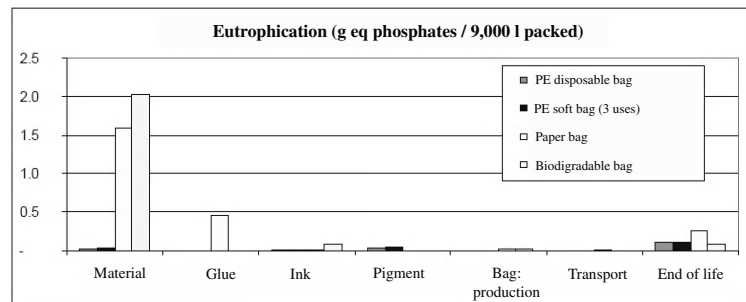


Figure 7.24. Water eutrophication

#### 7.4.2. Example of eco-design by a manufacturer of office furniture

The company considered offers solutions for office layout, has routinely used the evaluation of the lifecycle for each of its products. A lifecycle assessment of an office chair made in this company had therefore underlined the preponderant impacts of the stages of production of materials and seat. To reduce these impacts and to identify an eco-designed innovative solution for office chairs, the company has promoted the use of recycling and reuse for office chairs (see Figure 7.25). Thus, the materials that made this seat were at 44% recycled, free of heavy metals. This chair can be dismantled completely and each part can be replaced individually by the company. The seat and packaging are also recyclable at 99%. This seat was reduced to 7 kg and packed volume was reduced by 30%. The environmental impacts of the material and seat production are thus reduced, as well as impacts related to transport. Finally, the end of life was supported by the company that had established a recovery and replacement of parts and seats service. This product had been voted “Best French eco-designed product” at Pollutec in 2004 and has won the gold medal of Focus Green Award in 2008 in Germany.



**Figure 7.25.** *Eco-designed seat (Source: A. Malsch)*

#### **7.4.3. Example of eco-design from a manufacturer of detergents**

Conducting lifecycle assessments has also led a detergent company to offer innovative eco-designed products. Thus, in the framework of the development of detergents, very detailed lifecycle assessments of laundry have highlighted the main environmental impacts and the stages with the highest impact. These results have thus shown that the most important environmental impacts were related to the usage phase of detergent. In fact, 75% of the energy consumed in the lifecycle come from the energy consumption of the washing machine during the usage phase. This energy consumption is especially linked to the operating temperature of the washing machine. To reduce environmental impacts and to suggest an eco-designed innovative solution, the company has developed a detergent in order to reduce the washing temperature without reducing the performance of detergent. This “cold active” detergent makes it possible to significantly reduce overall environmental impacts and nearly 50% of major energy consumption have been consumed in the total lifecycle. Marketing material made to promote this product has also highlighted the savings for consumers, which will reduce their energy bills.

#### **7.4.4. The integration process of eco-design in the company**

These examples highlight the achievements of design and marketing of eco-designed products. These products have been designed in the innovation process based on lifecycle assessment to identify the axes of improvement related to the most important environmental impacts, the most contributing strategic stages to the lifecycle. We can thus, in the light of these examples, try to describe the integration process of eco-design in the company in five steps and extract the appropriation process from it.

To start an eco-design approach in the company, the first step is *to choose the product* on which the company wants to work. This choice is made based on the product strategy by studying the portfolio of technologies available, the current product range, and by achieving an appropriate *benchmark*. At this stage, the eco-design approach can already point out the product and company environmental problems and enable us to estimate the environmental improvement potential of the product.

The second stage defines the *design* goals associated with the chosen product, and will therefore have to convey the need in terms of function, based on market researches and a functional analysis. At this stage, an initial lifecycle assessment should be carried out on a reference model by choosing eco-design guidelines.

The third stage should enable us to bring out *technical solutions*, i.e. block diagrams accompanied with a cost estimate. The eco-design approach helps us to search for solutions of lower environmental impact and to conduct an environmental report.

In the fourth phase, *industrialization*, the company must optimize the production parameters, logistics, and supply. This work is accompanied with a collection on site of impacts such as energy consumption, real mass flow, amount of waste, etc, in order to conduct an environmental assessment of the final product and to prepare an environmental report.

The fifth stage concerns *marketing and communication*. Distribution channels as well as possible maintenance contracts are selected ... Communication about the product is made internally and externally based on the environmental report to establish a sales point, extract key figures, and communication media.

Beyond these five stages, this approach must also take into account the end of life of the product by providing recovery solutions for products, packaging management, reuse, recycling, etc. Finally, any further development of the product (features, packaging, etc.) should be reflected on the impact assessment and communication messages.

For a company, the appropriation of such an approach lasts and involves three phases, several stakeholders, and several deliverables. In a preliminary decision-making phase, management must signal its involvement by the drafting of guidelines. In a first *piloting* phase, the integration process must rely on an eco-design "pilot" experiment, with the support of management and with the help of an expert from outside the project team, from a consulting firm that acts as a provider. After this phase, the following stage of *framing* aims at formalizing the process within the company, with an in-house person in charge of the coordination of eco-design projects, helped by the outside firm to conduct training in house. In the last phase *of extension*, the approach becomes integrated to the company and is widely

applicable to all design projects, coordination is done in-house and all members of the project are competent in so far as the company is able to generate self-training. Management can then communicate about the external approach.

### **7.5. Limits of the tool**

The lifecycle assessment is thus a support tool for eco-design. This tool can be powerful, but also has some limits especially due to the complexity of its implementation. Indeed, resorting to expert software and often expensive databases reduces its use to a few multinationals and limits its contribution to the analysis of existing products and processes. LCA is therefore a particularly interesting tool because it enables a multicriteria analysis, on the entire lifecycle, without limiting itself to a single stage (end of life, etc.) or a single impact (carbon footprint, etc.). In addition, this tool is standardized through the ISO standards describing it. Moreover, a single impact, estimated at each stage, can be “added” to give a clear vision and helps decision-making. And finally, nothing is published without having been previously submitted to the journal of a group of experts.

However, if the LCA enables the identification during a given process of the stages generating the highest environmental impacts – such as stages of raw materials extraction – LCA gives a vision *a posteriori* but does not direct the course of the innovative process. LCA is indeed a study performed on an already developed or commercialized product and helps to identify the steps that have the greatest impact on the environment during the manufacture of this product. The objective of an eco-designed process is to bring about, in a second phase, some solutions to reduce the most significant impacts during the previously identified stages. Innovation is thus born from the search for solutions during the second generation, or from the improvement of the product manufacture process. Therefore, the primary objective of these lifecycle analyses is rather data compilation, the conducting of an environmental assessment, the production of results for the communication on the manufacture a product; the support for eco-design is performed a second time because LCA is best suited to evaluate its final impact of a product, rather than guiding its design. Furthermore, other limitations of this tool lie in the defining stages of the assumptions, in the allocation rules followed or the considered end of life. We will try to illustrate this through the following examples.

#### **7.5.1. On the importance of hypotheses**

In fact, in the lifecycle assessment of shopping bags described in section 7.4, conclusions strongly support the use of soft LDPE bags – in the event of reuse of these bags at least three times. The broad guidelines of the findings are that the reduction of the bag weight and reuse of the bag are two major factors reducing the impacts on the

environment. But at no time is considered a possible reuse of other considered bags (especially HDPE and biodegradable bags, which could be reused a second time, or at least as garbage bags). In addition, the study is comparing bags with very different volumes, which involves quite variable amounts of material depending on the bags. And yet knowing that the weight of the bag is an important parameter, it would have been appropriate to consider the solutions showing larger volumes for the same bag. Thus, we can clearly identify that the LCA evaluates selected products and helps in choosing the best product *within* this selection. But experience shows that solutions to a problem can often be found outside a preselection ... We must therefore be innovative to really find eco-designed solutions.

Another interesting example is the informative case study described by Jolliet *et al.* The goal of the presented LCA is to develop an environment-friendly computer by comparing the environmental impacts of two computers, a desktop PC with a CRT monitor and a LCD laptop. The functional unit given is 10,000 hours of usage of the computer (i.e. 2,000 h/year over 5 years). In the hypotheses considered, we compare two computers with similar functions, ignoring the transportability of the laptop. Infrastructures and manufacturing machine tools of computers are not included in the limits of the study and the battery of the laptop is not taken into account (production and disposal). The results of this lifecycle assessment show the following differences: the desktop computer has the most significant environmental impacts. The impacts of the laptop are actually lower by almost 40% to those of the desktop PC in all categories. And the screen is responsible for nearly 50% of impacts. So, the findings clearly guides us toward the laptop solution. But this case study shows that the results obtained are related to unrealistic and not rigorous hypotheses. In fact, the manufacture and disposal of the laptop battery are not included in the LCA. And yet this type of component and significant mass contains toxic and eco-toxic substances, its disposal is governed by the Waste Electrical and Electronic Equipment (WEEE) Directive. It is inconceivable not to include it in the LCA. In addition, as the screen supports up to 50% of impacts, it seems less rigorous to compare the PC with screens of different technologies. It would be more appropriate to compare a PC with an LCD screen. And finally, the life span of two PCs is not comparable; indeed, the life span of the laptop is reduced not only because of the potential damage caused during transport phases but also because it is difficult to replace its components. In contrast, the lifespan of a desktop PC can be extended, in so far as some components or materials will be reused in a new configuration (screen, keyboard, etc.). In this case, the functional unit can be changed. Therefore, this educational case study highlights the faults of the LCA tool when we lack rigor in the choice of the functional unit and hypotheses.

The example taken from the study of Kim *et al.* is also very illustrative of the importance of choosing the hypotheses of the LCA. Indeed, in their study, this team compared the environmental impacts of two types of polymers, the polystyrene



*PS* – obtained from the polymerization of styrene, a monomer coming from oil, and a *PHA* polyhydroxyalkanoate – polyester derived from the fermentation of sugars extracted from corn kernels, from agricultural source, by bacteria. The comparison is carried out at similar mass, despite any possible differences in properties. The results presented in this study show initially that the impact on the greenhouse effect is lower for the manufacture of polystyrene (2.9 kg<sub>eqCO2</sub> for PS and 3.5–4.4 kg<sub>eqCO2</sub> for PHA). However, in a second study/case, we add in the lifecycle the production of sugars from the co-produced straw and also the recovery of energy coming from straw valorization. And in this case, the production of PHA becomes a CO<sub>2</sub> well, to the extent that the indicator is –1.2 to –1.9 kg<sub>eqCO2</sub>. This example perfectly illustrates the importance of choosing the right hypotheses and limits on the final result.

### **7.5.2. On the relevance of inventory data**

Let us return to the lifecycle assessment of shopping bags described in section 7.4. The LCA has studied the *lifecycles* of four types of bags. For example, the lifecycle of the disposable HDPE bag (Figure 7.18) first takes into account the exploitation and refinement of oil for the synthesis of ethylene, the polymerization of ethylene by Ziegler-Natta catalysis, the production of HDPE pellets and their transport. However, these data come from the inventory database of 1999 APME (average on 24 European sites producing LDPE 3.87 Mt/year, i.e. 89.7% of Western European production). And yet in the study, we learn that the HDPE is manufactured in France, but also in Asia and Brazil. Not only the inventory data from APME related to the manufacture of HDPE date back to 5 years, but also they are not more representative anymore of manufacturing carried out in Brazil or Asia – they thus cannot be used to assess the environmental impacts. Similarly, the lifecycle of the HDPE bag also takes into account the production of HDPE bags. In this case, the data from inventory databases of the APME (1993 average of eight production sites in the UK). And yet, these HDPE bags are made in France. Thus, not only are these data old (over 10 years), but they also represent only part of the British situation and can never be representative of the French situation – in terms of energy consumption only. In fact, if the electricity production in France is mainly nuclear (78%) and then thermal (11%) and renewable (11%), this report is completely different in the UK, where electricity is mainly of thermal origin (75%), then nuclear (20%) and renewable (5%). As a result, environmental impacts are completely different (contribution to global warming) and cannot be used from one country to another.

### **7.5.3. On the influence of allocation rules**

The rules for allocating waste can also play a role in the results of a lifecycle assessment. Thus, if we compare two LCA on bioethanol as biofuels (a LCA conducted by ADEME in 2002 and another one conducted by EDEN in 2006), the

results are very different. In fact, the energy performance of bioethanol of wheat (returned energy/mobilized renewable energy) varies from single to double for both studies: 1.10 for EDEN and 2.05 for ADEME. These differences may be explained by the differences in the choices made for the allocation of waste from the bioethanol sector. Thus, EDEN has chosen to include, in its LCA, all the impacts generated by the waste from the bioethanol sector, thereby promoting a systematic approach, while ADEME allocates only 43% of the impacts of waste. ADEME has done for this LCA the choice of mass allocation – the bioethanol, product targeted by the sector, representing only 43% of mobilized dry matter. These two options can be chosen, but it is important to understand that the results can be radically changed because of this choice.

#### 7.5.4. On the choice of recycling

Concerning the rules of comparison on the end of life stage, the CIRAIG draws our attention on the relevance of the comparison of different ways of valorization. In fact, it is usually impossible to directly compare the environmental impacts generated by the two ways of valorization of a product. If we wish to process 1 ton of waste paper, we cannot directly compare *recycling* – that will produce  $X$  t ( $X < 1$ ) of recycled paper – and *thermal valorization* – which will produce a  $Y$  MJ quantity of electricity. In fact, in the first case, we will always need a power generation and in the second case, we will still need paper – these two systems do not render the same service. It is therefore necessary to complete this comparison by adding to each system the process avoided depending on the chosen option (see Figure 7.26).

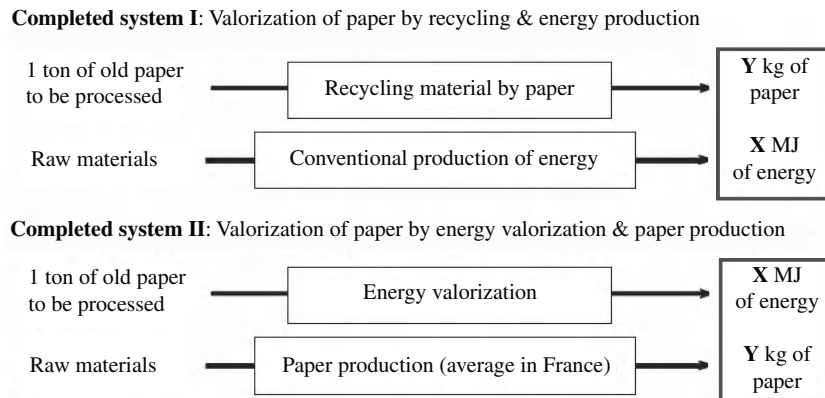


Figure 7.26. Comparison of two completed systems

Therefore, in the first case (paper recycling), we must also take into account in the impact assessment, the production of  $Y$  MJ of electricity depending on local

conditions of conventional electricity generation. And in the second case (the thermal valorization), we must also consider the conventional production of X t of paper from wood in the impact assessment. We can from now on compare strictly two systems that have the same products: X t of paper and Y MJ of electricity.

The LCA is a particularly interesting tool as it enables a multicriteria analysis, on the entire lifecycle, without limiting ourselves to a single stage (end of life, etc.) or a single impact (carbon balance, etc.). This tool is standardized through the ISO standards describing it and guarantees an expert review before publication. And the same impact, estimated at each stage, can be “added” to give a clear idea and help decision-making. However, this tool has certain limitations that particularly lie in the careful selection of the hypothesis definition, limits, and functional unit. Similarly, the followed allocation rules or the considered end of life may significantly alter the results. But the most restrictive limitations of this tool are qualitative and methodological. In fact, the impacts calculated are only potential impacts and do not reflect the local reality. In addition, this tool is not dynamic. Thus, inventory data, even when they come from measurements made on site, are only valid for a limited time and are rarely updated. As for the quality of the data, it is unreliable. When the inventory data are derived from databases (EU averages or others), they are not necessarily representative of local realities and are also limited by a low frequency of updating. In all cases, the results obtained are rarely updated. More importantly, the LCA does not enable taking into account the margin of technological progresses that it compares. Indeed, if we compare a very well-established and highly optimized technology with a new technology, it may be necessary to conclude that the first older, technology, causes less environmental impacts without realizing that the new technology has more room for progress. And we can thus decide not to develop this new technology even though it would cause less impact after a few optimizations. LCA eases everything, and does not include time as dimensional variable.

## **7.6. Conclusion: the future of eco-design**

Design processes in industry and in particular in chemical industries are now changing. They must now respond to a holistic challenge of reduction in environmental impacts at each stage of the manufacturing process. They must integrate eco-design of the product or process. In this approach, lifecycle assessment – LCA – is a crucial tool to support environmental assessment. And in doing so, the lifecycle assessment, by identifying the progress margin in terms of environmental impacts, of energy and resource consumption, becomes a strategic tool for innovation. This tool makes it possible to guide the efforts of research and development, thereby leading to the identification of innovative solutions to reduce environmental impacts, to lead to new products, which are “greener”, eco-designed, and responding to the more and more pressing demands of the market and regulations.

However, the process of lifecycle assessment is performed *a posteriori* on an existing product or process and helps us to analyze the environmental impacts of this product or process. The results of this LCA thus put the emphasis on the stages that have the greatest impact on the environment. We will have to work on these stages to reduce the environmental impact but only during a phase of product improvement or during the design phase of the “second generation” of this product. In the first approach, the lifecycle assessment only enables us to compare the environmental impact of two products to find the best compromise. And this tool has both qualitative and methodological limitations. Thus, the definition of the hypotheses, limits, functional unit, and followed allocation rules or of the considered end of life may significantly alter the results.

But the most restrictive limitations of this tool are qualitative and methodological. Qualitative, because the relevance of the data is essential when assessing impacts and because these data are not always relevant or updated in the databases, they are not always representative of the local reality. Methodological, as this tool only enables a comparison in time, an assessment of the relative impacts and does not take into account the margin of technological progress that it compares. Thus, we wish for this lifecycle assessment tool to evolve, remedy these limitations and to better assess impacts associated with the toxicity and pollution. In addition, to meet the new constraints in the innovation processes, to be upstream of the project phases, to support the design of the products and processes in the chemical industry, and to take into account the new regulatory aspects, we need new tools giving guidelines to be followed to guide the choices of researchers and chemists. It becomes more and more important to assist the innovation process with a tool that helps piloting, *gate to gate*, instead of concluding it from a comprehensive analysis *a posteriori*. And it is essential to extend this environmental design to all projects in the chemical industry to make eco-design emerge in this sector. For this, product and process designers in the chemical industry are in need of a suitable tool, easy to use and not just made for environmental balance experts, a tool that can guide them from the choice of access routes on final environmental impact. And industrialists must also expand the collection of inventory data and share these inventory data to contribute to update the database inventory, which is a real “Achilles heel” of LCA. In addition, it is crucial to link the inventory databases to those of the classification of dangerous substances. How can we imagine nowadays the identification of a chemical access way without anticipating the constraints imposed by regulations and in particular the REACH regulation? It is also important to be able to generalize the use of such a tool for smaller companies to increase their competitiveness. It is thus necessary to provide them with a tool usable at all stages of the project early in the stages of innovation, includes guiding the choices of R&D. Existing tools do not necessarily respond to this objective, particularly for SMEs in the chemical industry, which are looking for a simplified reference frame to enable them to integrate the concept of sustainable development in the design of their products. Thus, if quality management began in 1992 for major groups, these actions have only started about 2004–2006 for smaller structures. Nowadays, in the industrial sector, only a quarter

of the companies provided for the end of life of its products, and there are eco-design practices among 40% of them. Finally, it is essential for companies to take over the involvement in research and education and to help to mobilize the public research teams in this area.

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## Chapter 8

# Methods for Design and Evaluation of Sustainable Processes and Industrial Systems

### 8.1. Introduction

#### 8.1.1. *Concept of sustainable development in process engineering*

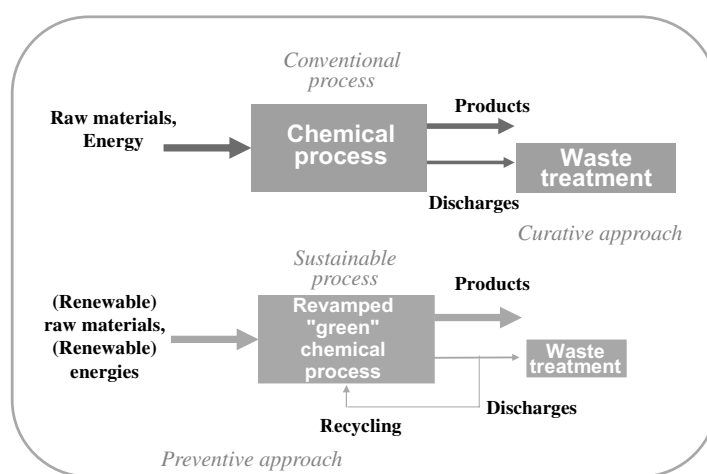
The concept of sustainable development is based on the creation of goods and services using processes and non-polluting systems, which preserve the energy resources and raw materials while being economically viable. The social demands relate not only to the continuity of employment but also ensure complete safety of a process for operators, consumers, and the public. The need and desire for continuous innovation, which characterize the industries of material and energy processing, must therefore be applied to the search for a new industrial socio-economics. The “eco-efficiency” period, which aims at promoting a more “efficient” use of raw materials and energy in order to simultaneously reduce the economic costs and the environmental impact of production must be followed by an era of “eco-design”, where environmental parameters are taken into consideration right from the design of the product and process. “Eco-design” thus appears to be the operational contribution of sustainable development.

In this context, process engineering must play an important role for two main reasons: (i) the production induced by this type of industry, which contributes significantly to the national income, is essential for the modern society: the development of the society depends on the chemical industry and vice versa; (ii) many environmental issues are either directly related to such processes or to the

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use of chemical products through impacts on water, air, and soil. The chemical industry develops products for multiple consumer markets, which have to be manufactured, used, and recycled by specific, safe, and economically viable processes. It is therefore necessary to improve the existing processes and to invent new ones that avoid waste production at the source rather than collecting and processing the produced waste, thus going from a curative approach to a preventive approach (see Figure 8.1).



**Figure 8.1.** Curative approach versus preventive approach in process design

This vision, which takes into account the product–process lifecycle and expands the scope of investigation, involves a systemic approach (see Figure 8.2). It is part of the concerns of the “roadmaps” published in the last 10 years. These concerns are stated through the 12 principles of green chemistry [ANA 98], 12 principles of green engineering [ANA 03], challenges for engineering outlined by the American National Academy of Engineering [NAE 08], or the roadmap of the *IChemE 21<sup>st</sup> Century Chemical Engineering (IChemE roadmap, UK, 2007)* [ICH 07].

### 8.1.2. Indicators, indices, and metrics of sustainable development in process engineering

The main objective of this chapter is to present the methods and tools to assess the performance of processes towards the criteria of sustainable development that could be applied in the preliminary stages of their design. The economy, society, and the environment are the three pillars of sustainable development. They are interdependent.



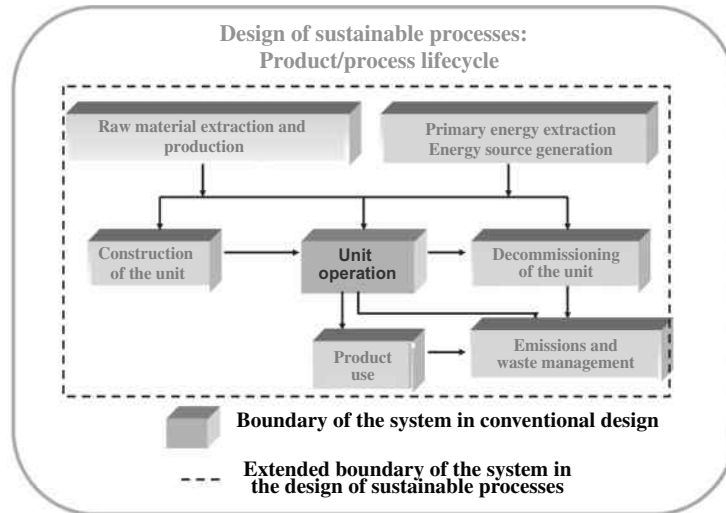


Figure 8.2. System approach and boundary of the system in conventional design process

The first classification of criteria proposed in [AZA 04] is illustrated in Figure 8.3. Let us note that several sustainable development criteria are often considered routinely in conventional design, especially the microeconomic criteria (e.g. costs and profits), and some environmental (e.g. energy consumption and water), or social criteria (e.g. employee health and safety).

Economic criteria	Environmental criteria	Social criteria
Capital cost	Use of energy	Number of employees
Operating costs	Use of water	Health and safety of personnel
Profitability	Water discharges	Health and safety of customers
Decommissioning costs	Solid waste	Nuisance (odor, noise, visual impact and transportation)
Added value	Biotic resource depletion	Social acceptance
Taxes, including "green taxes" (e.g. carbon tax?)	Global warming	
Investments (e.g. prevention of pollution, health, safety, decommissioning)	Ozone layer depletion	
Potential costs of environmental liability	Acidification	
	Summer fog	
	Eutrophication	
	Human toxicity	
	Ecotoxicity	

Figure 8.3. Classification of sustainable development criteria in process design according to [AZA 04]

It is generally accepted that sustainability results from a balance between the three components. The selection of an appropriate set of indicators for assessing sustainability is essential for a comparative analysis between the different versions of a process. In order to provide a method applicable for the analysis of systems with respect to the sustainability aspect, a typology of indicators is proposed in [SID 03a], classifying the three dimensions of sustainable development into three distinct hierarchical groups: (i) 1D indicators providing information on a single dimension: economic, ecological, or social; (ii) 2D indicators simultaneously providing information on two dimension: socio-ecological, socio-economical, or economic-ecological components; and (iii) 3D indicators leading to information on the three dimensions.

For the sake of illustration, let us consider the amount of non-renewable energy used to produce a unit quantity of final product, a criterion taken into account in the metrics proposed by the AIChE [BEA 02]. This criterion does not only provide information on a single branch coming under the economic, environmental, or societal aspect. These three dimensions are implicitly integrated. This is a 3D indicator. If we know the manufacturing cost, this indicator provides information on both the economic and social aspects and is called a 2D indicator.

The goal is not to exhaustively identify all the metrics proposed and applicable to the chemical industry processes, but rather to put the emphasis on the most important ones in relation to a decision-making objective.

It is useful to distinguish beforehand among the indicator, index, and metrics. An indicator is a tool for simplification, quantification, and communication of information; it is the first level of basic data analysis. Ideally, according to the classification by [SID 03b], an indicator of sustainable development should satisfy the three components simultaneously. However, the construction and selection of such indicators are not direct and have hence been the subject of numerous studies (see for example [SEG 02]). A good indicator must meet several requirements related to the technical soundness, the relevance towards the stakeholders, the cost towards data collection, reliability, spatial and temporal boundaries, ease of interpretation, access to a comparison standard, and the ability to show trends in the evolution over time. However, a reliable indicator can be difficult to interpret, thus failing in its function of communication. In most cases, the indicator assessment involves either a standardization or a comparison with a predefined value, to facilitate its interpretation (e.g. the percentage of renewable energy used with respect to the national average). An indicator is therefore an observable variable, which is used to characterize the complexity of a phenomenon. The term index refers to a synthetic indicator built by aggregating other basic indicators.

The other way to characterize the different aspects of a complex phenomenon is to use a set of indicators within a metric. The utility of a metric is necessarily related to

the number of indicators: an insufficient number is likely to misrepresent the phenomenon and a large number may make the implementation cost prohibitive.

The advantage of a single index instead of a collection of indicators thus lies in the ease of communication (e.g. ecological footprint). However, we can also notice many drawbacks: loss of details and accuracy due to the combination of parameters with different orders of magnitudes and levels of accuracy, and usage of conversion ratios to express all the variables with the same units.

This chapter exclusively considers the currently available approaches to assess the sustainability of processes and new or existing systems. It lists the most significant examples of indicators, indices, or metrics used in process industries. Economic indicators, widely used in the traditional process design methods will not be presented in detail. Readers can refer to reference books in this field (e.g. [CHA 01]). The design methods based on these indicators will complement this chapter.

## 8.2. AIChE and IChemE metrics

In order to analyze the sustainability of a process, we should first mention the two metrics developed by the AIChE (1D) and IChemE (3D), which consider indicators that are particularly adapted to the process domain and to a production system. The works conducted in Canada (*Canada's National Round Table on the Environment and the Economy*) [NRT 99] can be mentioned first. These works recommend eco-efficiency measurements, which are defined by ratios, with resource uses or environmental impacts as numerators and value creation as denominators or vice versa.

### 8.2.1. AIChE metrics

Following these principles, the eco-efficiency metrics have been refined to be applied on the operational level by the *American Institute of Chemical Engineers* (AIChE, [www.aiche.org/cwrt/projects/sustain.htm](http://www.aiche.org/cwrt/projects/sustain.htm)) in collaboration with a not-for-profit organization, *BRIDGES to Sustainability Institute* (formerly known as *BRIDGES to Sustainability*).

The metrics proposed in terms of eco-efficiency (a basic version is presented in Table 8.1), comprises the six following aspects:

- material consumption: the usage of materials, notably non-renewable materials, and materials with finite resources, affects the availability of resources and leads to environmental degradation during raw material extraction and during conversion as discharges;

– energy consumption: apart from the aspects related to its availability and use as a resource, the use of energy leads to varied environmental impacts. For example, the combustion of fossil fuels has an impact on global warming, oxidation of photochemical ozone, and acidification;

– water consumption: fresh water is essential for life and almost for all economic activities. As there is an increase in anthropogenic demands and a depletion of water resources in some regions of the world, water consumption is a key factor;

– emission of polluting products;

– solid waste;

– land use: the soil is considered to be a finite resource, which provides varied ecological and socio-economic services. However, the definition of an indicator seems to be complicated and does not appear explicitly in the basic metrics.

Denominator = Mass of products or Sales or Added value	Material intensity	$\frac{\text{Mass of raw materials} - \text{mass of products}}{\text{Denominator}}$
	Energy intensity	$\frac{\text{Net amount of energy (in primary energy equivalent)}}{\text{Denominator}}$
	Water intensity	$\frac{\text{Volume of fresh water used}}{\text{Denominator}}$
	Effluents (gases, liquids)	$\frac{\text{Total mass of effluents}}{\text{Denominator}}$
	Solid waste	$\frac{\text{Total mass of solid waste}}{\text{Denominator}}$
	Polluting effects	<i>Global Warming</i> <i>Depletion of the ozone layer</i> <i>Photochemical pollution</i> <i>Air acidification</i> <i>Eutrophication potential</i>

**Table 8.1.** Basic metrics of the AIChE [BEA 02]

The choice of ratios to express the metrics facilitates on the one hand the comparison between several options and, on the other hand, the choice of the process during the decision-making phase. As the indicator decreases, the generated impact decreases per unit of value created.

Heuristics and decision rules have been developed and tested on industrial pilots involving more than 50 processes of the chemical industry from the data of the *Process Economic Program* (PEP) of the SRI International (Menlo Park, California) [BEA 02]. The indicator values have been calculated for standard flowsheets. Some examples are presented in Table 8.2.

Product	Process	Material intensity /lb prod. (lb/lb)	Energy /lb prod (10 <sup>3</sup> BTU/lb)	Water /lb prod. (gal/lb)	Toxic effluents targeted /lb prod. (lb/lb)	Pollutants + CO <sub>2</sub> /lb prod. (lb/lb)	Pollutants + CO <sub>2</sub> /lb prod. (lb/lb)
Acetic acid	Carbonylation of methanol	0.062	1.82	1.24	0	0	0.133
Acrylic acid	Ammoxidation of propylene	0.493	5.21	3.37	0.015	0.008	0.966
Maleic anhydride	Partial oxidation of n-butane	0.565	0.77	1.66	0	0	2.77
Sulfuric acid	From sulfur dioxide: pyrometallurgy	0.002	0.073	0.57	-0.65	-0.63	-0.04
Sulfuric acid	From sulfur	0.001	-0.87	0.7	0.002	0.002	0.002

*Negative values used for the components indicate that the discharges from other processes are used as raw materials.*

*Water and air are not used in calculating the use of the material.*

*Negative values used for energy indicate that the process produces energy.*

**Table 8.2.** Application of the AIChE metrics for a few key processes in the chemical industry [ALL 07]

### 8.2.2. IChemE metrics

Significant efforts to establish the sustainable development metrics have also been made by IChemE (UK) [ICH 03] by adding the economic and social metrics to the metrics focused on environmental aspects. The indicators are specifically grouped into environmental, economical, and social categories. The list is

particularly suitable for a production site. The environmental indicators are related to resources or to categories of environmental impacts.

Metrics involves two types of quantitative indicators, i.e. the environmental burdens and impacts. The first group includes the use of material and energy, emissions in air and water, and the amount of solid waste. It is obtained from the flowsheet and material and energy balances. The information obtained from the burdens can then be used to calculate environmental impacts.

As mentioned above, most of the indicators of the metrics are calculated as ratios to provide an impact measurement regardless of the scale of the operation. They are based on a simple rule: the process gets more efficient as the indicator decreases.

They involve both the process inputs (use of resources) and outputs (emissions, effluents, discharges, products, and services). They involve a subset of the impact factors used in environmental science, which are the most significant towards process industries, for the calculation of environmental burdens.

The environmental burden (EB), caused by the emission of a range of substances, is calculated by adding the weighted emissions of each substance. The potential factor of the impact is identified as the impact factor of each substance. Let us note that a substance may contribute differently to different environmental burdens and have different impact factors:

$$FE_i = \sum M_N FP_{i,N} \quad [8.1]$$

where  $FE_i$  denotes the environmental burden  $i$ ,  $M_N$  is the mass of the emitted substance  $N$ , and  $FP_{i,N}$  is the impact potential factor of the substance  $N$  related to the environmental burden  $i$ .

Environmental burdens are determined with respect to a reference substance (e.g.  $SO_2$  for atmospheric acidification).

This approach involves a total of 49 indicators. However, the life span of chemical products in various environments is not taken into account. In addition, the indicator on human health (normalized with respect to benzene) is limited to carcinogenic effects. The set of indicators is given in Table 8.3.

We present all the social and economic criteria proposed by the IChemE in Tables 8.4 and 8.5.

Environmental criteria		Emissions, effluents, and discharges	
		Water	Air
Use of Resources	Water	Ecotoxicity with respect to aquatic life (metals) ( <i>in te/y copper equivalent</i> ) Ecotoxicity with respect to aquatic life (other substances) ( <i>in te/y formaldehyde equivalent</i> ) Eutrophication ( <i>in te/y PO<sub>4</sub><sup>3-</sup> equivalent</i> ) Aquatic acidification ( <i>in te/y H<sup>+</sup> released equivalent</i> ) Aquatic oxygen demand ( <i>in te/y oxygen equivalent</i> )	Air acidification ( <i>in te/y SO<sub>2</sub> equivalent</i> ) Carcinogenic effect ( <i>in te/y Benzene equivalent</i> ) Ozone Layer Depletion ( <i>in te/y CFC-11 equivalent</i> ) Global warming ( <i>in te/y CO<sub>2</sub> equivalent</i> ) Photochemical pollution ( <i>in te/y C<sub>2</sub>H<sub>4</sub> equivalent</i> )
	Energy	Total net primary energy use = input – output ( <i>GJ/year</i> ) % Total net primary energy from renewable sources Total primary energy ( <i>kJ/kg product</i> ) Total primary energy per unit of added value ( <i>kJ/€</i> )	
	Material	Total quantity of raw materials used ( <i>per kg of product, kg/kg</i> ) Total quantity of raw materials used ( <i>per unit of added value kg/€</i> ) Fraction of raw materials recycled in the plant ( <i>kg/kg</i> ) Fraction of raw materials recycled by consumers ( <i>kg/kg</i> ) Hazardous raw materials ( <i>per kg of product, kg/kg</i> )	
	Water	Net consumption of water used ( <i>per kg of product, kg/kg</i> ) Net consumption of water used ( <i>per unit of added value, kg/€</i> )	
	Land	Land Use ( <i>m<sup>2</sup></i> ) Waste ( <i>Tons of waste</i> )	

Table 8.3. Environmental criteria recommended by the IChemE

<b>Social criteria</b>	<b>Employment situation</b>	Benefices as percentage of payroll (%) Employee turnover (%) Number of promotions/number of employees (%) Working hours lost percent of total hours worked (%) Income + benefit ratio (top 10% / bottom 10%)
	<b>Health and safety</b>	Lost time accident frequency Expenditures on illness and accident prevention/payroll expense (€/€)
	<b>Company</b>	Number of stakeholder meetings per unit of added value (/€) Indirect community benefit per unit of added value (€/€) Number of complaints per unit of added value (/€) Number of legal actions per unit of added value (/€)

**Table 8.4.** *Social criteria recommended by the IChemE*

<b>Economic criteria</b>	<b>Profit, value, tax</b>	Value added (€/year) Value added per unit of sales value (€/€) Value added per direct employee (€/year) Gross margin per direct employee (€/year) Return on average capital employed (%/year) Taxes paid, as percentage of the net profit before tax (%)
	<b>Investment</b>	Percentage of increase (decrease) in capital employed (%/year) R & D expenditures as % of sales (%) Employees with a post-A-level qualification (%) New appointments/number of direct employees (%/year) Training expenditure as percentage of payroll expenditure (%) Ratio of indirect jobs/number of direct employees Donations in percentage of net profit before tax (%)

**Table 8.5.** *Economic criteria recommended by the IChemE*



### 8.2.3. Using sustainable development metrics

Sustainable development metrics can be used at different levels in the support process for decision making:

- evaluation of technical (variety of raw materials, options of process improvements, etc.) or financial (variety of suppliers, etc.) alternatives;
- comparison of industrial units;
- identification of environmental impacts of an industrial unit.

They can also be used for communication with the stakeholders.

We note that sustainable development metrics are becoming more and more complex by both their content and methodology [TAN 06]. The example of the two previous metrics shows that the choice of appropriate indicators depends on the specificities of the concerned industrial sector or even the product types. According to [LAP 04], indicators should reflect the by-products, discharges, and emissions characterizing the process or the product, but also the necessary resources to provide a service. It is therefore difficult to provide a universal list of indicators. It seems more sound to analyze and explain the choice of indicators in a few typical situations. In this way, two industrial examples are reported in the literature:

- example of GlaxoSmithKline (GSK): the use of a sustainable development metrics within this pharmaceutical company is described by [CON 05]. In order to adapt the metrics for its own requirements, GSK has developed a specific “green” metrics, including indicators related to the atom economy, carbon efficiency (CE), and reaction mass efficiency (RME) or the solvent recovery energy. The CE indicator takes into account the efficiency and amount of carbon in the reactants, which is incorporated in the final product. CE takes into account the yield and the amount of carbon in the reactants that is incorporated into the final product. RME takes into account yield, the actual molar quantities of reactants, and atom economy. Examples of calculation are proposed in [CON 02];

- example of BASF: an eco-efficiency analysis developed within BASF is described in detail in [SAL 02] and [SCH 05]. On the basis of the lifecycle assessment method, the approach uses the metrics based on the usage of resources and calculations of environmental impacts, health, and safety. The use of a standardization and weighting method to generate an environmental performance index was illustrated through examples (notably the production of indigo or ibuprofen). The approach was extended to cover the aspects of “socio-efficiency” by including the social aspects of sustainable development [SCH 04], and by developing a software tool SEEBalance [SCH 04]. The methodology was applied initially during product and process development phases. It was then implemented

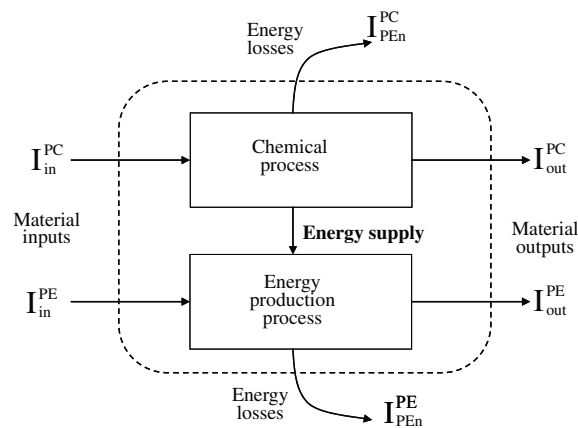
for the development of industrial and communication strategies towards industrial customers and other partners in the value chain.

Nowadays, there is still a lack of management and metric tools for sustainable development: the BRIDGESworks™ Metrics software [TAN 04] is one of them. It is clear that such tools will help to take into account sustainability criteria, especially if they are integrated into the global system of information management of the company. Hence, such an approach will encourage the lifecycle thinking throughout the product's lifecycle.

### 8.3. Potential environmental impact index (*waste reduction algorithm*)

As it is difficult to provide all the information required for calculating the indicators of a metrics, at the preliminary design stage of a process, some studies have focused on the development of an environmental balance.

The method, commonly cited in the literature and identified by the term Waste Reduction Algorithm (WAR), is based on the concept of environmental balance, which is similar to material and energy balances. This is not a lifecycle assessment tool: the approach is essentially based on the process and generation of associated utilities within the lifecycle of the product and does not include the other phases, i.e. raw material acquisition, distribution, usage, and recycling of the product (see Figure 8.4).



**Figure 8.4.** Recognition of energy in the WAR algorithm (according to [YOU 00])

This method is used in the design phase of a process and uses the process information (flow rates and mass fractions), as well as the toxicological data

to calculate the environmental impact of a process. It requires the use of a flowsheeting software tool. This American method was developed within the EPA (*Environmental Protection Agency, National Risk Management Research Laboratory*) to take into account the environmental aspect from the preliminary design phase of the process.

### 8.3.1. Theory of the potential environmental impact

The approach is based on the calculation of the potential environmental impact (PEI) of a process, which results from an environmental balance. This type of balance must be carried out during the design phase of a process, as the material and energy balances.

The result of the PEI balance is the calculation of an impact index (I) that provides a quantitative measurement of the impact of a process discharge. This methodology consists of minimizing the PEI for a process rather than minimizing the amount of waste generated by the process.

The concept of potential environmental impact of the WAR algorithm is based on the traditional mass and energy balances. The key points of the method are briefly recalled below (see the article by [CAB 99] for a complete presentation).

In steady state:

$$I_{in}^{PC} + I_{in}^{PE} - I_{out}^{PC} - I_{out}^{PE} - I_{PEn}^{PC} + I_{Gen}^{PE} = 0 \quad [8.2]$$

where  $I_{in}^{PC}$  and  $I_{out}^{PC}$  are, respectively, the input and output rates of the PEI for the chemical process;  $I_{in}^{PE}$  and  $I_{out}^{PE}$  are, respectively, the input and output rates of the PEI for the energy production process.  $I_{PEn}^{PC}$  and  $I_{PEn}^{PE}$  are respectively the PEI outputs associated with the energy losses of the chemical and energy production processes.

Young [YOU 99] considers that the fugitive emissions are negligible compared with those relative to the amounts of energy consumed and produced by the process ( $I_{PEn}^{PC}$  and  $I_{PEn}^{PE}$  are neglected). In addition, the impact of input flow rates in the energy production process  $I_{in}^{PE}$  is neglected.

Equation [8.2] is simplified to give:

$$I_{in}^{PC} - I_{out}^{PC} - I_{out}^{PE} = 0 \quad [8.3]$$

This balance can be written as:

$$I_{in}^{(t)} - I_{out}^{(t)} + I_{Gen}^{(t)} = 0 \quad [8.4]$$

$I_{in}^{(t)}$  is defined as the total potential environmental impact that lies in the material inputs of the process, including the product development and energy generation process, which is estimated exclusively by the impacts within the chemical process  $I_{in}^{PC}$ .

$I_{out}^{(t)}$  is defined as the total potential environmental impact that lies in the material outputs of the process, including the product development and energy generation process, which is estimated by the impact that comes from both the chemical process  $I_{out}^{PC}$  and the energy production unit  $I_{out}^{PE}$ .

The input potential environmental impact index  $I_{in}^{(t)}$  can be approximated as follows:

$$I_{in}^{(t)} = \sum_i^{Cat\ Approx.} \alpha_i I_{i,in}^{(t)} = \sum_i^{Cat\ Approx.} \alpha_i \sum_j^{flow\ rate} M_{j,in} \sum_k^{Comps} x_{kj} \psi_{ki}^s + \dots \quad [8.5]$$

$\alpha_i$  denotes a weighting factor assigned to the category of potential environmental impact (PEI)  $i$ ,  $I_{i,in}^{(t)}$  denotes the input PEI index for the category  $i$ ,  $M_{j,in}$  is the mass flow of product  $j$  (either input or output),  $x_{kj}$  is the mass fraction of component  $k$  in product  $j$ , and  $\psi_{ki}^s$  represents the standardized value of the environmental impact of a component for one of the identified impact categories  $i$ .

Let us note that the weighting factors  $\alpha_i$  are used to combine the impact categories into a single index and represent the relative importance attributed to an impact by the designer. Most of the studies listed in the bibliography attribute equivalent values to the weighting factors.

Similar reasoning is applied to determine an output potential environmental impact index:

$$I_{out}^{(t)} = \sum_i^{Cat\ Approx.} \alpha_i I_{i,out}^{(t)} = \sum_i^{Cat\ Approx.} \alpha_i \sum_j^{flow\ rate} M_{j,out} \sum_k^{Comps} x_{kj} \psi_{ki}^s + \dots \quad [8.6]$$

Finally, two types of environmental indices are used to assess the environmental nature of a process: an index based on time PEI/h or on production PEI/kg of a product, i.e.:

$$\hat{I}_{out}^{(t)} = \frac{I_{out}^{(t)}}{\sum_p^{products} P_p} \quad [8.7]$$

In this expression,  $\hat{I}_{out}^{(t)}$  represents the output PEI index expressed in PEI/kg of a product and  $P_p$  denotes the mass flow of current  $p$ .

A similar transformation is performed to convert the environmental impact generation index in terms of PEI/kg:

$$\hat{I}_{gen}^{(t)} = \frac{I_{gen}^{(t)}}{\sum_p^{products} P_p} \quad [8.8]$$

The objective of the WAR algorithm is to provide a means for comparing the potential environmental impact between process design alternatives: as the index becomes lower, the process becomes more environmental friendly.

### 8.3.2. Categories of environmental impacts

The toxicological data are classified into eight environmental impact categories: global warming potential, acidification potential, ozone depletion potential, photochemical oxidation or *smog*-forming potential, human toxicity potential by ingestion and inhalation, and aquatic and terrestrial toxicity potentials. A brief description of these impacts is given below and illustrated in Figure 8.5. The classification of these impact categories is based on a study by [HEI 92]. These categories have been proposed to highlight the most representative indicators in the field of process design. These indicators can be classified into two domains: global atmospheric domain and local toxicity domain (see Table 8.6).

The global warming potential (GWP) is an index that compares the contribution of greenhouse gas emissions to global warming with that of carbon dioxide (CO<sub>2</sub>), over a given period.

Carbon dioxide (CO<sub>2</sub>) being the reference index, its GWP is equal to 1. The GWP takes into account the measurement of radiative forcing capacity (amount of

infrared that a substance can absorb,  $a_i$  in  $\text{Wm}^{-2}$ ) induced by a molecule with concentration  $C_i$  in the atmosphere in ppm. This is followed by the integration of the radiative forcing capacity over a given period of time (usually 100 years):

$$GWP_i = \frac{\int_0^n a_i C_i dt}{\int_0^n a_{\text{CO}_2} C_{\text{CO}_2} dt} \quad [8.9]$$



$X$  denotes the chemical substance initiating the acidification, and the molar stoichiometric ratio  $\alpha$  represents the ratio of the number of moles of  $H^+$  per mole of  $X$ . Acidification is usually expressed in terms of mass ( $\eta_i$ , mole  $H^+$ /kg):

$$\eta_i = \frac{\alpha_i}{M_i} \quad [8.11]$$

where  $M_i$  denotes the molecular weight of  $X$  (kg  $i$ /mole  $i$ ). As mentioned before, a reference compound  $\text{SO}_2$  is used to express the acidification potential:

$$AP_i = \frac{\eta_i}{\eta_{\text{SO}_2}} \quad [8.12]$$

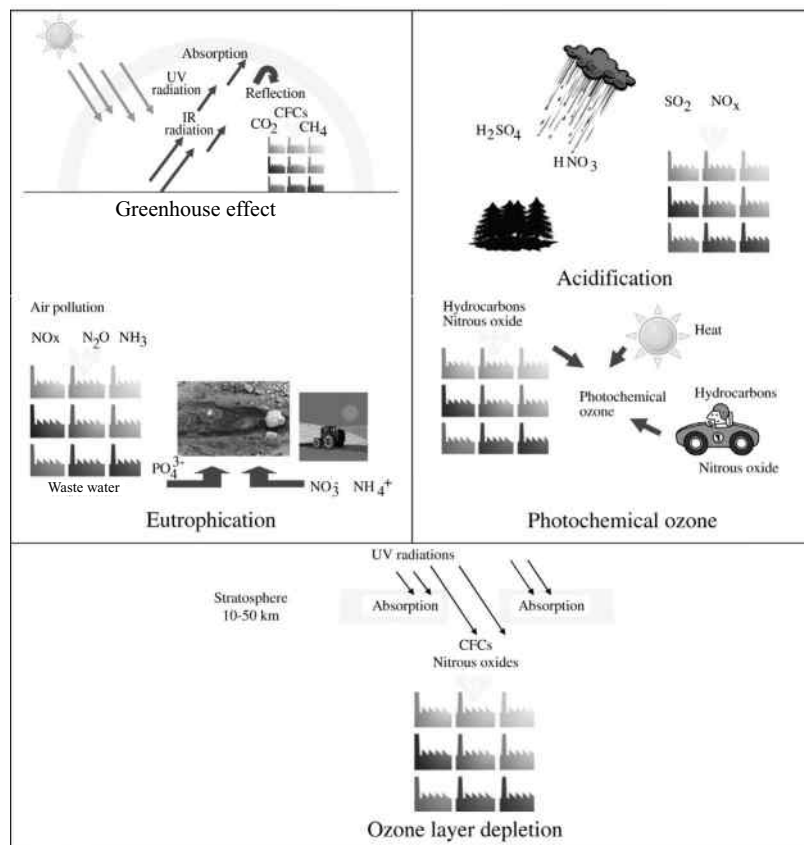
The acidification potential (AP) of a compound is related to the number of moles of  $H^+$  created by the number of moles of compound according to the reaction.

Local toxicological		Global atmospheric impact	Regional atmospheric impact
Impact on man	Ecological		
<ul style="list-style-type: none"> <li>– Human toxicity potential by ingestion (HTPI)</li> <li>– Human toxicity potential by inhalation or dermal exposure (HTPE)</li> </ul>	<ul style="list-style-type: none"> <li>– Aquatic toxicity potential (ATP)</li> <li>– Terrestrial toxicity potential (TTP)</li> </ul>	<ul style="list-style-type: none"> <li>– Global warming potential (GWP)</li> <li>– Ozone depletion potential (ODP)</li> </ul>	<ul style="list-style-type: none"> <li>– Acidification potential (AP)</li> <li>– Photochemical oxidation potential or “smog”-forming potential (PCOP)</li> </ul>

**Table 8.6.** Environmental impact categories used in the WAR algorithm

Ozone depletion potential (ODP) in the stratosphere is based on the calculation of the variation in time and space of  $O_3$  concentration ( $\delta [O_3]$ ) due to the emission of a specific gas with respect to the same amount for a reference compound, trichlorofluoromethane (CFC-11,  $CCl_3F$ ).

The photochemical oxidation potential or smog-forming potential (*Photochemical Oxidation Potential*, PCOP) quantifies the contribution to the smog phenomenon (photochemical oxidation of certain gases, which produces ozone). It is expressed in equivalent ethylene,  $C_2H_4$ .



**Figure 8.5.** Schematization of the principal environmental impacts

These four indicators (GWP, AP, ODP, and PCOP) depend on the global or regional atmospheric domain.

The Human Toxicity Potential by Ingestion (HTPI), Human Toxicity Potential by either inhalation or dermal Exposure (HTPE), Aquatic Toxicity Potential (ATP), and Terrestrial Toxicity Potential (TTP) are related to the local toxicological domain. As a first approximation, the lethal dose 50 (LD50) or LC50 (lethal concentration 50) is used to estimate HTPI. This indicator measures the dose of substance causing the death of 50% of a given animal population (often mice or rats) under specific experimental conditions. ATP is estimated from the study of the effects on the “fathead minnow” (*Pimephales promelas*). Data are expressed in the form of a concentration causing death (LC50) for 50% of the organisms exposed to a substance for a given limited duration.

### **8.3.3. Application of the WAR algorithm**

The WAR algorithm has been used on many processes and the application process is well illustrated in process test cases (we can refer to the works of [HIL 96] and [DIW 02] on penicillin or benzene by toluene hydrodealkylation production processes).

### **8.4. SPI (Sustainable Process Index)**

Another approach to analyze the sustainability of a process is based on the calculation of an aggregate indicator proposed by Krotscheck and Narodoslowsky [KRO 95], the SPI (Sustainable Process Index), an expression of the ecological footprint concept for a process that measures the total environmental impact of various human activities. The SPI calculation is based on the mass and energy balances of the process. It is independent of the legal standards that can vary over time, making it particularly attractive. The aim of the SPI is to compare the mass and energy flows generated by human activities to natural material flows, on a global and local scale. In this approach, the planet is seen as a thermodynamically “open” system, i.e. open to the flow of solar radiations toward its surface and which emits energy in the universe. Solar radiations are the only natural driving forces for all the environmental processes and those resulting from human activities. They constitute a limited flow, although available indefinitely, which is received by the planet’s surface. This means that all natural processes or those induced by human activities require some part of this limited flow and a certain surface: in other words, technological processes compete with each other and with the natural processes for this surface, which is a limited resource. Human activities impact the environment in several ways: any process considered in a “cradle-to-grave” analysis requires raw materials, energy, facilities, staff, and rejects waste or emissions into the environment. The total area to integrate a specific process in the ecosphere in a sustainable manner is then given by:



$$A_{tot} = A_{MP} + A_E + A_I + A_S + A_D \text{ [m}^2\text{]} \quad [8.13]$$

where  $A_{MP}$  represents the area for the extraction of raw materials,  $A_E$  denotes the area relative to the energy resource,  $A_I$  denotes the area relative to facilities,  $A_S$  denotes the area relative to staff, and  $A_D$  denotes the area to discharge all waste and emissions.

Processes produce services or goods. The impact per unit of good or service is represented by a specific area  $a_{tot}$ :

$$a_{tot} = \frac{A_{tot}}{N_p} \quad [8.14]$$

where  $N_p$  represents the number of goods or services produced by the process, such as the amount of kilowatt per hour produced by a specific energy system. The reference period is generally one year. Finally, we can link this specific area, for the production of a certain good or service, to the statistically available area per person to provide goods or services in a sustainable manner. The following ratio defines SPI as:

$$SPI = \frac{a_{tot}}{a_{in}} \quad [8.15]$$

where  $a_{in}$  is the available surface relative to the annual supply of goods and energy per person. It is usually estimated by dividing the total area of a region by the annual number of its inhabitants. Actually, the SPI indicates how much of the area, which is theoretically available per person to ensure their livelihood under sustainable conditions, is used for the production or the service in question: as the SPI (or  $a_{tot}$ ) gets lower, the impact on the ecosphere to provide the good's or service also becomes lower. A key point of the SPI assessment is the ability to specify and compare the different impacts of a technology. The detailed description of the SPI calculation and application would go beyond the scope of this chapter. Readers may refer to the articles by [NAR 95] and [KRO 96], which illustrate this approach. The authors propose correlations to determine the different areas [NAR 06]. An interesting case study of this indicator is proposed by [STE 99a,b] for the case of a bioprocess (penicillin production).

In order to provide a more comprehensive analysis of the interaction of environmental burdens and financial costs, an environmental performance strategic map has been proposed, based on the combination of different footprints [DEB 09]: carbon footprint [HUI 08, WIE 07], water footprint [HOE 02], energy footprint (renewable, non-renewable) [STO 03], and footprint due to emissions (air, water, and soil) [SAN 07].

### 8.5. Exergy as a thermodynamic base for a sustainable development metrics

Another way to define a sustainable development indicator is to use exergy. A presentation of all the concepts is proposed in two parts in [GON 01a, GON 01b]. The use of exergy [DEW 08] makes it possible to quantify, on the whole, the resources consumed and the emissions into the environment, to the extent that it is a physical magnitude that can integrate mass and energy transfers.

Exergy analysis is based on the combination of the first (energy conservation) and second principle (development of entropy, consideration of irreversibilities, and energy degradation) of thermodynamics [AHE 80, BEJ 96]. Due to the generation of entropy, the energy available in the outgoing products (exergy of outgoing products) is lower than the one available in the resources. This deterioration in quality is quantifiable by exergy destruction and is involved in physico-chemical processes, either in the natural ecosystem (biomass production, for example) or in the industrial ecosystem (production, consumption, etc.).

The first applications of exergy analysis in the 1980s mostly focused on the analysis of industrial systems. The research in this area includes both methodological developments and applications to specific industrial processes and to their supply chain. Let us note that many studies have been conducted on the combination of exergy analysis and “pinch” methods (e.g. [SOR 99, FEN 97]).

Cumulative exergy consumption (CExC) extends the exergy analysis beyond the simple process to consider all the processes from natural resource extraction up to the final product. Here again, the major interest of this overall analysis is to provide guidelines for the improvement of one of the involved processes and to compare several approaches [MOR 91].

Decision support systems and techniques based on the combination of exergy and economic analysis concepts have also been developed, thereby leading to an exergy cost.

Exergy analysis was applied to various energy conversion and chemical processes, particularly comparing different energy sectors [DEW 05, DEW 06]. It is particularly interesting for cogeneration systems, ([GOM 09, KAN 09] for example).

### 8.6. Indicators resulting from a lifecycle assessment

Life Cycle Assessment (LCA) is an environmental management tool that enables us to identify and quantify the environmental impacts of a product, process, or activity from the “cradle to the grave”, i.e. from the extraction of raw materials up to its end of life processing (waste discharge, incineration, recycling, etc.).

Its methodology will not be presented here in detail, since it is the subject of a specific chapter of this book (see Chapter 7). An excellent summary of the use of LCA and its prospects is proposed in [GUI 10].

### 8.6.1. *Main methods of impact categories*

There are different methods to translate the inventory results into environmental impact indicators at different levels. These are generally classified into two broad categories based on their position on the continuum of the cause and effect chain (some examples are shown in Figure 8.6), the “mid-point” methods on the one hand, and the “end-point” methods on the other hand:

- “mid-point” methods, the most recognized and currently used methods, are used to characterize the inventory flows into potential impact indicators (or mid-point indicators), of about a dozen in number. They model the impact relatively closer to the environmental flow and hence consider only part of the environmental mechanism. Their advantage is to reduce uncertainty. Mid-point methods include: the CML 2001 baseline method of the Leiden University in the Netherlands [HEI 92] which has a broad consensus, or the EDIP 97 or 2003 method [HAU 98]. This method, particularly used in Scandinavia, models the impacts corresponding to higher-order effects. It enables a better communication but is more uncertain because of the many hypotheses that it involves. The impact categories commonly considered in mid-point methods generally involve global warming, ozone layer depletion, tropospheric ozone formation, acidification, eutrophication, toxicity, ecotoxicity, resource depletion, and land use;

- “end-point” methods model the impacts relatively far in the environmental mechanism, i.e. which act directly as damages to human health, ecosystems, and resources. These indicators are more relevant in terms of communication and are therefore more simple to use, but their modeling is more uncertain due to the complexity of the mechanism and difficulties to completely model it. Typical methods are the EPS [STE 00] and Eco-Indicator 99 [GOE 01] methods. The damage types concern human health, biotic and abiotic natural environment and resources, and the human environment;

- mid-point and end-point methods: some methods model the impacts both in terms of mid-point and end-point (Impact 2002 + method [JOL 02]).

### 8.6.2. *Choice of the method of impact categories*

The advantages and disadvantages of the methods of impact categories and indicators have been extensively presented [AZA 06]. Some users prefer mid-point indicators because they describe the impacts in the cause and effect mechanism at the earliest moment and prevent the accumulation of uncertainties when modeling the indicators to the closest end point [PEN 04].

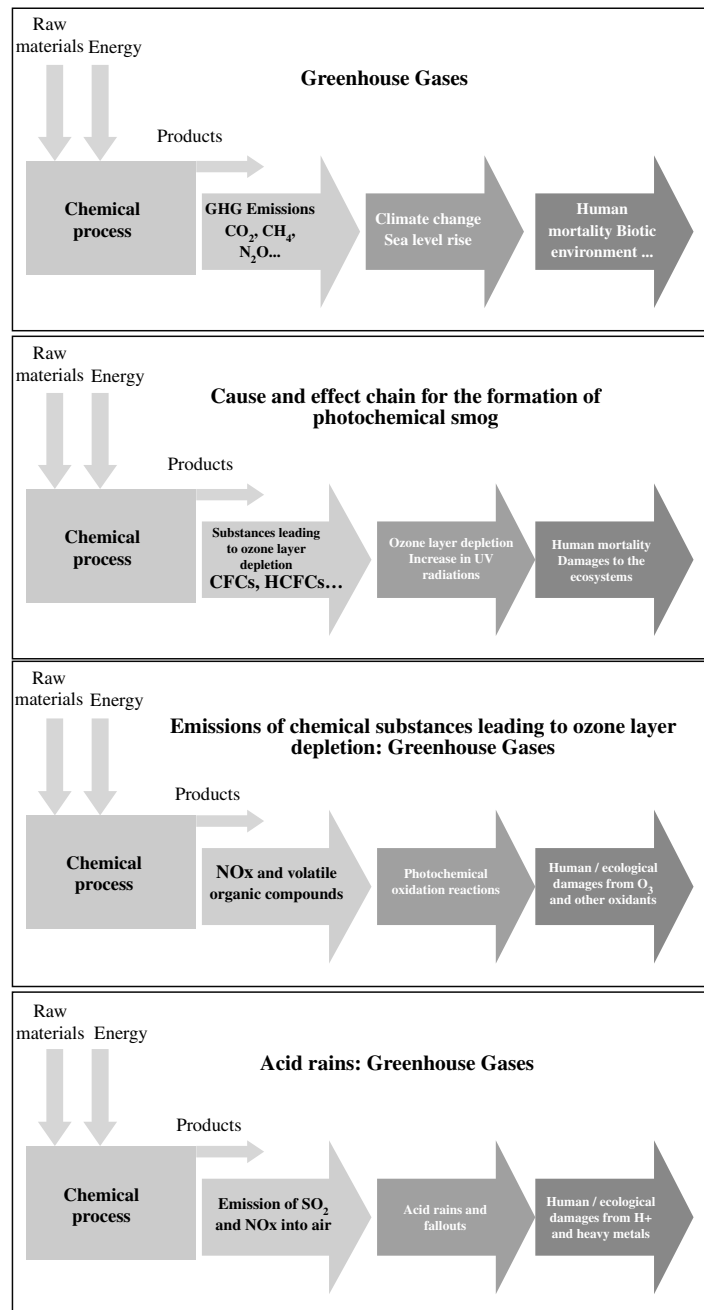


Figure 8.6. Some examples of cause and effect chains

These methods are also more transparent to the extent that they do not introduce weighting factors *a priori*. According to [AZA 06], we can also use traditional multicriteria decision support methods (Analytic Hierarchy Process (AHP) and Multi Attribute Utility Theory (MAUT), for example). Other users prefer indicators that are involved later in the cause and effect mechanism, as it makes the weighting of impact categories explicit and structured.

However, the main problem is that it assumes the weighting factors that are universally applicable in all decision-making situations. In addition, the weighted results are often difficult to interpret.

### **8.6.3. *Toward a sustainable lifecycle assessment***

In a review article on the past, present, and future of LCA [GUI 10], it is mentioned that the development of the LCA has undergone various phases, which eventually included the method as a decisional tool for environmental management, in order to design sustainable products, processes, and systems:

- past of LCA (1970–2000): there were two periods. Initially, the 1970–1990 period with two decades of method *design* with often divergent approaches, terminologies, or even results, thus showing the absence of scientific discussions and exchange platforms about this method. This was followed by a decade of *standardization* with efforts in the scientific activity and coordination of activities (works of the SETAC, definition of standardization activities (especially ISO 14040 Environmental management – lifecycle assessment – principles and framework);

- current LCA (2000–2010): this period is characterized as the decade of *development* of the methodology.

However, the LCA method, as mentioned explicitly, is interested only in the environmental component of the lifecycle assessment. The current challenge is clearly the extension of the methodology to other components of sustainable development (LCSA, Life Cycle Sustainable Analysis).

## **8.7. Process design methods and sustainable systems**

The above analysis shows that the recognition of sustainability criteria in the process design phase is not an easy task. In general, process simulators are used to determine the material and energy flow on a boundary related to the process. Cost models combined with these performance models are used to study the process profitability. Till now, simulation and modeling tools had been used mainly to minimize an economic criterion under environmental constraints.

In the last 15 years, a substantial number of works in the PSE (Process Systems Engineering) domain dedicated to these subjects [CAN 98] is reported in the literature. The available methods can be classified into two categories, either qualitative or quantitative methods. The qualitative methods include summary techniques based on the Douglas' hierarchical procedure model [DOU 88], the onion diagram [SMI 95], or environmental optimization ENVOP [ISA 95], which can be applied to identify the solutions for minimizing the potential discharges of a process. Quantitative methods include the pinch technology [LIN 95], mass exchange networks [ELH 97], superstructure optimization [DAN 96], or simulation. All these methods can be used to better integrate the process and/or its utility network.

The process simulator has become a standard tool for process engineers. Its main advantage is the ability to easily evaluate process changes using commercial software (Aspen Plus, CHEMCAD, gPROMS, HYSYS, PRO/II, ProSim, etc.) in a rather short time period without using difficult and expensive experiments or a pilot test. Such simulators have also been used for environmental studies. The Aspen Plus simulator was coupled with an optimizer to determine the optimal superstructure, thereby reducing waste generation and energy consumption while satisfying a profitability criterion. The methodology was applied for the production of methyl chloride. The CHEMCAD simulator coupled with the WAR algorithm was used by [CAB 99] to compare the environmental impacts induced by changes in the production unit. The objective was to reduce the environmental impact by recycling in a methyl ethyl ketone unit and an ammonia unit. Another study [FUD 00] combined the Aspen Plus simulator with multiobjective methods to reduce the environmental impact and maximize profitability. The methodology was illustrated in the process of benzene production by toluene hydrodealkylation (HDA process). The HYSIS simulator was used with an optimization module to evaluate the design alternatives for a maleic anhydride process [CHE 04]. More recently, several design choices relative to a biodiesel production process have been studied by combining the Aspen Plus simulator and multicriteria decision support tools [OTH 10].

Another approach to sustainable design is adopted by [CAR 08], based on a *SustainPro* indicator to identify, screen, and evaluate the design alternatives. *SustainPro* uses the process information in the form of mass and energy balances from a simulator and applies a set of mass and energy indicators. The methodology is based on a reverse design method, where target values are assigned to the indicators and where the most sensitive variables towards indicators are identified.

A study based on the combination of a simulator coupling the process and the utilities producing unit with a multiobjective optimizer of genetic algorithm type is proposed in [AZZ 09]. A key point concerns the use of the ARIANE<sup>TM</sup> ProSim software, a simulator dedicated to the production of utilities (steam, electricity, process water), to calculate the needs in primary energy and quantify the emissions of pollutants, which come from the energy producing unit. Among the set of optimal

solutions in the Pareto sense, it is important to determine the one(s) that correspond(s) to the best choices, in order to guide decision-makers in these final tasks. A method for decision support has thus been used to establish the best compromise between the criteria (TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method [HWA 81]): the fundamental idea of this method is to choose a solution as close to the ideal solution (better on all criteria) as possible and as far from the negative-ideal solution (which degrades all the criteria) as possible. The general framework is illustrated in Figure 8.7.

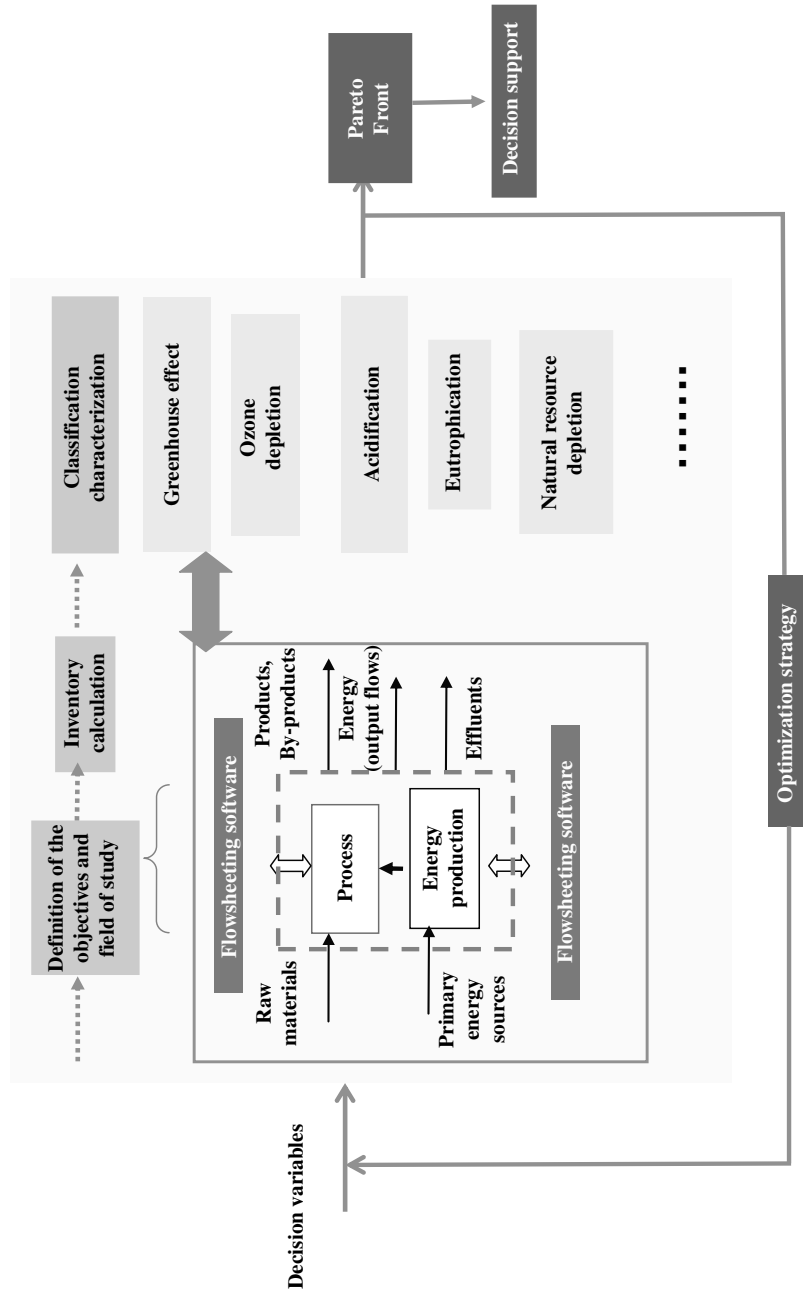
### 8.8. Conclusion

This chapter has presented a review of the various indicators and metrics recommended in the design or the evaluation phase of processes and sustainable systems. It shows a rich literature in the field and various ways of defining indicators or metrics, with different levels of sustainability assessment, for instance the use of a (AIChE, IChemE) metrics, a potential environmental impact, an SPI which can be viewed as a process sustainable footprint, an energy approach or an approach based on lifecycle assessment, etc. The design of processes and sustainable systems involves extremely varied fields or methods, and affects key products and processes.

So far, the developed works have mostly focused on the simultaneous consideration of environmental and economic aspects. The social factors are indirectly addressed through the impacts on human health, process safety, and the reduction in emissions of toxic discharges. This reflects the difficulty of quantifying social indicators and their interconnection with the operational part of the process.

In this context, it seems clear that the systemic approach of process engineering, which bases its methodology on a holistic view combining modeling, simulation, and optimization, integrating and unifying process engineering concepts, must play an important role. This will necessarily lead us to review design methods and operating procedures to make them more reliable and sustainable, but also to propose innovative methodologies integrating products, processes, and systems, following the principles of sustainable development at the preliminary stages.

The review of the literature highlights the need to couple process simulators, the tools for quantification of environmental impacts (lifecycle assessment type), and the design optimization methods, in order to achieve an overall acceptable solution. Due to the conflicting nature of the involved criteria, especially related to the presence of many uncertainties in the calculation of impacts, multiobjective optimization, as well as uncertainty analysis methods are an interesting field of investigation.



**Figure 8.7.** General framework of the study [AZZ 09] coupling process simulator – multiobjective optimization – decision support



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## Chapter 9

# Project Management Techniques: Engineering

### 9.1. Engineer and engineering

#### 9.1.1. *The engineer*

The organization and completion of a project are the business of a man or more precisely of a team managed by a leader, the engineer [DAL 06].

The engineer is a person who applies scientific principles and theories to solve the practical problems economically. Most often, his job is to establish a link between scientific discovery and the creation of products, plants, industrial artifacts, and industrial facilities.

The engineer was one of the main architects of the fantastic progress, which in two centuries, shaped the Earth's surface, changed society profoundly, and transformed our lifestyles, and gave access to space. The engineer as to our current understanding is the culmination of a long history. He makes, embodies the field of scientific knowledge from "learning" to "art" in any facility type, means of production, transportation, communication, and objects produced in series. He cannot do it alone; he has to have a *team* with the most of varied skills. He needs an organization and resources which he must use properly. The field of engineering will be considered below.

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Chapter written by Jean-Pierre DAL PONT.

France can boast of being the birthplace of the first engineering school, in the sense that it is currently understood, the Ecole des Ponts et Chaussées established in 1747 by Jean-Rodolphe Perronet (1708–1794) and Daniel Charles Trudaine (1703–1769). Perronet, a royal’s engineer, bridge builder, including that of Neuilly in Paris, systematized the use of mathematics and physics to build structures: like bridges, canals, and water facilities.



The whole world recognizes the Eiffel Tower. This tower was built in only 26 months from 1887 to 1889, to celebrate the first centenary of the French Revolution during the 1889 Exhibition and today it is the symbol of Paris. Gustave Eiffel was an outstanding organizer, a creative genius, and a leader of men who knew how to select his employees.

A graduate of Ecole Centrale, at the age of 26 he was managing the construction of Bordeaux bridge, then the Garabit viaduct and many other achievements: bridges, viaducts, civil and religious buildings, the bridge over the Douro in Porto, not forgetting the framework of the Statue of Liberty in New York. Focusing on steel and cast iron instead of stone, he was a pioneer of prefabricated structures that he built in his workshops in Levallois-Perret close to Paris. He was also a shrewd manager who negotiated a contract with the government for operating the tower that bears his name. Being a hard worker throughout his life, he can be considered as the father of aerodynamics. He built the first wind tunnel at the age of 70 and contributed to the advancement of aviation and the emerging wireless technologies. He can also be credited with the introduction of scientific meteorology. In 1917, at the age of 85, he received a patent for a fighter monoplane and at the age of 88 he published a new treaty on propellers. Eiffel embodies the engineer of the 19th Century, which is renowned as the “century of the engineer”.

**Box 9.1.** *Gustave Eiffel (1832–1923)*

One is always struck by the “creativity” of the French revolutionary period which, in the middle of the tumult, gave birth, along with other schools, to the

prestigious Ecole Polytechnique: the familiarly nicknamed “X” founded by Gaspard Monge (1746–1818). The “X” served as a model for certain US engineering schools of the era including the famous *United States Military Academy* at West Point, founded in 1802, where education was imparted in French during the early years ...

In the USA the *engineer* is both a graduate (*civil, electrical, mechanical, and chemical engineer*) as well as the one who makes the *engine* work, that is to say a simple mechanic (*locomotive engineer*).

Gustave Eiffel in France symbolizes the engineer at the end of the Industrial Revolution [CAR 02, MAR 89]. Eiffel, the immortal builder of the tower that symbolizes Paris, was the inventor of innovative techniques (see Box 9.1).

### 9.1.2. Engineering

Engineering encompasses all those activities which aim to make an investment, that is to say, to transform financial resources into a facility or a piece of equipment, be it a bridge, a factory, a dam, a plane, which are so many projects for an engineer...

Engineering work typically includes several stages. Let us recollect and define more precisely the stages that were described in Chapter 6, “The industrialization process: preliminary projects”.

Preliminary studies are aimed at determining the merits of the proposed investment and demonstrating its *industrial feasibility*. *Profitability* is a major feature of these studies. At this stage let us say that engineering work includes:

- support for collaborative design usually with the client, or research centers or architectural firms;
- preparation of diagrams, plans, and specifications that are necessary for the construction;
- preparation of tenders for pieces of equipment and services that are required to carry out the work;
- cost estimates and evaluation of the amount of investment, with a determined accuracy (e.g.  $\pm 10\%$ );
- coordination and control of the construction.

NOTE.– The client may decide to entrust the complete or partial execution to a different company from the one who made the study: and give the jobs to a company more specialized in construction work;



– start-up assistance, staff training, and operating procedures.

NOTE.– The client may keep this activity in-house in whole or in part, because it is often very closely related to his expertise.

GENERAL NOTE.– Engineering jobs in the process industries are perceived differently by commercial and engineering companies themselves. The problem lies in the boundary between the *design process* (early engineering studies for corporations) and the *design of the facility* (beginning of engineering studies for engineering companies).

## **9.2. Project organization**

### **9.2.1. Project concept**

Projects have existed ever since humans started making tools and controlling fire. Who has not marveled at the pyramids of Egypt, Notre-Dame in Paris or the Millau viaduct!

The type of projects is very diverse and the projects vary in size, and their cost may range from tens of thousands of dollars to billions of dollars, depending on the scope of the project, the technologies involved or the location of the facility.

The construction of an oil refinery, a bridge, a vaccine unit, a fine chemicals plant uses very different resources and technologies but the management techniques used are very similar in most cases.

The project has to produce a unique product, a change: it has a beginning and an end. This is a temporary activity [LEB 00a]: *a project is born, lives, and dies*.

It is an action limited in time and involves a team, the project team, which, after completion and the beginning of the project will be scattered or assigned to other activities. This team will go through times, which are sometimes exhilarating, sometimes depressing, with happy or unhappy consequences for the individuals and the company.

The Bhopal disaster in India on the night of December 2–3 in 1984 resulted in the disappearance of Union Carbide, a company over 100 years old, and has painfully affected the lives of people involved in the construction of this plant, not to mention the thousands of victims of methyl isocyanate.

A project consists of interactive tasks performed in a logical order.

To build a house, one digs foundations, and then raises walls and places the roof on top of the walls.

These tasks involve skilled workers: the mason builds the walls, followed by the roofer who places the tiles on the roof.

Tasks, as well as the procurement of raw materials, must be planned along with the means to implement them with the adequate financial resources.

Project management was conceptualized and organized in the United States, during the 1960s by the major state agencies (*Department of Defense, NASA*), who developed methods of management planning, such as PERT system used in the development of Polaris missiles.

The Apollo project, which sent man to the Moon, involved about 400,000 people.

A project is owned by the *client* who entrusts the *contractor* with its implementation. *The client, person or entity, decides on the project, and thereby incurs liability and money.*

A company can be its own contractor for projects that are under its jurisdiction provided it has the means to deal with them through its engineering and design department. In this case, it must at least have the required resources, at the time needed so that it can supervise those subcontractors to whom it is forced to subcontract parts of its project.

Chemical companies do not always have at their disposal the means necessary to carry out civil engineering, electrical engineering, and other streams of work both from a design point of view and in terms of achievement. These are not their *core competencies*.

For “big jobs”, the company mostly deals with engineering and design departments or engineering companies.

The Company’s executive committee may appoint a project manager, who reports to the committee for projects which are categorized as *corporate projects* and whose aim is to rethink, reshape, or modify its operation. This can be an IT project, which will distribute skills and require large investments in training. In this case, a member of senior management is well qualified to perform this type of activity in addition to his normal work. He will be supported by a project team.

In the case of a major capital investment such as building a new plant, the executive committee may assign a project manager to the job who will take charge of it if he considers that the success of such an undertaking is crucial for the future of company. The project manager will justify the use of resources that he has been granted for achieving the results, with the hope that the results meet expectations.

*Project-based management is increasingly becoming a leadership style. It is indispensable for this type of achievement.*

*For a contractor, managing a project means carrying out all the necessary actions to be carried out to offer the client the work he has ordered, on time, in accordance with the quality and cost determined by the contract.*

Few organizations may, like King Louis XIV, undo what after realization, does not please them and have it rebuilt anew [TIB 02]! However the SUN King can be praised for the construction of the palace of Versailles, the largest construction site of the 17th Century which involved 40,000 men for up to 53 years, and marked a breakthrough in construction and organization methods.

Innovation has played a major role, with contributions from the French Academy of Science. The Marly machine which pumped water from the Seine to feed the fountains and ponds in the park via the aqueduct of Louveciennes was one of the largest engineering feats of the 17th Century.

### **9.2.2. Organization of an engineering project – client/project manager interface**

For more information, it is useful to refer to the articles in Techniques de l'ingénieur [AUR 99, CHA 01, LEB 00a, LEB 00b, LEB 00c].

The company, after the validation stage which follows the development process stage (see Chapter 6), may decide to launch the *Process Engineering* stage. As the company does not have all the resources for performing this step, it seeks the help of another company, generally an engineering company.

This is even more necessary for the company during the *Basic Engineering* phase and *a fortiori* for the construction phase, given the diversity of jobs, the number of tasks to be performed and their volumes. *The volume is expressed in hours for which the cost will vary depending on the qualifications of the contractor's personnel/staff assigned to the job.*

Figure 9.1 shows an organization where relationships between the key players in the project are as follows:

- the representative of the client who communicates with the contractor, and sometimes the future manufacturer;
- the contractor, who appoints a project manager.

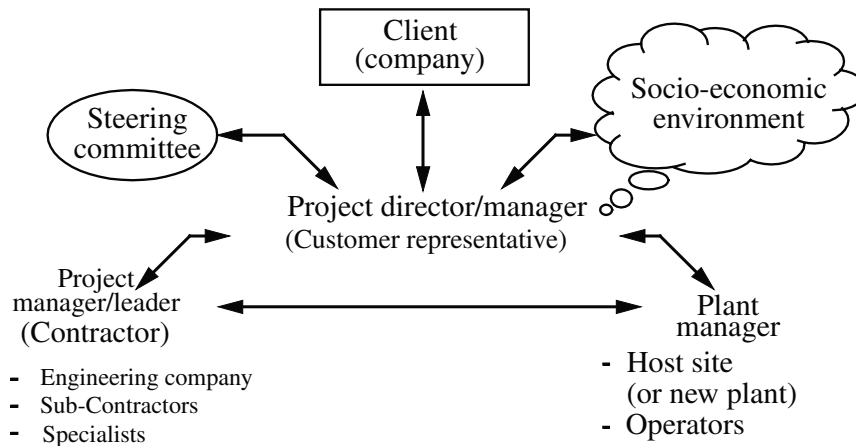
The project manager representing the contractor is responsible:

- for defining, implementing, and managing the project team (*Project Management*);

– for using Project Management techniques (*Project Control*) and all tools required to respond to the contractual terms, which include cost, schedule, and quality;

– for implementing all the corrective actions that are necessary to achieve the project objectives.

The client must establish a *steering committee* whose role is to monitor the development of the project, inform the executive committee about its progress, and act as a moderator between players when problems or crises arise whose origin may be rooted in the change of the socio-economic environment, social conflict, bankruptcies of suppliers, procurement difficulties, the tightening of regulations, an overrun of budget, delays in equipment procurement, and so on. The list is long! This will be discussed further.



**Figure 9.1.** *Simplified organization of an investment project (realization stage)*

This type of organization is valid for large projects, to be specific, between 10 and 20 million dollars, which cannot be undertaken by the company's personnel such as the person in charge of contractors, due to time constraints. Here, one finds the operational/entrepreneurial conflict described in Chapter 2.

Small projects cannot afford a structure manned by many experts, and incur the risk of generating unbearable supervision costs, *although all the functions of the small projects are the same as those of the large projects!* Assigning a project manager is an expensive operation which most often requires finding a replacement. This is also true for the plant manager. So, there is a major problem in human resource management which was highlighted in the Chapter 2 on operational/entrepreneurial conflict. Small projects therefore require a different style of

management compared with that of the major projects, and have to be led by versatile performers in the field.

### 9.3. Management tools for industrial projects

Project management tools have been developed since the 1960s. The *Project Management Institute* (PMI) has distributed these tools throughout the world. PMI was founded in 1969 and is a Philadelphia-based not for-profit organization with half a million members in 185 countries.

Paris-based *AFITEP* (French Association for Project Management) has the same objectives: it ensures the publication of the “Dictionary for Project Management”. The AFITEP is part of the *IPMA* (*International Project Management Association*).

*AFNOR* has standardized practices relating to project management.

This book does not describe *all* project management techniques; we will focus on some of them which are very important from the management point of view. This book does not aim to make the reader an expert, what is important is to know that methods exist! Any reader who wants or feels the need to deepen their knowledge may consult the specialist reference books; there are lots of them!

#### 9.3.1. WBS (*work breakdown structure*)

##### 9.3.1.1. *Concept of WBS*

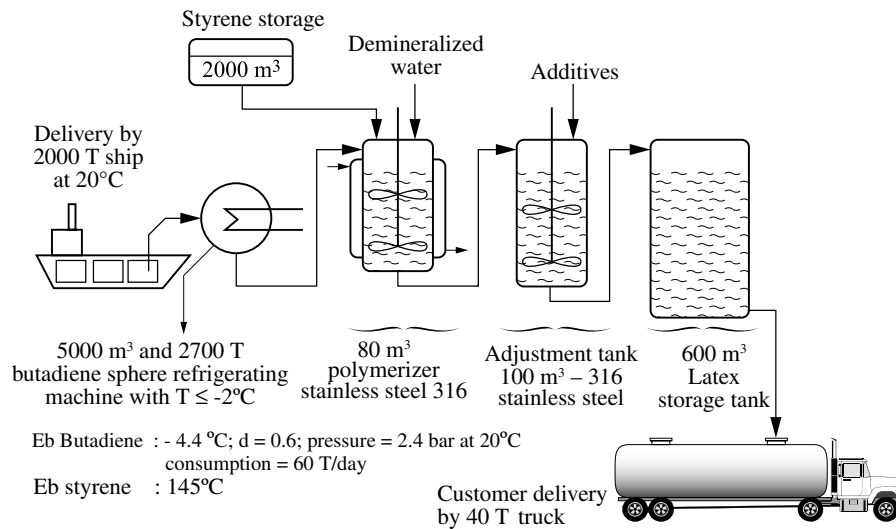
WBS divides the project into autonomous units, which are consistent and interrelated. With the help of a simplified diagram, one can quickly view the contents of the project to examine the essential characteristics, and establish the “identity card” to see where its major difficulties lie, the significant costs, the elements that require the longest time for procurement, installation, start-up, and so on. WBS makes it possible to organize the project into consistent parts to better perform studies, undertake construction work, and better control the project cost and schedule.

##### 9.3.1.2. *WBS analysis of a project of a latex plant in China*

The project considered by us involves setting up a plant in China where the technology is transferred from France. The capacity planned for the plant in China represents about three times the capacity of the French unit.

Figure 9.2 describes in a simplified manner the process involved in latex production. Latex is an emulsion of microparticles in water, obtained by the

copolymerization in a suspension of styrene and butadiene monomers in water. The latex considered is used in paper coating and the formulation of paints.



**Figure 9.2.** Simplified diagram of a latex plant

Styrene is a liquid that boils at 140°C. It can easily be stored in steel tanks. Butadiene can be assimilated as a liquefied gas and is usually stored in pressure-resistant and cooled spheres or “cigars” to prevent its polymerization.

The polymerization reactor is an agitated and cooled device and has a complex design. The agitation system of which will depend on the particle size, is a key element to ensure the value of use of the finished product. The introduction of reagents, as the mixing of reactants, is a key design factor. The tank must be perfectly polished to avoid the build up of films that could create unwanted lumps and disrupt thermal exchanges. As the polymerization reaction is exothermic, the reactor must be cooled. It is usually cooled by a jacket with cooling water. This is also part of the *design* problems.

The process is intermittent; each batch is subject to a devolatilization process to remove the traces of monomers at the end of a reaction. Each batch is provided with a number of additives which will give the finished product its commercial characteristics.

Latex, the finished product, is a non-hazardous product stored in carbon steel tanks. It is generally shipped by truck, tank cars, or containers; and it is a major consumer product.

The WBS of the plant, shown diagrammatically in Figure 9.2, highlights the following five elements and technical systems:

- storage of butadiene, unloading the ship and supply of polymerizer;
- storage of styrene and supply of polymerizer;
- polymerization reactor and its annexes;
- latex adjustment tank and addition of additives;
- latex storage tanks and shipping.

The WBS considered does not *deliberately* include the utilities system, fire protection, the administrative building, laboratory, maintenance plant, WWTU, and so on. At this stage it is judged that they are not key items in the analysis of the system because they do not present major technical difficulties or simply because the process unit considered is being integrated into an existing plant where these means are available.

The WBS analysis of the latex project in China highlights the essential characteristics of the project and the points that will require special attention:

- *safety of the system*: it mainly depends on the flammable butadiene product;
- from the *technical point of view*: the polymerizer is the biggest technical challenge because its size is very large compared with that of the existing polymerizer. One must reconsider the key functions such as agitation, heat exchange, and devolatilization. Protection of the know-how should be taken into account;
- what can one infer from WBS research? There are two essential criteria, namely system safety and design of the polymerizer, which should also be taken into account;
- *safety*: this plant should be located away from habitation by a distance that will depend on the design of the storage of butadiene, which can be aerial, buried, or semi-buried. Handling this product should be the main objective of an extensive safety study and will require training the operators;
- *polymerizer*: scaling up, by a factor of 3, creates some problems of design and construction. It is decided that the polymerizer will be manufactured in France. Transport and customs issues should be taken into account from the beginning of the project. This unit is probably on the critical path. It is therefore an essential element which will determine the deadline for the completion of the plant.

The other components of the WBS system have no specific difficulties. In China, one could easily find supplies of liquefied gas storage system of 5,000 m<sup>3</sup> or more. It is enough to investigate and find good suppliers. The tank used for additives, like other storage tanks, does not pose any problem.

### 9.3.2. Value analysis (VA) [AFN 97, DAL 03, LED 91]

#### 9.3.2.1. History of VA

Value analysis (VA) is an essential management tool, which has its place in the tool set and methods that the company must use to improve its operation and ensure its sustainability. *This is a major managerial revolution of the 20th Century!*

During World War II after the attack on Pearl Harbor on December 7 1941, Japan had virtually occupied all of Southeast Asia. Singapore, the impregnable fortress, collapsed on February 15 1942. America was cut off from many sources of raw material procurement such as rubber, copper, and tin.

Similar to other companies, *General Electric* was forced to use substitutes, and this encouraged Harry Erlich, Vice President of *General Electric* who was in charge of purchasing and transportation, to research methods to improve quality and lower costs. He placed Lawrence (Larry) D. Miles in charge to develop methods to create a *change*. Miles had a flash: he realized that a product is made to perform one or more *functions* (such as a vacuum cleaner is designed to *remove dust*, by *drawing air*).

*To create a change, it is not the parts that make up the product which must be examined, it is the function or functions that the product is supposed to ensure.* Miles developed his value analysis methodology between 1947 and 1952, and in 1956 he published *Techniques of Value Engineering Analysis*, a highly acclaimed book.

Miles created a specific department which was responsible for cost reduction. It achieved spectacular results. Reconsidering the manufacturing process sometimes led to better products and cheaper costs than before the war. He refined his method, which aimed to prioritize the functions, determine the cost and eliminate unnecessary functions.

The VA concept took hold in the American industry and in the powerful military-industrial complex during the 1960s under the leadership of Robert McNamara, US Minister of Defense at that time. The *Society of American Value Engineers* was created in 1959. The VA concept then spread slowly around the world.

VA has several names: *value analysis*, *value management*, *value engineering*, *value control*, and *value insurance*.

*Value analysis* has a broad meaning. *Value engineering* is applied to the products under development. *Value management* concerns with the company's processes and its management structures.



Value management (VM) is the subject of European standard NFEN 12,973, June 2000 (NF X50 -154). VM tends to encompass all the VA techniques.

The VA concept has been developing in *France* since the 1960s. It has a very strong base in the automotive, aerospace, weapons, household appliance, and electronics sectors. The *AFAV* (French Association for the Analysis of Value) was founded in 1978 and is headquartered in Paris. *AFNOR* has been strongly focusing on VA from the 1980s and had published the initial standards in 1985 (NF X50-150 and NF X50-153).

#### 9.3.2.2. *VA: product and service*

Although the basic principle remains the same, the definition of VA has changed, which is normal in a period of over 50 years.

A commonly accepted definition nowadays is: *VA is a method for designing new products or improving existing products to meet the need(s) of the customer(s) at minimum cost.* It is a method of innovation.

Let us eliminate ambiguity upfront: VA is seen in a different way by the supplier and the customer. The supplier of the product or service looks for the lowest procurement cost; he wants to minimize the resources used. Resources mean raw materials, energy, wages, and costs associated with the manufacture and distribution of the product. The VA perceived by the supplier can be written:

$$\text{VA (supplier)} = \frac{\text{customer satisfaction}}{\text{manufacture and distribution cost}} \quad [9.1]$$

The customer is not concerned by the production cost. He is interested in the product quality, a term which will be discussed widely, and the purchase price. The VA perceived by the customer can have the common meaning as follows:

$$\text{VA (customer)} = \frac{\text{quality}}{\text{purchase price}} \quad [9.2]$$

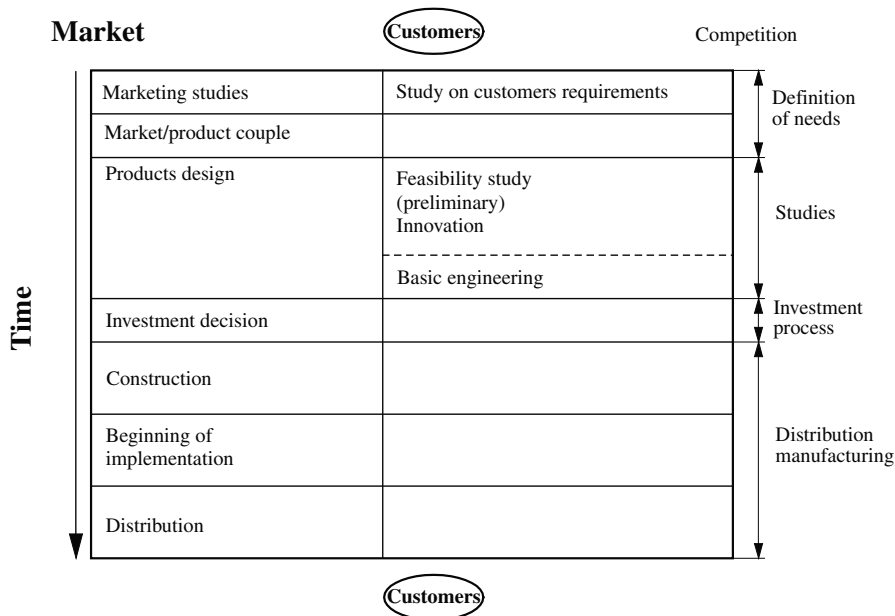
Analyzing a product, or a service according to this aspect involves asking questions like: How much profit does this offer? Is it useful? How can it be made? Can it be made? What does it cost? Can it be done at a reduced cost? Do we know how to make it?

#### 9.3.2.3. *Functional analysis (FA) is the keystone of VA*

A word function to which we will return in detail corresponds to the service(s) that this product is supposed to provide. The VA concept applies to the design of

new products, improving existing products, the analysis of administrative processes, manufacturing processes, and so on. It is an approach that formalizes the problem in terms of *purpose* and not in terms of solutions. It considers the costs associated with each function [TAS 95].

Figure 9.3 shows the generally accepted phases for the development of a product.



*Resources: human, intellectual, financial, physical tools (plants, process units and all means of production), working methods (know-how, feedback).*

**Figure 9.3.** *Developmental stages of a new product*

Table 9.1 briefly describes as a reference the steps related to an implementation of VA [BAL 02] and the players involved.

A typical process involves the decision-making person who heads the project and a multidisciplinary team which may include the product manager, sales manager, an expert in VA and line management that is to say those who make it possible to achieve the product. *VA is performed by a team!*

Group work techniques apply particularly in steps 3 and 4 of creativity and innovation.

	<b>Action</b>	<b>Resources involved</b>
Step 1	Define the project	Marketing/sales and R&D
Step 2	Functional analysis-FS* preliminary	Decision maker and VA team
Step 3	Look for alternative ideas Determination of TF** Cost analysis	Decision maker Team VA + line management
Step 4	Evaluation of ideas Definitive analysis of functional costs Establishment of definitive FS	Decision maker VA Team + line management May involve laboratory test, prototype tests, test campaigns
Step 5	Decision to invest	Person authorized by the society
Step 6	Product realization	Decision maker Operational teams (VA teams if needed)
Step 7	Product distribution Project tracking	Society officials VA team

\*FS: functional specification (see section 9.3.4)

\*\* TF: technical function

**Table 9.1.** *Developmental stages of a new product*

#### 9.3.2.4. *VA and cost management*

Two methods have been developed in the United States to control costs at the design stage of a product.

#### 9.3.2.5. *Design to cost (DTC) objective*

The DTC method [DEL 91] is a VA method which stipulates that the cost of the finished product remains below a value fixed in advance. This method was incorporated by the US Ministry of Defense into its contracts for weapons procurement in order to control the cost, in the late 1960s, under the *design to cost* policy. This policy came into existence after military projects incurred excessive costs, mostly due to the change in definition during the project (*project scope*<sup>1</sup>). In this method, the unit cost of the product (aircraft, cannon) is assimilated into its performance, like the range or shooting accuracy. The industry in which we impose a DTC must review the contents of the project, its working methods, and its ceiling price. It has more freedom in design of the finished product. Expenditure control in all phases of design and construction, is critical.

<sup>1</sup> *Project scope* has a very strong connotation. It is used in all projects to define the content. General Foch was in the habit of asking his generals: "Gentlemen, what is it?" This is a good definition of *scope*.

The *design to cost* policy leads to a radical change of old habits, where VA is a key element to its success.

#### 9.3.2.6. *Lifecycle cost (LCC)*

This method was also developed in the United States as the *Design to Lifecycle Cost (DTLCC)*. The total cost, or *Lifecycle Cost (LCC)*, is the cost of the product throughout its life: the purchase price, operating costs, maintenance costs, and possible destruction or recovery costs [DEL 91].

For a car, it will be the purchase price, fuel and oil consumption, maintenance, scrapping, insurance, and so on. Do not forget the mileage that one is entitled to expect. The LCC is an extension of the DTC.

#### 9.3.2.7. *VA in the management of the company. Value management (VM)*

Any system can be improved, everything can be done differently but it is not always easy to accept ... and to make some one accept it!

The value management (VM) concept is applied to business processes in order to improve performance, motivate people, and implement strategic plans, so that its partners and *stakeholders* are satisfied.

Value Management (VM) is part of the process that the Americans called *re-engineering*. The company asks questions about its operation and often its mission! Which are the markets that the company needs to focus, and with what products? Does it make or buy? How? This process is difficult, sometimes brutal, and always requires coaching by facilitators from outside the company.

This will be further discussed in Chapter 13, “Change Management” on techniques such as:

- *benchmarking*: that is comparing with the competition to identify strengths and weaknesses;
- PARETO type analysis (cause/effect), which makes it possible to focus the efforts on the most important points for which the gains are achieved in the shortest time;
- taking into account the *human aspects*, which cannot be eliminated.

We have emphasized that the VA concept must bring together multidisciplinary teams, where these teams are asked to participate in creating a common impulse. VA has to depend on all the team work techniques:

- *management by project*, which targets setting the scope, cost analysis, planning methods, and defining the tasks are the essential features;

– *creativity techniques*, heuristic techniques (techniques of research and invention), where the *brainstorming* techniques were invented by Alex Osborn in the United States in 1935, and are the most commonly known and most widely used;

– *communication*.

### 9.3.3. Functional analysis (FA)

#### 9.3.3.1. Concept of function

Functional analysis (FA) is based on the concept of function which the French standard NF X50-151 defines as “the action of a product or one of its constituents expressed exclusively in terms of purpose”.

A function is expressed by a verb followed by a complement. Miles recommends the use of a verb in the infinitive. A function does not advocate any solution for realization. Any product can have many uses that are unexpected, to say the least.

A hair dryer serves *to dry hair*: it does not say how! By blowing hot air? With what energy source? The electricity network? A battery? However, it is often used to dry laboratory equipment, and to heat certain products very gently. A hair dryer can be fixed, portable, and so on.

The functions of a product are described with respect to meeting the expectations and *needs* of a customer. The customer needs are generally difficult to identify. The head of a company used to say: “*A customer knows what he wants; he does not know what he needs*”. A need can be either objective or subjective. It may vary over time by having the object or using the service, for better or for worse. The test of time is a formidable test.

To cope up with this complexity, in functional analysis, a product is considered as a collection of functions and not as an assembly of parts. The classification of functions varies according to the authors. Simplicity is what will be focused on.

#### 9.3.3.2. Ranking functions

##### 9.3.3.2.1. Service functions (SF)

Service functions directly affect the user. To satisfy a need, a product must often have several SF. The main SF and secondary SF will be discussed. The SF can be broken down into functions of use (FU) and estimating functions (EF) can also be called “aesthetic” functions. The FU meet the *objective* needs, whereas the EF meet *subjective* needs.

A cabinet may be old (Louis XIV style, for example) or modern. Its FU is always to provide a storage space. It is clear that the customer attaches a completely different value to two products and is willing to pay a different price for each type of furniture.

The EF must meet the emotional part that almost always accompanies the purchase. The presentation aspect is very important, even for highly technical products. Will a piece of high fashion women's clothing serve to protect the body against external attacks, covering the body, or the contrary?

#### 9.3.3.2.2. Technical functions (TF)

Technical functions or internal functions of the product, link the different components among them. Technical functions are required to achieve the SF.

For example, the motor of the hair dryer must be supplied with power. Its fan is powered by a motor which, in turn, is powered by electricity, along with a switch that closes or opens the circuit. The customer operates the on/off switch, and he is not concerned with the functioning of the parts of the fan or motor.

The TF are generally ignored by the user except sometimes in the case of failure!

#### 9.3.3.2.3. Constraint functions (CF)

Any product design, any project, any action is normally limited by the constraints. The list is long:

- regulatory constraints (codes, standards, etc.);
- physical constraints;
- product incompatibility with other products;
- current voltage;
- limited availability of building materials;
- time constraints (*Time is money*): spending a lot of time in design can lead to putting a product on the market after the competition. A new car should be ready to be exhibited at a well-known car show;
- patents;
- feasibility constraints (one does not know how to do it, one does not have the financial resources to do it and so on);
- dependability (RAMS).

This final constraint is unavoidable in our overly mediatized society and society accepts fewer risks associated with the products and their means of production. This will be further discussed in Chapter 13.

#### 9.3.3.2.4. Useless, harmful functions

This category consists of functions which are considered to be unnecessary by the customer (some radios have many nice silver buttons: are they all useful or placed there by the supplier to add questionable value?). The functions that are clearly harmful have to be eliminated as far as possible. Let us talk about noise, vibration, toxicity, all of which pose a usage risk. The VA involves hunting for unnecessary and harmful functions.

#### 9.3.3.2.5. Environmental protection

Respecting the environment throughout the lifecycle of the product is now a necessity. In particular, the recovery or destruction of the product at the end of its life will assume more and more importance. Let us consider scrapyards.

#### 9.3.3.3. *Characterization and flexibility of a function*

A function must be characterized by criteria and if possible by measurable levels. Functions related to an automobile may be the speed (criterion) expressed in kilometers per hour (level), the time taken to travel a kilometer, standing start (seconds), the consumption of fuel per 100 kilometers (L/100 km), and so on.

The measurement of value functions (VF) is inherently difficult; the evaluation can be carried out by a panel of consumers. But to formalize the dialog that must be established between the customer and supplier, the FA characterizes the level of performance by its flexibility.

The *flexibility of a function* expresses the degree of negotiability or imperativity set by the client. It is expressed by:

– an acceptance limit: let us consider the case of a car. The car considered should not consume more than 9 liters of gasoline per 100 km (standard conditions). It is clear that the supplier who does not meet this requirement is eliminated;

– an exchange rate: the appreciation or depreciation assigned to the product between the level of performance offered by the supplier and the level desired by the customer. For the car with a maximum limit of acceptance of 9 liters per 100 km, the desired level is 8 liters per 100 km. The customer is ready to accept a 5% increase in cost if consumption is 7.5 liters per 100 km and requires a 5% decrease if the consumption is 8.5 liters per 100 km. An exchange rate can thus be defined as the cost/benefit ratio.

The flexibility class specifies the degree of imperativeness or negotiability. The flexibility can range from zero (the level is imperative) to very high (level is negotiable). The flexibility often represents the “ignorance” of the customer who

wants to know what it would cost him if he changed the nature of a material with a material that is more noble, or if he wants a lower noise level ... It is often a method to push the supplier to its limits.

#### 9.3.3.4. *Functional costs*

The assumed functional cost single-handedly represents the set of expenditures necessary for obtaining it. The determination cost of the forms part of cost accounting of the company. It was discussed in Chapter 2.

Let us consider, for example, a hybrid car, that is to say a car where the engine of the car is powered by a fossil fuel and electric batteries. The “moving in electric mode” function leads to an additional purchase cost which can be made profitable by gains in fuel that has lower CO<sub>2</sub> emissions.

#### 9.3.3.5. *The methods of functional analysis (FA)*

The supplier, from a preliminary FPS (functional specification), must express the need under the form of functional services (FS) and technical functions (TF). The TF will “materialize” the device by components and define their interaction. It is from this phase that the supplier will calculate the cost of each function, since each function will result in the presence of certain parts, where some of them are entirely devoted to a specific function.

There are many FA methods of which some are owned by consulting firms. It is surprising the number of features included in the most ordinary objects! There were about 20 functions for a pair of sunglasses! As an illustration, we will give some information about the “intuitive” type of method and the FAST method.

#### 9.3.3.6. *The intuitive method [TAS 95]*

This is a method used at the beginning of the study. It lends itself well to *brainstorming* techniques. Its objective is to identify the functions. A small team, generally limited to 6 or 7 people, review the product and interface with the user, environment, lifecycle aspects, movement, and distribution of the product.

Let us apply this method to the list of functions of a lamp used for underwater diving. The “bubbles” around the lamp (Figure 9.4) represent potential interactions. Several essential functions can be listed. The main service function (SF) is to illuminate the marine environment. The criteria may be the length of the beam, its width, and the possibility of adjusting it.

Among the other service functions, can be mentioned:

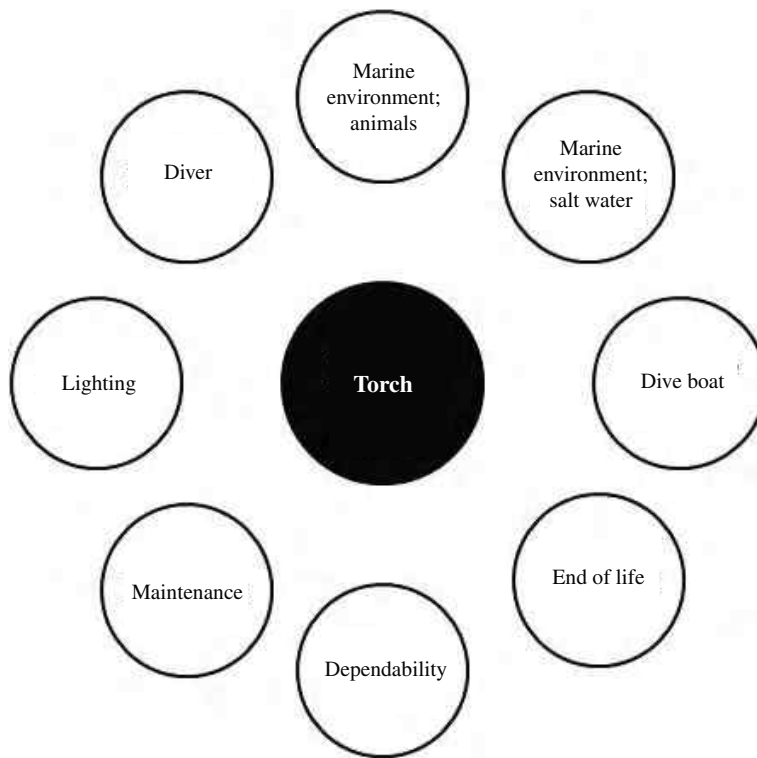
- lighting life: number of hours;



- handling: taking with one hand connected to the diver by a cord;
- reliability: it must be total as the life of the diver may depend on it;
- whether or not to double certain functions.

The constraint functions are as follows:

- resistance to water pressure at 100 m deep (no flexibility);
- corrosion resistance to sea water.



**Figure 9.4.** Functions analysis of a torch for diving (very simplified)

Value functions related to reliability functions are typical of equipment used in scuba diving.

For a torch that is used during scuba diving, a draft of the functional specifications is given as an example (Table 9.2).

Function	Nature	Criterion	Level	Flexibility		
				Limit	Class	Exchange rate
FS1	Illuminate the space	m	10	8 mini		
FS2	Rechargeable battery Autonomy	hours	3	2 mini	Negotiable	Non-rechargeable battery: price = -20%
FS3	Manageable with one hand					
FC1	Resistant to pressure	m	100	100	Imperative	
FC2	Resistant to sea water corrosion				Imperative	
FC3	Total reliability	On/off	1,000 tests	800 tests	Imperative	
FE	Give the impression of robustness, reliability					

**Table 9.2.** Outline of the FS (function specification) of a torch (for example)

#### 9.3.3.7. The FAST method [TAS 95]

FAST stands for *Function Analysis System Technique* (Figure 9.5). It is used to represent and organize the functions on a diagram, to show dependency functions. It allows only a comprehensive and visual method in the sense of visual management, that is the project team “is” immediately in the project.

Let us apply this method to the list of functions of an electric hair dryer. Whoever is in charge of the dryer fan knows its function, knows how it is operated. The functions are classified from right to left of the question: why? The functions that appear at the same time are arranged on the same vertical. In a very simplified example of Figure 9.7, the hair is dried with a stream of hot air produced by a fan driven by an electric motor. The dryer is connected to the electricity network. The power is put into the motor and heater simultaneously.

The diagram from the 220 V electrical plug leads to the function of the main service: drying hair. One can imagine that the hair dryer has a recyclable battery and requires only the power supply for recharging, so that its life can be enhanced.

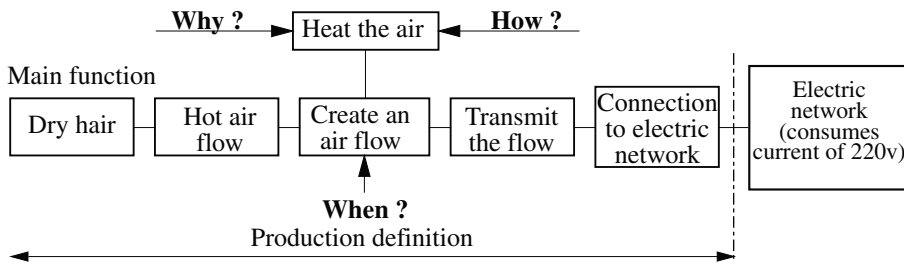


Figure 9.5. The FAST method applied to the analysis of the value of a hair dryer

### 9.3.4. The project scope (PS)

#### 9.3.4.1. Objectives of the PS

The PS is the subject of the AFNOR X50-151 standard [ZAN 97]. It accompanies all the phases of design or redesign of the product. The PS is the result of a *dialog* between the customer and the supplier. Initially, the customer expresses his needs as he perceives it. A VA expert who is from an external firm or is an employee of the supplier, will condition this dialog.

The PS is designed to:

- list the functions as we have described them without identifying any solutions;
- prioritize them according to their importance (main SF and secondary SF);
- specify the levels of performance, flexibility, and acceptance limits.

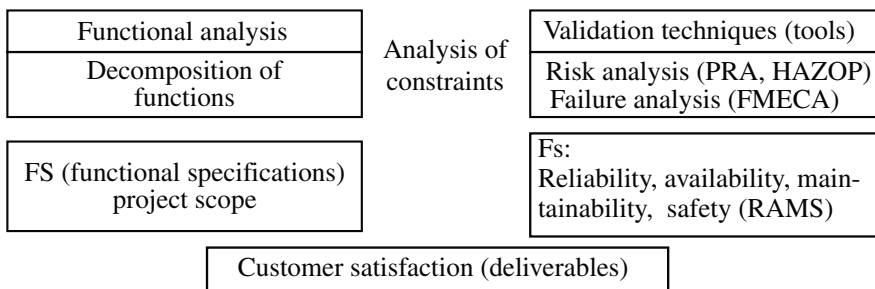


Figure 9.6. Development of functional specifications, or FPS

At this point, the FA allows the supplier to know what the customer wants. The preliminary PS is a document that can be contractual and which will therefore enable the supplier to work on solid ground by using his internal resources in research, design, and trades of various kinds.

NOTE.– The HSE aspects in accordance with the ethics of the society and its local regulations must always be addressed.

#### 9.3.4.2. Case study: latex process unit described in section 9.3.1.2

The VA is applied to the whole system and to each major component of the WBS, itself divided into subsets.

In the first analysis, the butadiene sphere, as shown in the diagram, has at least three SF: unload the boat, store butadiene, and feed the polymerizer, hence the following questions can be raised:

- is the butadiene sphere necessary?
- can one use the boat as storage and then eliminate the sphere?
- can the addition of additive be made in the polymerizer?
- can one finally eliminate an expensive device at first, even if one has to install it later when sales will have increased in power?

*The VA based on the FA can challenge, innovate, create new solutions, find the best compromise [DEL 91].*

### 9.3.5. Planning

A project consists of a series of tasks related to each of the previous and the next by a necessity of succession. For example, in the construction of a building, one can only raise the walls after constructing the foundations, which can be achieved only after completing the excavation. The minimum duration of a project is equal to the cumulative duration of *critical path* tasks. It follows that one can reduce the time of execution of a work by reducing the length of one or more critical path tasks.

Various techniques, some of which are very sophisticated, are made readily usable by IT, and help to view tasks and their sequence.

Keeping a schedule is an essential project management tool. It makes it possible to view at any time the degree of progress of the work, to take corrective action to catch up as far as possible, and to involve different trades wisely. Two widely used methods, namely GANTT and PERT, will be simply described.

9.3.5.1. Gantt chart or bar chart

Henry L. Gantt (1861–1919) was an associate of Frederick Taylor. He developed numerous methods including a graphical diagram which bears his name.

It is a simple method which applies well to a small project where the number of tasks does not exceed 30 [KER 89]. Its weakness mainly lies in the fact that the interdependence of tasks is not taken into account.

In Figure 9.7, we have considered the example of planning related to the latex plant in China as mentioned above.

A simple reading of the diagram which is based on the WBS analysis of the project shows that:

- the plant can be built in 20 months after the credit agreement in the first month;
- the polymerizer and butadiene sphere, which are the two essential parts of the project, must be ordered in the fourth month.

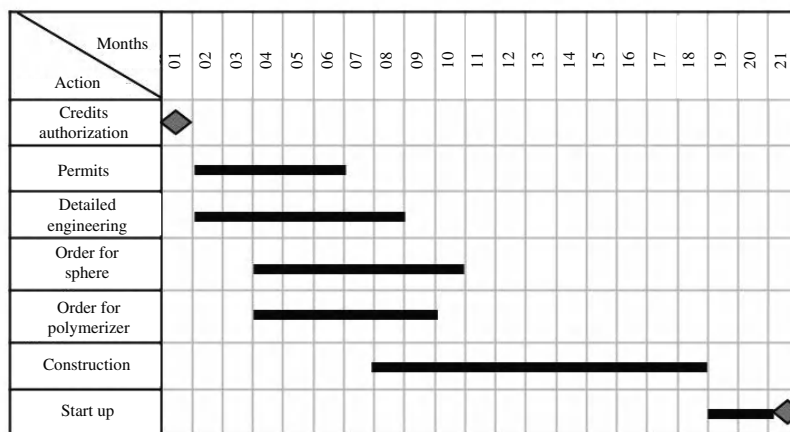


Figure 9.7. Example of a Gantt chart for a construction project for a latex plant in China

NOTE.– The announced schedule assumes that the funds are authorized before August of year N, the construction must start before March of year N +1 due to the monsoon that will make it impracticable in June/July.

9.3.5.2. The PERT (Program Evaluation & Review Technique) method [KER 89]

The PERT method was developed by the US Navy in 1958 for the construction of Polaris missiles which could be fired from submerged nuclear submarines.

It is used to plan the best use of resources for very large-scale projects through the use of IT. It assesses the impact of the delay of a task throughout the project.

*This is an interactive method.* The PERT method determines the project’s critical path, which is the longest duration in the sequence of tasks, at any time in the project: this is the time required to complete the project.

Figure 9.8 illustrates the use of the method in a silica compaction project in Asia.

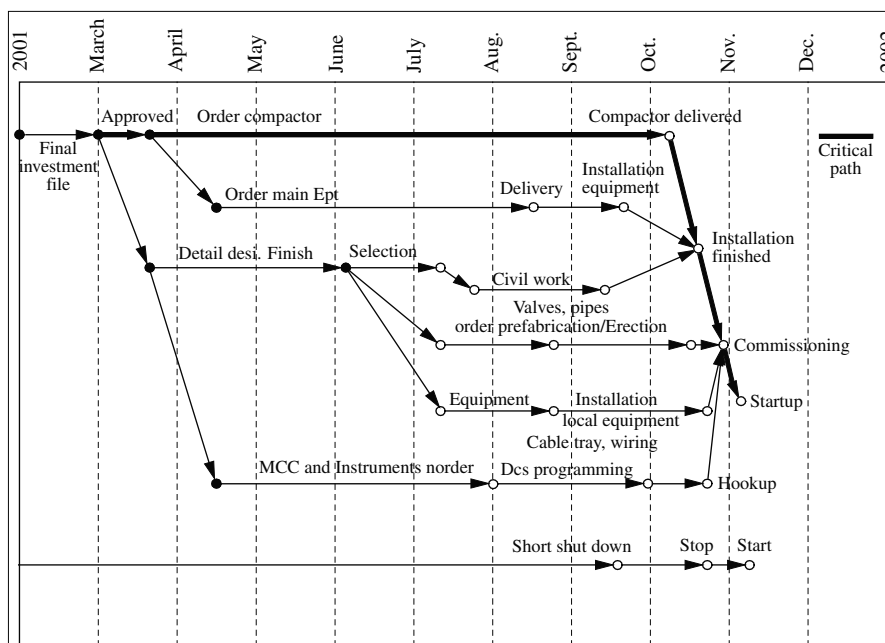


Figure 9.8. PERT method applied to a silica compaction project in Asia

#### 9.4. The engineering project: from *Process Engineering* to the start of the facility

##### 9.4.1. *Process Engineering*

*Process Engineering* follows the feasibility studies. It assumes different names according to the company; the term *preliminary study* is widely used.

This is the design phase of the process and is generally carried out by the client, in collaboration with research or testing centers, or with architectural firms and often with the support of an engineering firm.

It includes the establishment of material and utilities balances, design of major equipment, the establishment of a process flow chart, and a general layout.

*It is during this phase that one must implement the above methods of functional analysis, value analysis, and risk analysis.*

This step must demonstrate the industrial feasibility of the project taking into account the technical aspects, HSE, cost and time delivery, and profitability.

In many companies, the accuracy of the cost estimate is  $\pm 25\%$  of the PFC (probable final cost) as described in Chapter 6. It is clear that for a project whose PFC is estimated at 100 million dollars, one performs the tasks needed to ensure that the forecast cost of investment has a high probability of being between 75 and 125 million dollars.

*This is an important step in decision-making! This is usually the step when after validation it is decided to launch the basic engineering step.*

#### 9.4.1.1. Basic engineering

The step called “basic engineering” aims to develop the specifications of the system, which will be subjected to execution engineers, and to write the operating manual to be used in the “detailed engineering” step. It also aims to determine the probable final cost of investment, with an accuracy of about  $\pm 10\%$  in general.

It is a “highly” expensive step, and its cost can range from 3% to 7% of the PFC, for example, 5 million dollars for a plant valued at 100 million dollars!

*It should be only launched if it is believed that detailed engineering will be performed.*

#### 9.4.1.2. Detailed engineering: tools and goals

The main objective of *detailed engineering* is to handover the construction plans to the companies that are responsible for construction. Detailed engineering is expensive and since it is very labor-consuming, it is essential that the file “basic engineering” is explicit and comprehensive to avoid misunderstandings and subsequent amendments.

It carries out different trades including methods, projects, general studies, setting up, lay out, vessel design, mechanical engineering, civil engineering, electrical engineering, instrumentation, cost and time, fire protection, and so on.

The piping, in chemical and petrochemical industries, plays one of the most significant roles in set up cost, about 20% of the PFC; it is necessary to make their drawings (isometric) exact, position them in space, define the components’s support, and so on.

Information technology has profoundly changed the manner in which engineering companies function. A multitude of software packages helps the prime contractor to design, plan, control, and manage all aspects of the project.

Calculation software helps to carry out, in few minutes, certain calculations which took hours, days, or weeks a few decades ago: calculations of heat transfer coefficients, fluid mechanics, structures, and so on. They have allowed us to make simulations, that is to say, to model a system and analyze its reactions when some of the parameters vary. The peculiarity of IT is also to create documents, store them, and transmit them in the form of emails.

CAD (computer-aided design) aims to integrate the “trade” software (structural calculations, fitting, etc.) and the studies belonging to detailed engineering, such as those relating to the design of the pipes.

CAD unites the various skills in a single location to create a 3D virtual model which can be visited by climbing the stairs, and by “walking” on the floors. The detailed engineering requires the use of standards and procedures: codes will be selected for the system to be installed. The procedures define the methods to be used to run the project, thereby ensuring overall coordination.

#### 9.4.1.3. *Schematic*

The schematic can be defined as the graphical representation which is composed of diagrams, plot plans, necessary for defining the design of the facility and the definition of the main equipment; drawings are needed to define networks associated with utilities (steam, power, nitrogen etc.) waste disposal. It is also used to describe the project organization in the form of organizational charts, thereby characterizing the sequences of tasks and monitoring progress on the site.

NOTE.— The figures in this section are from the article “Réalisation de projets dans une société d’ingénierie [Realization of projects in an engineering firm]” [CHA 01] courtesy of *Techniques de l’ingénieur*.

Figure 9.9 illustrates the general organization of a project.

Figure 9.10 describes the tasks and project schedule up to construction, where the sequence of tasks is included.

Figure 9.11 shows the typical organization of the team responsible for the construction of the facility. The different trades can be noted: mechanical, piping, rotating machinery, electricity, and so on.

Figure 9.12 shows the process flow diagram of a gasoline stripper with instrumentation, flow, temperature, and pressure for each stream.



The attached tables specify:

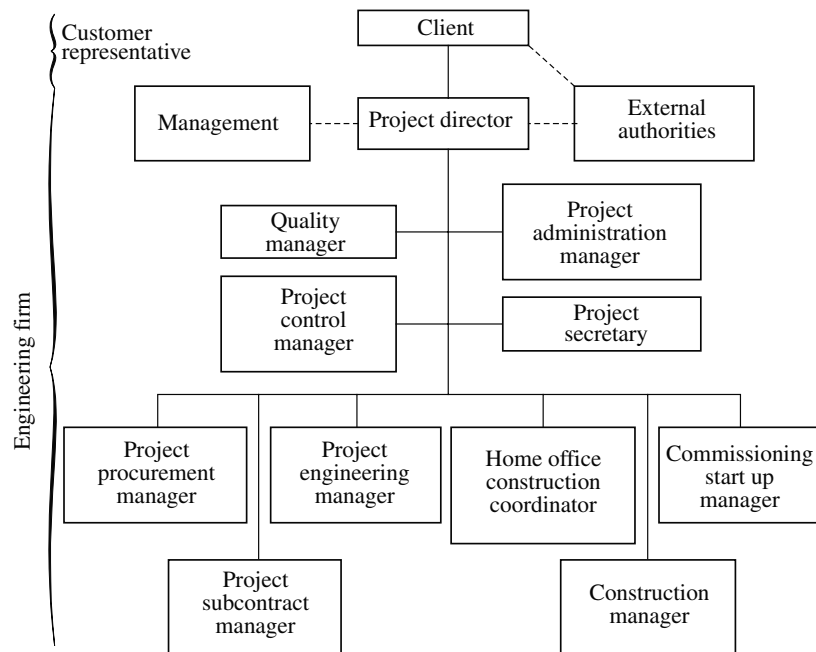
- the nature of materials of construction (MOC) for the various elements;
- temperature design data, pressure required to calculate the plate thickness;
- the conditions of hydraulic tests.

Figure 9.13 is a typical specification sheet. The stripper is defined with its dimensions, the positioning of fractionation trays, the nozzles, and manholes to allow inspection during shutdown.

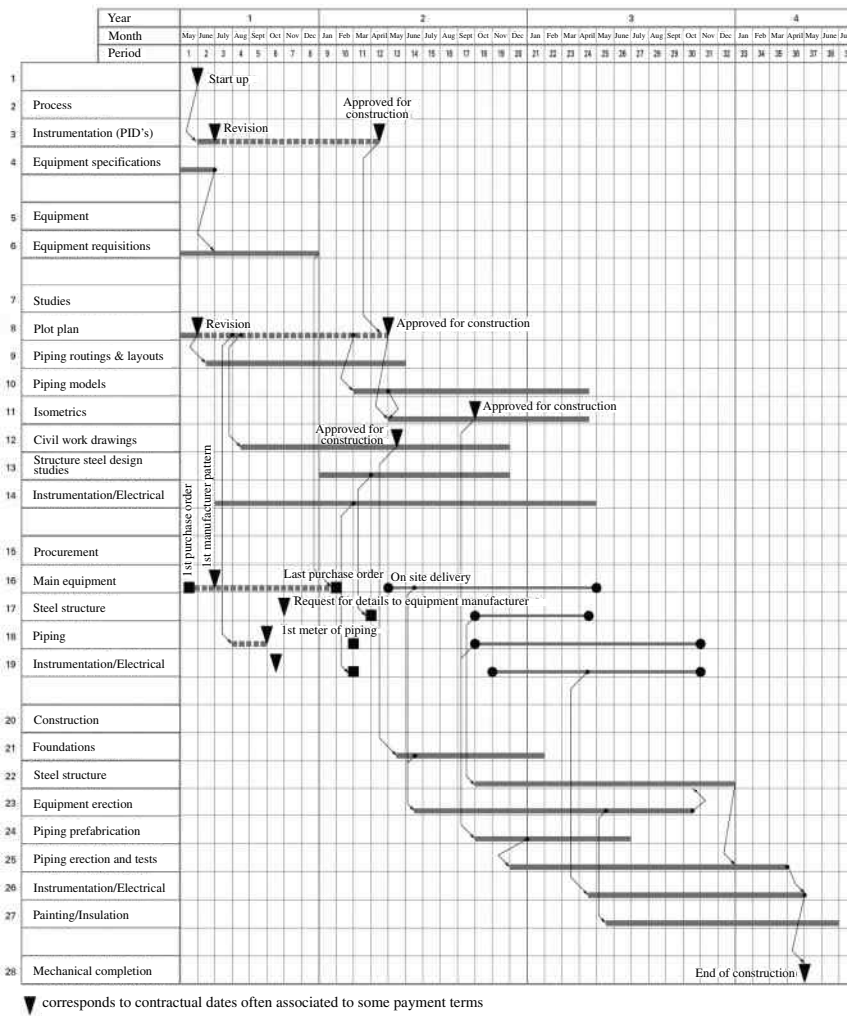
Figure 9.14 is a PID (*Process and Instrumentation Diagram*). The evolution from the process flow diagram to the PID can be seen. The PID includes the size, item number and specifications of the pipes, and the details of the instrumentation. There is a shift from basic engineering to detailed engineering.

Figure 9.15 shows the layers of a pipe. Appropriate software programs are available to ensure that the pipes do not intersect!

Figure 9.16 shows the plant in 3D view. It will be useful to have an overview of the facility.



**Figure 9.9.** General organization of a project realization phase



**Figure 9.10.** Typical chart related to the construction of a refining unit

9.4.1.4. Construction

This step may take several months for small projects and several years for large projects; it is the realization of what was initially a vision.

Construction sometimes occurs in difficult conditions due to severe climates, remoteness, which require an appropriate organization and dedicated management techniques especially for raising funds, and human resource supply.

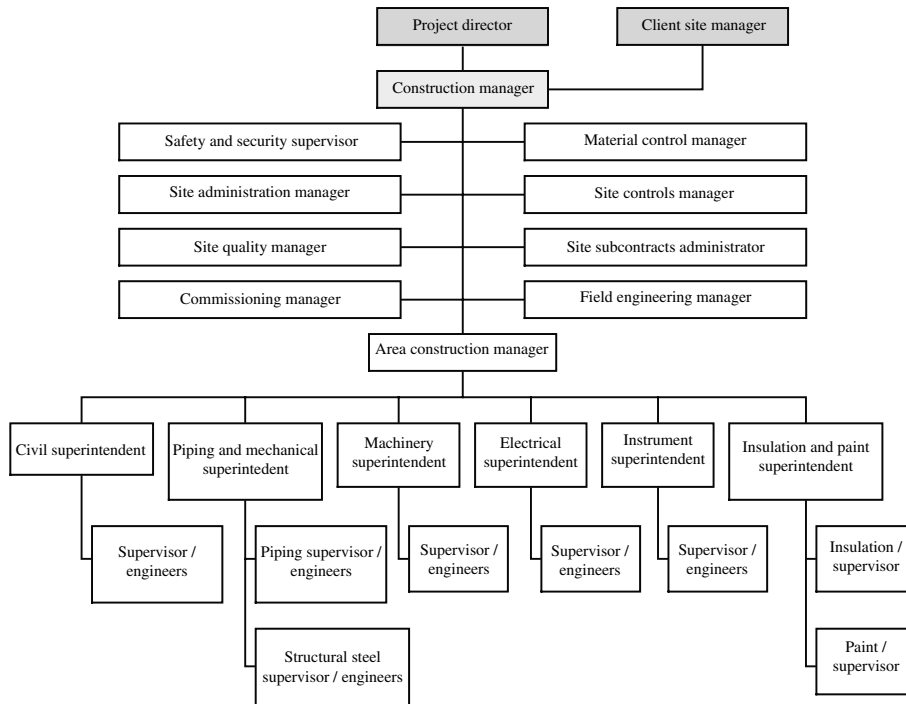


Figure 9.11. Typical organization of team in charge of the construction

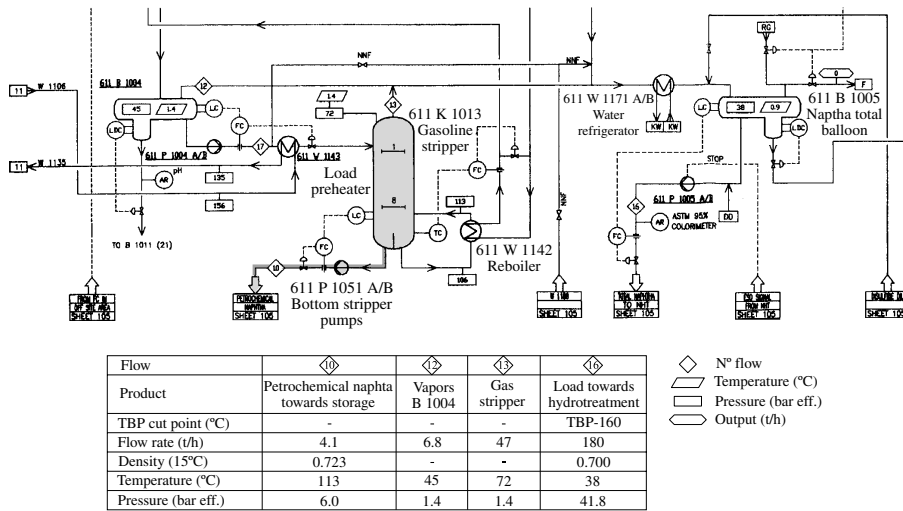


Figure 9.12. Process flow diagram – gasoline stripper

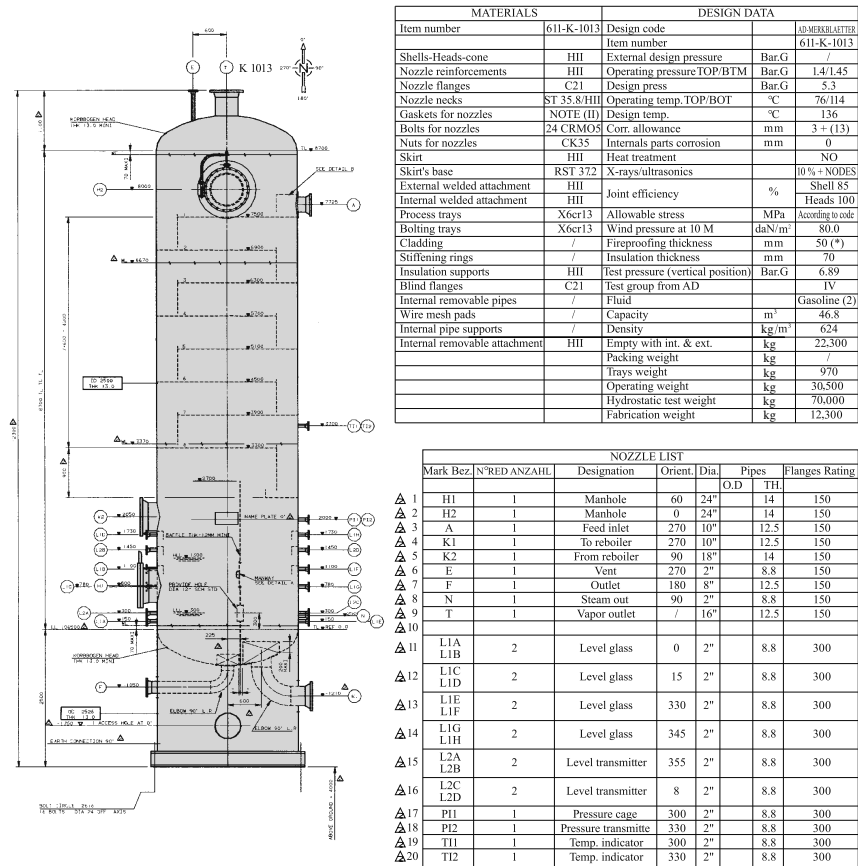


Figure 9.13. Engineering specifications – gasoline stripper

A significant portion of the project team moves, sometimes for months, on to the site during construction. A light habitation structure is located at the headquarters where it facilitates interaction between stakeholders and implements “sovereign” functions, such as expenditure tracking, contract compliance, and so on.

9.4.1.5. Contracts/insurance

The contracts will define the respective responsibilities of different stakeholders. *The most important one is the one which binds the client to the contractor.* Contracts are critical and must be written by engineering professionals and approved by lawyers who must have understood the nature of the project to ensure adequate preparation. Contracts should reflect, in good faith, what each party expects from the other and under what conditions; see [JOL 89a] for more information.

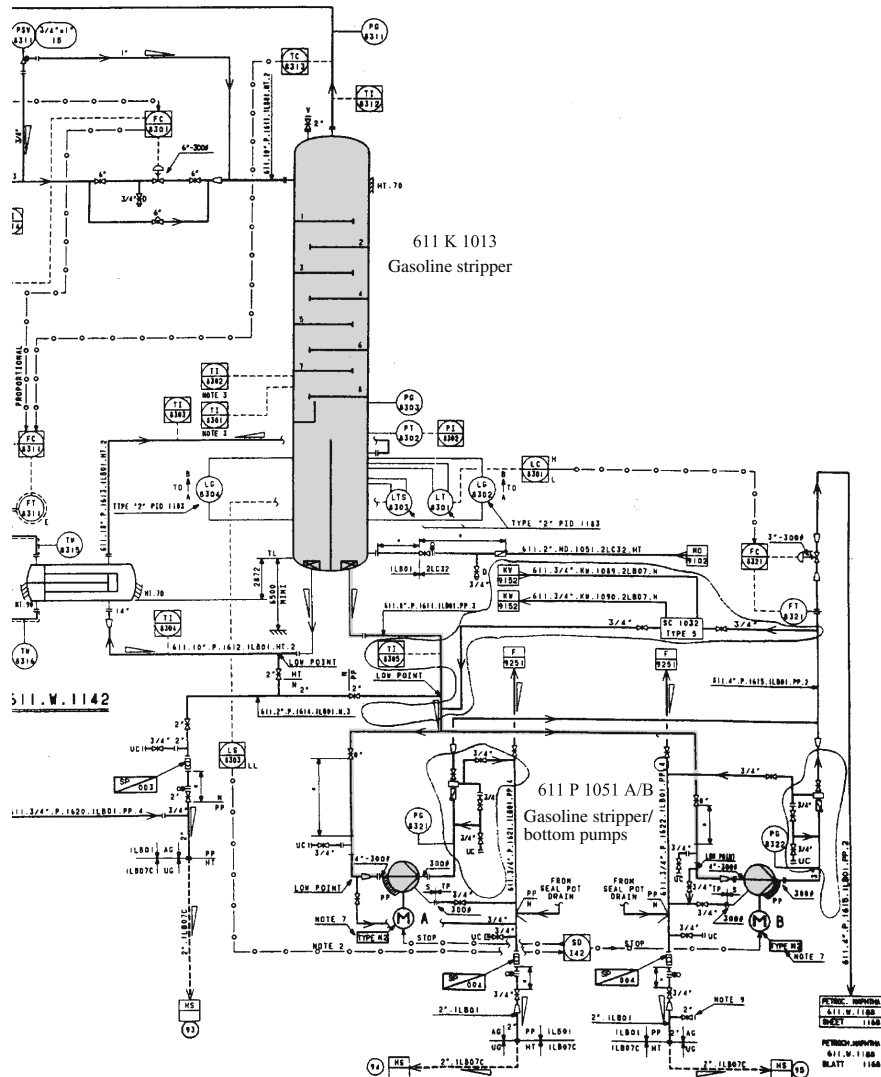


Figure 9.14. Process and instrument diagram (PID) – gasoline stripper

A client in possession of basic engineering may decide to consult various companies for what is commonly called an EPC (M), that is, “Engineering Procurement and Construction (Management)” contract. Engineering refers to detailed studies, procurement to the supply of equipment, whereas construction management is self explanatory.

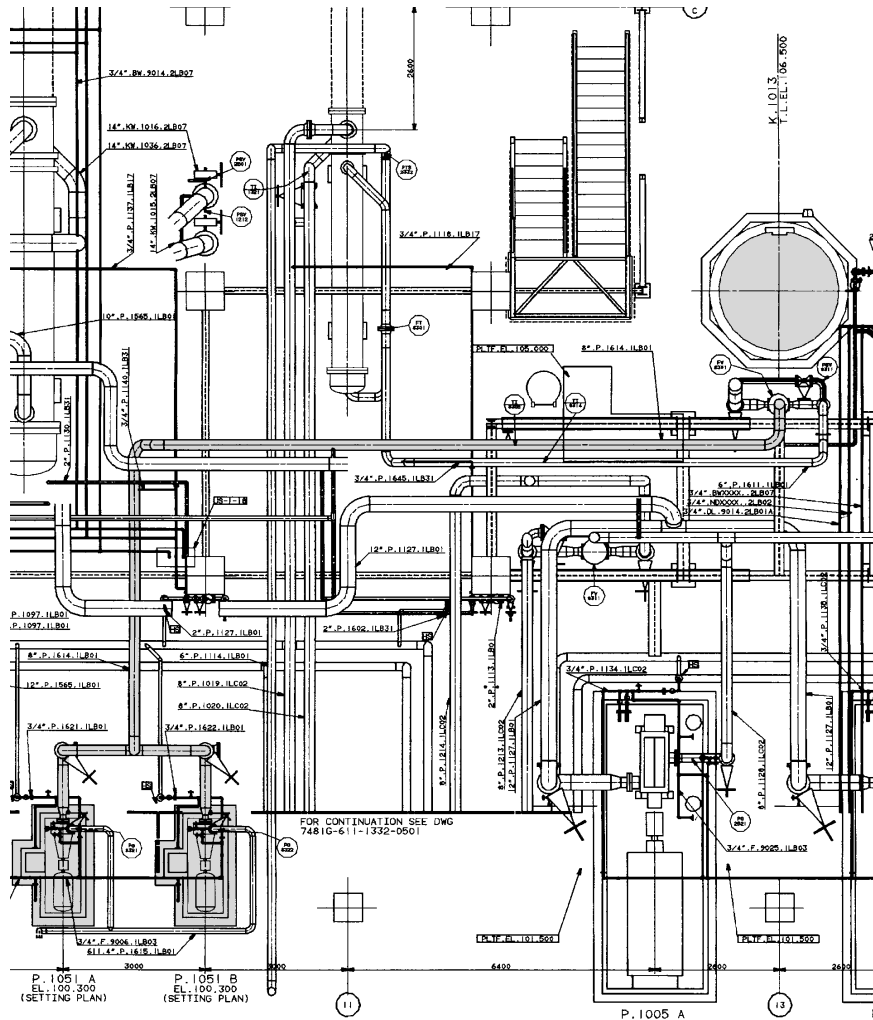


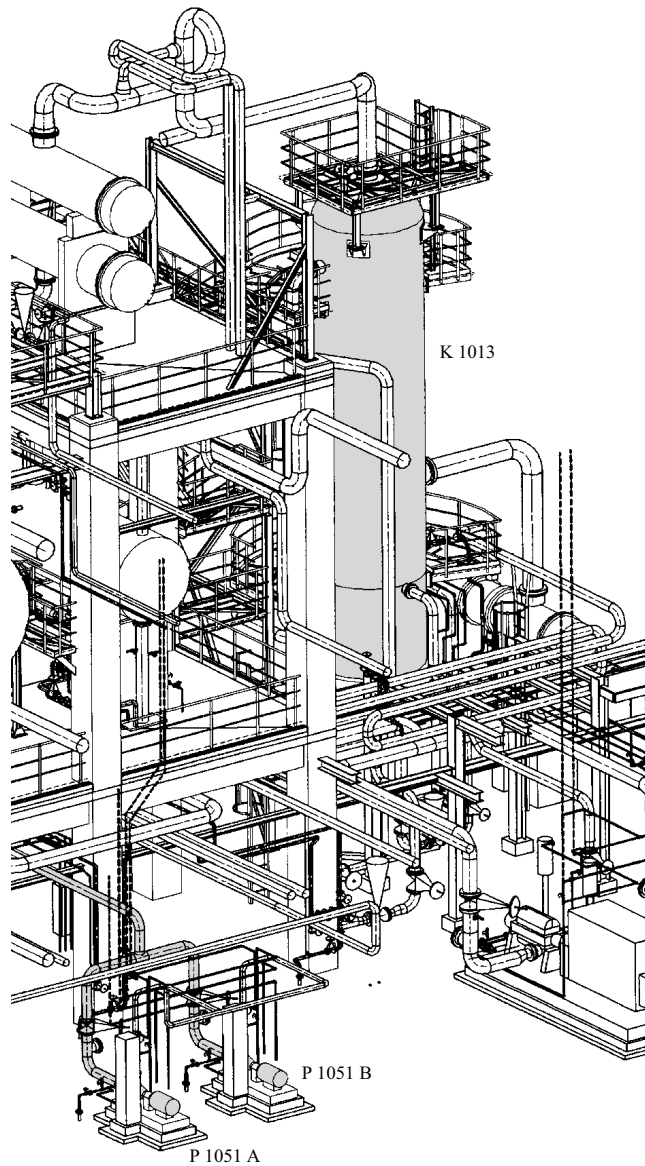
Figure 9.15. Piping layout – gasoline stripper

Obviously, the company that carried out the basic engineering has an advantage over competing companies, due to the fact that it has a team that knows the file which was created by it.

Let us retain two types of contracts among the most common ones:

– *turnkey*: the prime contractor gives the client a plant that is ready to start. The client has “nothing to do” during construction but wait. He has the opportunity to train operating personnel;

– the “*cost + fee*” contract means the client pays the prime contractor for the *actual* work performed which usually concerns the studies and construction to which he adds a *fee*. The *fee* is the profit of the contractor. It can be fixed or variable depending on the work performed. The *cost + fee* has alternatives.



**Figure 9.16.** 3D model – gasoline stripper

*In this type of contract, it is strongly advised that orders for material prepared by the contractor have to be signed by the client; this allows the client to control the project.*

The precision of defining the project will influence the nature of the contract. A turnkey contract requires that the project be clearly defined and strongly involves the responsibility of the contractor. The client can rest peacefully, knowing how much he has to pay. *On the contrary*, a cost + fee contract is more appropriate when the project may be subject to hardly apprehensible random factors such as construction abroad when the quality of subcontractors is poorly understood.

Normally any contract is subject to penalties, in contrast, bonuses induce the contractor or the company to shorten the completion time, for example. The absolutely necessary insurances represent a particular type of contract, and they aim to protect all stakeholders in the project.

*By the convention of January 8, 1887 between the State, the City of Paris and Gustave Eiffel, the City provided Eiffel with a grant of 1.5 million francs and enjoyment of operations for 20 years. The cost of the tower amounted to 7.4 million francs; due to revenue generated by the visitors, the operation was almost balanced in the first year [MAR 89].*

#### 9.4.1.6. *Selection of companies, staff*

The selection of engineering firms, contractors, and subcontractors is of paramount importance. It is worth checking references by onsite visits, and appropriate surveys of plants of the same type; this is essential before choosing a particular firm. It is the work of commercial representatives to promote them: its not them who does the work.

Good practice is to select project staff at the same time according to their ability and experience. Examining the CV (*resume*), surveys, interviews, and so on, is useful and avoids many disappointments.

#### 9.4.1.7. *Procurement, inspection*

*Buying is a job!* The term procurement includes processes other than the purchasing function itself. It is a question of preparing the tenders specifying the material and associated contractual terms, choosing suppliers, inspecting during construction, ensuring the recovery, equipment transportation to the site, receiving it, carrying out payments, and so on.

This is an important function because the “itemized” and “bulk” material cost in a plant represents 40% of the total investment.



The “itemized” material is the material with an item number on the PIDs (heat exchangers, pumps, distillation columns, etc.). Equipment such as pipes, bolts and nuts, are classified as “bulk”.

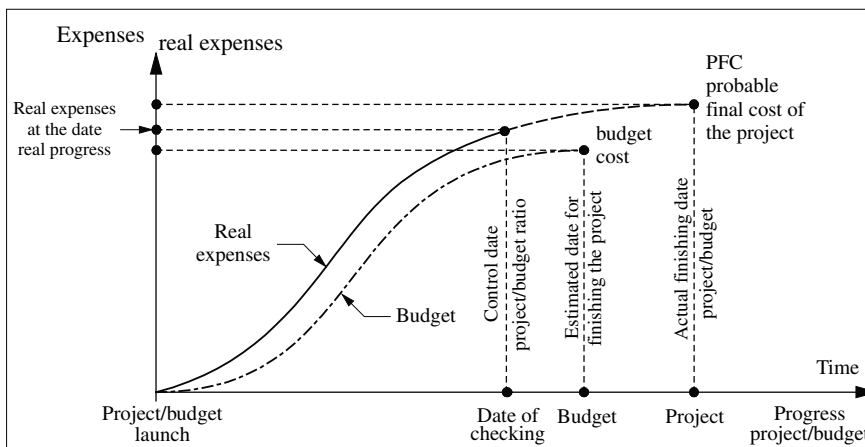
#### 9.4.2. Construction management – monitoring the progress of the project – cost and time

##### 9.4.2.1. Site management

A building site where hundreds or thousands of people will bustle around clearly needs organization for special monitoring. Safety, protection of goods and people are of particular importance. A building site has its own disciplines: secretarial, administrative, social, and regulatory. A site has many interfaces: administration, customs, community, roads, police, electricity providers, water providers, and so on. Almost every day, the project director faces many problems.

*Managing a project in the construction phase is to control costs, deadlines, and quality.* The key is to identify the deviations to correct them in time, as far as possible. The objective of planning is to be proactive, that is to say to establish corrective actions in the case of deviations. A schedule is a living thing! It must anticipate events and not be limited to delays.

The project director must track expenditures (commitments and payments) based on the *degree of progress*, which is the percentage between the actual work achieved and the work necessary to complete the work (Figure 9.17). It can be measured by tonnes of steel structures installed, meters of piping, and so on; see [JOL 89b] for more details.



**Figure 9.17.** Project management: monitoring of expenditure versus budget depending on the degree of progress

*What the customer wants to know is the date of delivery of the facility and the estimated cost!* Adequacy of reporting, to create trust between all stakeholders in the project, is essential for the success of the project. It includes a *balanced scorecard* which reflects the situation of the project, its stage of completion, actual expenditures based on budgeted expenditures, the analysis of accidents if unfortunately there was any, *procurement*, and so on. *Reporting* refers to “hard points”, problems, how to overcome them; it is a projection into the future. It must meet the recurring questions: date of delivery of the facility and at what cost.

#### 9.4.2.2. *Start-up*

The onsite operator, since the beginning of the construction, will have to be involved in hiring and training the staff, writing the operating manual that contains instructions, procedures and all that is required to understand the plant and its operation.

The maintenance manager must receive process plans regarding devices, “as built” drawings, and operating manuals to set up a maintenance plan in due time.

It is essential that operators are involved in detailed engineering, and to make it short “own it”.

#### 9.4.2.3. *Commissioning*

The delivery of the work by the contractor to the client is a delicate phase of the project both on the technical aspects (the client wants a tool that meets his needs for a long period) and on the contractual aspects.

Definition of responsibilities at each stage is essential, along with *contradictory* findings, which help to clarify the responsibilities of each party rather than creating suspicion.

It is always difficult to “tie up loose ends” such as painting, insulation, cleaning, remediation of soil, and so on. It is not easy to obtain all drawings, and all specifications of equipment essential to the maintenance department. The engineering contract must include deductions, which are the only way to force contractors to meet their commitments.

One must simply note the following terms (the engineering contract should specify them in detail) that are not always understood in the same way by everyone:

- *mechanical acceptance*: the works are almost completed and in accordance with drawings and specifications (*as built*);
- *pre-commissioning*: water tests, dynamics tests, commissioning utilities, and so on;
- *start-up*: actual plant start-up using the specific raw materials;

– *commissioning*: contract data verification of the product and performance of the plant;

– receiving the plant after a test run by the client, who is apparently eager to take possession, is an important contractual phase. An indiscriminate reception will identify the responsibility of the contractor whose interest is obviously to leave quickly.

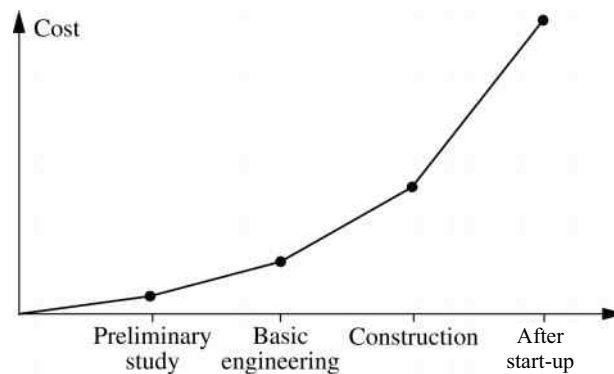
The transfer of ownership takes place during mechanical reception and modifies the respective roles of the contractor and the client. After this step, the contractor must request permission from the client to intervene in the plant.

Final acceptance of the plant does not relieve the contractor of obligations related to long-term guarantees. This is the case, for instance, with rotating machines which can work perfectly for a few months and present unacceptable defects in future.

#### 9.4.3. Management of change orders

During the detailed engineering, assembly, and testing at reception, change requests will be made to accommodate the vagaries and *wishes* of operators. These *change orders* will create additional costs and delays. They are often an opportunity for engineering companies to charge overtime not provided in the contract, at full price.

The management of these changes lies with the project manager representing the client to evaluate its basis and decide the action. *It is a disease to be avoided.*



**Figure 9.18.** Impact of a change order to the probable final cost (PFC) with time

A *change order* will cost more if it is taken at a later stage. This is illustrated in Figure 9.18. If the *change order* is taken at the preliminary stage it changes only on “paper”. If done during construction it may lead to changes in location of structures, connections, and so on!

#### 9.4.3.1. *Real life cases*

In the framework of a fine chemicals project in Texas, it is expected to reuse a stainless steel distillation column from an existing plant. During the development of the process of corrosion tests, it was shown that the stainless steel should be replaced with graphite and that the separation considered required 26 theoretical plates! It was necessary to specify this column, a marvel of technology, supply, install, and connect it. The executive community approves this significant *change order*, and the additional cost does not lead the project's profitability to be at risk. This is not always the case!

#### 9.4.3.2. *Risks and uncertainties of projects*

For more information please see [BAR 00, DES 08].

Every project is subject to some hazards, whose origin can be traced to technical causes of administrative problems, personal conflicts, social conflicts, failures of suppliers, construction accidents, bad weather, negligence, order modification, and so on. Let us make a short list:

- *risks associated with people in the organization*: lack of skills, lack of ethics, lack of team spirit, poor organization, instability, turnover, lack of loyalty to the employer;

- *risks associated with partners, shareholders*: financial problems, lack of ethics, and so on;

- *technical risks associated with the process and the needs expressed by sales people*:

- poor definition of the process: the basic engineering or even the construction are launched too quickly, the assumptions are false (see the real life case above),

- the product must be further purified, or put into a different form (real life case: a drilling tower must be erected. The customer does not accept a dusty product; he wants a *free flowing* product);

- *administrative and contractual risks*:

- permits to build, produce, release into the environment when expected are not granted, there are delays or additional constraints,

- partners in a JV make changes to the contract;

- *risks associated with engineering, suppliers and subcontractors*:

- underestimation of the costs of engineering, equipment, and construction,

- strikes, bankruptcies, late delivery, transport problems, customs clearance, all that comes under the administration of various authorizations (*permitting*),

- defects: the material provided does not meet specifications, and does not have the expected performance (case study: welds for pressure storage in Asia must be 100% X-rayed. The work is poorly done, it must be repeated, and it becomes

compulsory to use an organization from Europe to control, repeat the X-rays and, repeat some of the welds);

– *risks associated with socio-economic, political, cultural aspects:*

- political unrest, economic turmoil, inflation, exchange rates, and market fluctuations,

- problems associated with religious practices, organized crime, and so on. (Case study: in 1997 in Asia, the Thai currency – the Baht was devalued by 90%, followed by the Indonesian Rupiah and the Korean Won in the following month! Economies collapse in a few weeks!);

– *market risks:*

- sales does not conform to forecasts either in volume or in price,

- competition makes an equivalent product cheaper, puts a better quality product onto the market,

- the competition has a “*breakthrough*” technology, a new process has an innovative technique that reduces production costs significantly;

– *miscellaneous:*

- natural hazards, floods, earthquakes, tornadoes, and so on,

- piracy, terrorism, and in general all that relates to the loss of know-how. These risks are exacerbated when setting up abroad in countries where the “protection of intellectual property” is not guaranteed, in countries at risk.

Let us note that there is a positive risk! Case study: projects conducted in China and Brazil on the skill of the players and especially their willingness to move forward for their sake and that of their country. Business is conducted in record time, and in an excellent atmosphere. One is far from the gloom of some aging countries. The countries of the BRIC group (Brazil, Russia, India, and China) and the Dragons of Southeast Asia attract investors; this is where there are projects!

*Project risks are managed as technological risks.* The different scenarios are classified based on the Consequence X probability couple [OF 08]. Kiviat and Farmer diagrams help to define the *criticality* of the risk about which the decision(s) is (are) wisely taken.

## 9.5. The amount of investment

The amount of investment is the figure that will retain the “non-technicians “of the company, those who move at headquarter level. This figure will be recorded in the files, reports of the planners, of the finance People. It is always difficult for the Industrial Director to change a figure by usually a larger one!!

This is extremely important for major projects, that is to say, for projects that involve the future of the company; this is in the case of strategic projects whose profitability is sometimes uncertain. What follows will deal with physical investments (factories or plants).

From the preliminary feasibility stage, it is necessary to get an idea of the amount of investment. It is a key parameter of profitability calculations as discussed below. It is also an amount that the CEO wants to know as soon as possible to find adequate funding. *Few companies can pay for themselves, one must resort to banks.*

The amount of capital investment includes:

- the cost of studies (preliminary study, basic engineering, detailed engineering);
- the cost of equipment and materials;
- the cost of construction (work contracts, supervision, administration of the site, etc.);
- start-up costs (cost of staff, products, miscellaneous);
- taxes, insurance, customs duties and transport, contingencies, and so on.

NOTE.– *The client usually separates these costs and the cost of research and development, which can be considerable. The development of a drug may require 8–10 years at a cost of around 1 billion dollars!*

To clarify, the cost of a large organic chemistry plant in France is as follows:

- equipment (itemized equipment) from 15% to 20%;
- piping: from 15% to 20%;
- instrumentation: from 15% to 20%;
- electricity: from 5% to 10%;
- civil/structural engineering: from 20% to 25%;
- insulation/painting/other: 5%;
- engineering: from 15% to 20%;
- total: 100%.

The cost of a plant having the same capacity in a given product will vary widely depending on its location, the degree of instrumentation, its overall design, climatic constraints, the organization of work, taking into account the HSE constraints and its mode of construction! This book does not deal with such a complex subject in detail, only some guidance and advice is given.

*For further information the reader can refer to [VAN 96].*

EXAMPLE 9.1.— The coordinator of this book led a major biotechnology project in the American midwest. Looking for a source of carbohydrate, he was able to visit a dozen plants which were very similar for corn processing, from the Great Lakes to the Carolinas, thus in extreme climatic regions. As an example, the cost of the plants ranged from 100 million to 150 million dollars. This huge variation was due to the conditions of design, engineering, closed or open structures, organization of work: a single control room or several scattered throughout the plant ...

*Estimating is an art.* One must have some flair and experience in the field!

Engineering companies of significant size have cost statistics related to:

- the projects achieved with their history;
- the “main equipment” such as heat exchangers depending on the type, material, and design conditions. The same goes for tanks, distillation columns, filters, and so on;
- the “units of work” such as the cost per cubic meter of earthwork...

One must distinguish between the expenditure in the limit of the production unit (*ISBL, inside battery limits*), that is to say everything concerning the means of production itself, and expenditures excluding the manufacturing unit (*OSBL; outside battery limits*).

The OSBL expenses include, unless limited to land, the production of utilities (water, steam, electricity, etc.), the WWTU, storage facilities, offices, shops, and laboratories. *The border between ISBL and OSBL is not always well defined; the key is to know what is included and not forget anything!*

The following methods are within the reach of small engineering offices or companies:

– *estimation by the type of activity or analytical estimation*: the process industries assemble “blocks”, and “unit operations” (reaction, distillation, crystallization, storage, etc.). Knowing the price of each block, the overall cost amounts to an addition;

– *similar method*: this is very valuable for the estimation of plants manufacturing the same product under similar conditions. Only the capacity is different. The following equation gives good results:

$$C_1/C_2 = (P_1/P_2)^e \quad [9.3]$$

where  $C_1$  and  $C_2$  represent the cost of two units of capacity  $P_1$  and  $P_2$  for the same finished product. The value of  $e$  is close to 0.6 for organic chemistry plants.

Let us note that this method works well for calculating the cost of basic equipment.

Let us consider the example of two exchangers of the same type. In this case,  $P_1$  and  $P_2$  are replaced by an equipment surface expressed in square meters. In the analytical method, one knows the cost of a “block” for a given capacity. The similar method allows us to calculate *a priori* the cost of the “block” for another capacity, where the problem is apparently to find parameter  $e$ .

Preliminary estimates mostly provoke passions; Business Unit Managers find it too high. They have their own idea, and ask the amounts to be reviewed. One tries to understand, to eliminate! The fact that they are given provisionally is forgotten and it is not considered whether they are given with some accuracy.

The estimates will succeed as the project progresses. It is necessary to follow their evolution. Figures that are too high are likely to “kill” the project. Low figures will sometimes make “*Heroes of the day*”. The moment of truth will arrive!

*Estimating is a professional matter. It requires common sense, experience, and intuition.*

Some traditional sources of common errors include:

- lack of general definition;
- forgetting a piece of equipment: an impurity that “appears during the development of the process” may require an additional distillation to be estimated;
- error in the construction materials (stainless steel which has to be replaced with a Hastelloy);
- design error: building designed “open” at the beginning and ends in a closed structure to improve the comfort of operators. The air of this structure must then be renewed in the case of emission of toxic products which results in the addition of ventilation systems;
- type of contract with engineering, lack of definition, unsuitable contract;
- subcontracting; underestimation of costs.

The most common mistake is forgetting a particular “item”. *It is important to list all items even with imprecision which is usually the case at the beginning of the job.*

The estimate of *revamping* poses particular problems, where one denotes by *revamping* the act of altering an existing plant in use. Modifying equipment of which conditions are not known, and working on plants that operate and require



stringent precautions will pose great difficulties. This will be discussed in Chapter 13.

## 9.6. Profitability on investment [DOR 81, MIK 10]

### 9.6.1. Principle of calculation of cash flows

Physical investment (plant, facility) is made in the hope of gain. It is a “sacrifice of resources”, a desired risk, carried out with the hope of obtaining after certain time, usually years, a higher profit in terms of incurred expenses. An investment is part of the strategy of the society; it is a *capital asset* which is contained in the balance sheet.

In what follows, we will focus on physical investments knowing that any investment of this nature can lead to research costs, additional needs for working capital from operations, advertising, hiring, training staff, travel expenses, transfer, reclassification, expatriation, and so on. What follows is not complete!

Calculating the profitability of an investment is like comparing cash flow as shown in Figure 9.19.

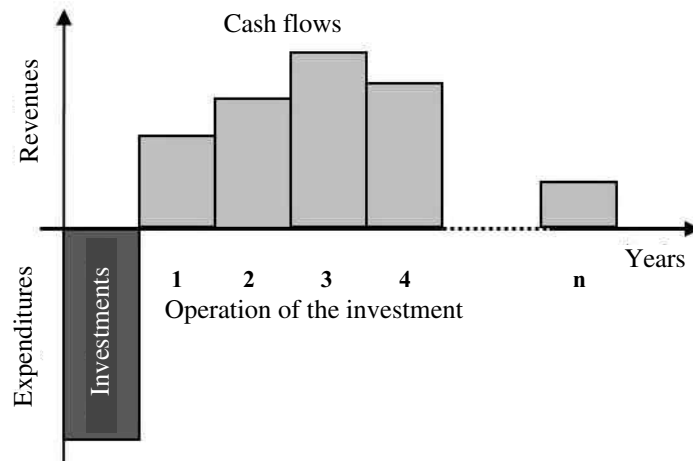


Figure 9.19. Cash flow

The first cash flow normally corresponds to the capital investment within a short period of time. The second is positioned at intervals of time. It corresponds to the excess amount that leaves the sales revenue net of expenses which they have created

including the purchase of raw materials, manufacturing costs, taxes, financing costs related to loans, management fees, and so on.

### 9.6.2. *Depreciation and amortization*

This is not a simple concept! Let us take the main idea. Any equipment wears out and loses its value (That is the case of an automobile!). Land does not wear out, it is not depreciable.

The legislature accepts and requires that a percentage of the amount of the property be brought into the operating costs column which diminishes the margin, thereby reducing taxes. Depreciation is charged to the cost of returns of the production [CON 01].

Depreciation is not an expense; it does not cause cash outflow, it is a *resource*. *Depreciation is expected to finance the renewal of the means of production.*

The *net accounting value* of an asset is its *gross value* (of purchase) subtracted from depreciation.

Depreciation may be *linear*; it is estimated that the wear is linear in time. It may be *declining*, the depreciation is very high in the first year.

### 9.6.3. *Concept of discount [MAR 79]*

Currently, 1 dollar will be worth  $(1 + i)$  dollars after one year,  $i$  is the *interest rate*,  $1 + i$  is the *discount factor* [CON 01]. If  $i$  is assumed to be constant then today's dollar will be worth  $(1 + i)^n$  in  $n$  years. This is the formula of simple interest, only the capital generates interest. If the interest is reinvested, then it is called the *compound interest*.

This leads to the concept of *capitalization*, a capital of  $C$  dollars in recent days will be worth  $C(1 + i)^n$  dollars in  $n$  years.

Inversely, the *update* of  $C$  dollars in  $n$  years is equivalent to  $C/(1 + i)^n$  dollars today.

The *net present value (NPV)* is the excess of cumulated cash flow (CCF) relating to the operation of the investment calculated on its lifetime and deducted from the amount of it,  $I$  [MAR 79]. It is worth:

$$NPV = \Sigma(CCF) - I \quad [9.4]$$

For a project to be profitable, the NPV must be positive.

An investment may have a residual value at the end of its life. Some pieces of equipment can be sold, the land also *but* this is not always the case.

#### **9.6.4. Concept of internal rate of return (IRR)**

Some companies use the term IRR. *The IRR is the rate for which NPV is zero with the same definitions as before.* One must make calculations with different rates of  $i$  to achieve a zero NPV.

The higher the discount rate or rate of return of IRR, the more profitable the investment. The CCF is “crushed” when the amount of investment  $I$  is constant.

NPV and IRR are assessment tools which make it possible to choose between different projects.

#### **9.6.5. Rapid methods: the calculations of the grocer (examples)**

An industrial manager, a plant manager, and a financier very often have to decide quickly or simply give their opinion on the merits of small investment, particularly on investment maintenance or capital maintenance. These are investments that are aimed at maintaining the production equipment in the same state, improve productivity, and generate efficiencies in raw material usage. Let us note that small investments can be considered as very significant investment by small companies.

One simply divides the amount of investment by the expected gain; the result expressed in years is often called *Pay-Back* or ROI (*Return on Investment*).

Let us consider a simple example.

A plant examines an investment that aims for a gain of raw material (RM). The expected gain of 0.1 kg of RM/kg of finished product, or for a production of 10,000 tonnes of finished product/year, a gain of 1,000 tonnes of RM/year. If the cost of the raw material is 3,000 dollars/ton, then the expected annual gain is 3 million dollars/year.

One also considers that the approximate capital investment, research costs, and technical start-up costs correspond to 1.5 million dollars.

Such an investment would have a *pay-back* of six months! Studies can be launched immediately. If the investment is 9 million dollars and therefore the payback is 3 years it has to be thought about! In many companies, a *pay-back* of 3 years is the upper limit of acceptance of the investments.

## 9.7. Conclusion

Investment is a major act for the company; its future depends on it at least for major projects, called strategic projects, for which it keeps in most cases the “know-how”. Know-how that originates most often in its research and development laboratories.

Industrialization and implementation require close cooperation between the client and the contractor. The former knows the process; the latter has the know-how, the skills of project management procurement, construction management.

The client will never know how to provide all the details of the process in a process file as complete as it is, and an engineering firm despite all its skills, will not know how to “invent” these details. One must plan meeting points (PID reviews, project reviews, verification of specifications of critical devices, etc.), so that one can ensure that the engineering firm has understood and assimilated all *know-how* that “the designer” owner of the technology wanted to convey and implement in devices of all kinds.

The project team faces this task!

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PART 3

The Necessary Adaptation  
of the Company for the Future

## Chapter 10

# Japanese Methods

### **10.1. Japan from the Meiji era to now. The origin of the Japanese miracle**

#### **10.1.1. *A bit of geography***

The Japanese archipelago consists of thousands of islands and it stretches to about 3,000 km. Seventy percent of the 377,835 km<sup>2</sup> of the country is mountainous; less than a quarter of the total area is arable. Moreover, Japan has very few raw materials. On average, it has at least one earthquake per day, excluding the volcanic eruptions and tsunamis. About 117 million people, less than 2% of the global population, live on the equivalent of French Brittany in a not particularly hospitable country [DOB 95]. Japan, the second world power since 1968, has just been surpassed by China, which is 11 times more populated.

#### **10.1.2. *A bit of history***

Japan was confronted with the West in 1542 with the arrival of European merchants followed by the Jesuits (St. Francis Xavier). It closed its doors to the West during the 17th Century.

It was in the mid-19th Century, after the mission of the American Commodore Perry in 1853, that Japan was forced to trade with the West. The ascension of Emperor Meiji (1852–1912) to the throne in 1867 marked the transition from a feudal state to a modern state. Japan sent its best students to study in Europe and in

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Chapter written by Jean-Pierre DAL PONT.

the United States. It had brought its modernization and industrialization to become a leading power with its own means!

In 1905, the destruction of the Russian fleet in the Tsushima Strait took the world by surprise. Japan was done with affronts by the West. The white people were no longer invincible!

After World War I, it became the sole Asian colonial power, it ruled over Korea and Taiwan, and participated in the Treaty of Versailles.

In 1942, it occupied a part of China and a large part of Asia Pacific (Philippines, Singapore, Malaysia, Burma (today Myanmar), Pacific islands, etc.).

The attack against Pearl Harbor on December 7, 1941 resulted in the entry of the United States into World War II.

In 1945, Japan was defeated and signed its surrender on the *Missouri*, anchored off Tokyo on September 2 of the same year. Japan was occupied for the first time in its history.

The country was devastated; the incendiary bombing by General LeMay using the *B-29* Superfortress flying at 1,500 m altitude caused massive destruction, especially in Tokyo. One-third of the capital was burnt; the wooden buildings had caused thermal effects which were previously unknown; the doors of houses went high up in the sky and hit the bombers. The atomic bombs dropped on Hiroshima and Nagasaki put an end to a terrible war.

General McArthur was appointed as governor of Japan. The United States decided to help the country to rise from the ashes fearing that poverty would lead the country toward communism.

In 1947, in order to put the telephone network back on track, McArthur made an appeal to W.E. Deming.

Deming met with the executives of Keindaren, one of the largest associations of Japanese private companies. The ideas of Deming, poorly received in his native country, were adopted by the Japanese.

From 1960, the results expected by the implementation of the Deming system materialized and Japan started to export its products to the West.

At the end of the 20th Century, more than half of American cars were of Japanese origin.



At the beginning of the 21st Century, Toyota was the premier car manufacturer in the world.

Gone are the days when the Japanese product was synonymous with “junk”; before World War II, did Japan not sell watches in kilos?

Human qualities and the intelligence of people accustomed to sacrifice are undoubtedly among the causes of this success. We are interested only in the technological aspects of the “Japanese system” the best illustration of which is the Toyota system.

Deming is inseparable from the Japanese miracle.

The disaster of the nuclear power plants of Fukushima in March 2011 caused by an unprecedented earthquake and tsunami tarnished the image of Japan and the nuclear industry throughout the world. This did not alter anything in the Japanese industrial system and the country’s capacity to react in adversity.

## **10.2. W.E. Deming and Japan**

During his stay in Japan, Deming exhibited his theories of management at popular conferences attended by employers, who put them into practice.

Starting in 1950, the Deming Prize was awarded to Japanese companies that were of the highest order in terms of management. In Japan, Deming was revered as a demigod and received the highest awards.

It was not until 1980 that his ideas started to establish themselves in the United States, due to the supportive collaboration with the journalist Claire Crawford Mason of NBC who hosted a TV show on the theme “*If Japan Can Why Can’t We*”.

This program broadcast the principles of Deming through videotapes that reached university campuses.

### **10.2.1. A brief account of the Deming system**

The Deming system deals with the management of the company, public administration, and education. It is based on process control, coordination of operations, and prediction. Its philosophy and “creed” are expressed in Deming’s 14 points [BRE 99]. His method for continuous improvement is symbolized by the famous Deming wheel or the PDCA (*Plan, Do, Check, Act*) approach described in Chapter 13, “Change Management”.

W.E. Deming was born in 1900 in Sioux City, Iowa in the United States.



He obtained a PhD in theoretical physics from Yale University. He worked for 10 years on nitrogen fertilizers in a laboratory at the Ministry of Agriculture.

In 1938, he took up the post of statistician at the *Bureau of the Census* in Washington DC. From there, he developed statistical techniques from surveys by sampling, which was internationally acclaimed.

He implemented the concepts that Walter Shewhart (1891–1967) had executed right from 1924 in the Hawthorne plant of the Western Electric Co.

*Shewhart was considered to be the father of Statistical Quality Control (SQC) of which the Shewhart Charts represent the most famous element.*

During World War II, Deming assisted the arms industries. With Shewhart, he taught technicians a management system that aimed at improving the productivity and quality of war materials. Not many listened to him.

In 1946, he became Professor of statistics at New York University.

**Box 10.1.** *W.E. Deming (1900–1993)*

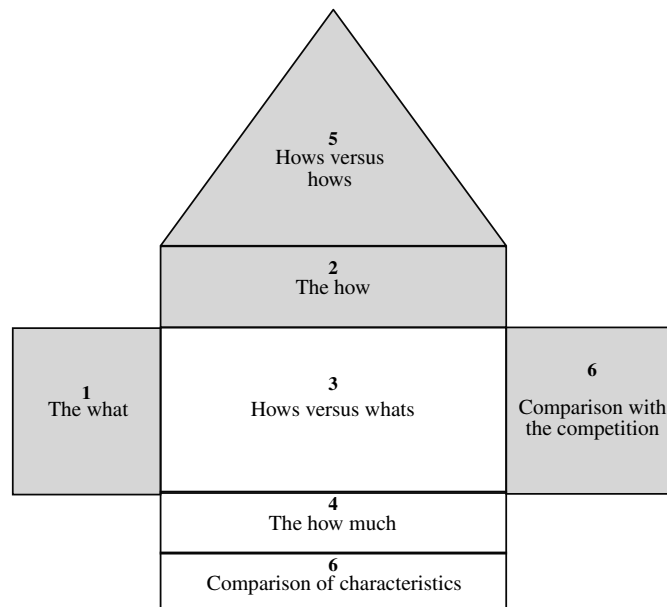
### **10.2.2. The Japanese system from SQC to TQM**

Post-war Japan started to progress in heavy production (metallurgy, automobile industry, and so on), and set up a *QC Research Group* (QC–Quality Control) in order to be able to offer quality products.

This group sought the help of Deming, who was a world-renowned statistician [HOD 92], right from 1949. In fact, the Japanese engineers very quickly recognized the effectiveness of statistical methods in order to correlate manufacturing defects and operating conditions.

Japan moved on from SQC (Statistical Quality Control) toward TQM (Total Quality Management), thanks to J.M. Juran [JUR 98]. TQM included SQC by extending its field of investigation to the actual production, marketing, sales, and so on [JUR 98]. All the processes of the company were reviewed!

TQM aims for customer satisfaction. Japan took on value analysis, developed by Lawrence Miles (see Chapter 9, “Project management techniques: engineering”) [PAR 99], and implemented QFD (Quality Function Deployment).



**Figure 10.1.** The “house of quality”

In 1972, this method was used by Mitsubishi in its Kobe shipyards. It is an accurate method that translates *customer* requirements into *technical objectives*. The basic tool is the “house of quality” (Figure 10.1) which enables integration of quality in the development of a new product at a very early stage. The method requires answers to the following four questions:

– what are the first and foremost expectations that need to be satisfied in order to ensure the commercial success of the product?

- what are the technical solutions that need to be worked on?
- what are the critical points to be examined?
- what are the risks that need to be controlled?

The method takes place in two phases: the construction and deployment of the house of quality. QFD “brings” the customer into the engineering and design department.

The construction of the house of quality includes the following six steps:

- identifying the customer’s needs (Whats);
- defining the technical characteristics of the product to be offered (Hows);
- establishment of the relationship between the characteristics and needs of the customers (Hows versus Whats);
- setting the level of technical performance of the characteristics (How many);
- determining the connection between the characteristics (Hows versus Hows), and ensuring that there is no redundancy or conflict between two characteristics;
- comparing the product with those of the competitors (the comparison).

### **10.3. The Toyoda family – Taiichi Ohno – The Toyota Empire**

Sakichi Toyoda (1867–1930) [APP 10] was the son of a carpenter. He took up the construction of looms. He sold the license of an automatic loom to an English company.

On his deathbed [APP 10], he urged his son Kiichiro (1894–1952) who had the same inventive genius to get into the automobile industry; the Toyota Motor Corporation was founded in 1937.

In 1949, Toyota was in great difficulty; a strike for 15 months had put the company close to bankruptcy. Kiichiro resigned in 1950.

Eiji Toyoda (1913–), nephew of Sakichi Toyoda, succeeded him after several years. He led Toyota for 25 years after starting as an engineer in the family loom business. He described himself as an engineer–manager. He visited the Ford plants in the United States. He reproduced their gigantism but incorporated quality as well. He was considered to be the father of the Toyota system assisted by a man of genius, Taiichi Ohno.

### 10.3.1. Taiichi Ohno (1912–1990), the man of JIT (just in time)



Taiichi Ohno began his career in the textile sector of the Toyoda family before joining its automotive sector in 1939. The story was that during a study visit in the United States, he observed that, in a supermarket, the shelves were not restocked with the products until the stock was almost gone.

*This observation would be the cause of his flash of genius that led him to develop the Kanban system, also called just in time (JIT).*

#### Box 10.2. Taiichi Ohno (1912–1990)

*Kanban* in Japanese means label; a label is attached to the container of machined parts at the upstream post that will supply a downstream production post. The upstream post will not start a new production cycle until the return of the kanban of the downstream post. This is the system of zero inventory; one produces only what one needs [LU 89].

This is control by downstream “flows”. The customer’s requirements launch the production process: it is not the company itself!

This *a priori* simple idea took about 10 years to be implemented, the labor unions opposed it initially. It was implemented starting from the 1960s.

For many authors, JIT is a synonym for “Toyota”. Toyotism is actually a complex system which, in addition to JIT, includes a wide range of methods and tools that propelled Toyota to the forefront of the international scene.

### 10.4. Toyotism

It is difficult for a non-Japanese person to understand this system. Japan is a country whose culture and the type of relationships between people are very different from that of the other countries, especially Western countries. The language barrier makes it difficult to analyze!

The methods involved are numerous; it is not easy to find one's way around! We will try to highlight the salient features of the system.

#### 10.4.1. *General philosophy – principles of management*



**Figure 10.2.** *A Toyota plant*

Toyotism seeks customer satisfaction by providing a quality product that meets his or her requirements [OZE 90].

It believes that wealth is created at the plant, at the *workplace*. The worker contributes to this creation of wealth by being effective, that is by not producing rubbish, while improving his productivity.

Toyotism is a system based on the philosophy of *Kaizen* or continuous improvement. The Japanese quickly adopted the PDCA (Plan, Do, Check, Act) approach of Deming which seeks the same goal. The PDCA approach is discussed in Chapter 13.

Toyotism is the kingdom of TQM (Total Quality Management). This total quality approach was performed without computers, robotics, and other words ending in “ics”, and for a good reason!

Toyotism is also described as the system of five zeros: zero defects, zero breakdowns, zero setup time, zero inventory, and zero paper. Here, zero is synonymous with optimum!

Stock is synonymous with waste; products are manufactured but are not sold, inventories are accumulated because the machines do not work at the same pace. There are bottlenecks, poorly managed constraints, and a lack of synchronism. As mentioned above, *Kanban* or JIT reduces the stocks to the minimum and results in financial gain by reducing the costs associated with the inventory.

There is constant assessment.

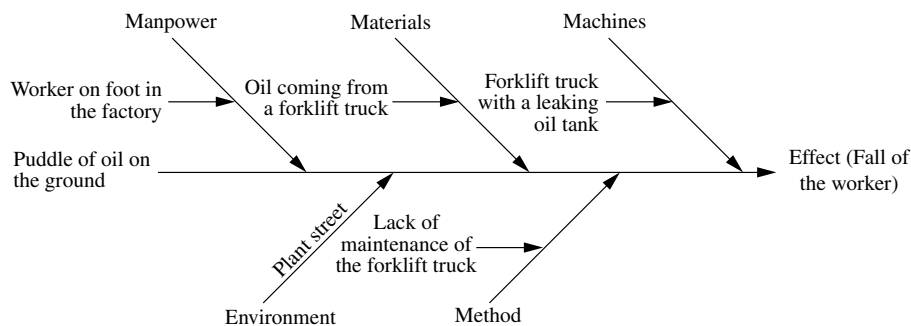
Graphs of all kinds, histograms, bar charts (Gantt charts), pie charts, polar diagrams, or web charts; dashboards giving goals, standard deviations, performance indicators, projections for the future, and so on, with some explanations. These are the essential tools of management reports.

**10.4.2. Problem solving**

The most common method that the West uses easily is the cause-and-effect diagram. This diagram is also called as the Kaoru Ishikawa diagram, named after its promoter, or the fishbone diagram. It makes it possible to establish the connection between an effect (that is observed) and the causes that are likely to be its source [OZE 90].

To classify the causes into categories, one often uses the five M's, which cover: manpower, materials, machines, environment, and methods. But, the categories vary according to circumstances. By being very visual, the diagram clearly shows the structure of causes of the problem, generally put forward during a team *brainstorming*.

EXAMPLE 10.1.– Causes for the fall of a worker on a puddle of oil in the plant.



**Figure 10.3.** Example of an Ishikawa diagram

### **10.4.3. *The KJ method or affinity diagram***

This method, invented by Professor Kawakita Jiro (KJ), an anthropologist, uses Post-It notes. This is the basic tool for solving problems whatever their nature or complexity. The group works on a given theme; each participant formulates his or her idea in a sentence (subject, verb, complement). The sentence does not contain any negation. The leader gathers the Post-It notes on a board. This is a way to structure the brainstorming.

### **10.4.4. *Statistical process control***

Any process has a tendency to drift, either for unpredictable but identifiable causes (power failure, error of raw materials, control error), or for random or unknown causes, also known as unidentifiable causes, which depend on the process (slight variation of raw material, failure of a measuring device, etc.).

Let us recall that W.E. Deming was invited to Japan for his expertise in statistical process control; we have mentioned it above (from SQC to TQC). SQC is an essential tool for zero defects.

### **10.4.5. *Improvements at the workplace***

One of the characteristics that seems to differentiate Toyotism from Taylorism and Fordism is job enrichment, the involvement of workers in improving the working conditions and overall effectiveness.

In this section, we will discuss creating the work environment, quality of ambiance, and the tools that are available for the first level of supervisors.

#### **10.4.5.1. *Visual management***

This is about making the workplace, particularly the plants, “transparent”, pleasant, welcoming, and a place for delivering positive messages. Cleanliness, orderliness, interior design, and display are key factors. Ground lighting, signs, reference points, and maps, so that visitors are not lost, are important and should not be underestimated.

The display of performance indicators related to the commitments of management and staff, and to quality, safety, and the environment helps show that there is dynamism, a desire in the system to move forward. The display of improvement objectives clearly indicates that an improvement plan has been established and is being followed.



#### 10.4.5.1.1. The 5S method [HIR 95]

This Japanese method takes its name from the first letter of five Japanese verbs:

- *seiri* = removing (remove the unnecessary); organizing;
- *seiso* = cleaning;
- *seiton* = setting in order;
- *seiketsu* = standardizing;
- *shitsuke* = sustaining the discipline.

Many Western industrial managers have observed that this method is extremely effective in Japanese factories. It is not sweeping the floor; it is a state of mind that goes far beyond “everything in its place”. It aims to take a fresh look at the workspace.

Fighting the dirt can be very difficult in a process unit that handles powders. In this case, having an immaculate workshop requires redesigning the equipment (no more leakages) and its mode of operation. Tags indicate defects. One part of the tag is attached on the equipment that has a problem; the other part of the tag is displayed on a board of the control room. While entering the control room everyone sees where the problems lie. They must be quickly remedied. This is Deming’s wedge of the PDCA wheel (*shitsuke!*).

#### 10.4.5.2. SMED (*Single Minute Exchange of Die*)

SMED is an organization method that tries to reduce the changeover time systematically, with a quantified objective and is the object of the AFNOR NF X50 – 310 standard. This Japanese method, conceived in 1970 by a Japanese engineer named Shigeo Shingo on behalf of Toyota and an emblematic figure of *lean manufacturing*, consists of finding ways to quickly adapt one machine to another job in batch processes and processes in series. This method is based on the differentiation between internal and external tasks:

- internal tasks are the tasks, whose implementation requires plant shutdown;
- external tasks are the tasks that are not directly dependent on the operating process of the plant.

Preparing for changes in “concurrent operation time” (during the operation of machines), organizing the operations, and adapting the equipment parts can provide significant time, productivity, and financial savings. The method is usually associated with “just in time” (JIT). It is carried out according to the following four steps:

- identification of the operations performed when changing the series;
- separation of internal and external operations;
- conversion of internal operations into external operations;
- rationalization of the internal operations as external operations.

#### 10.4.5.3. *Poka Yoke [SHI 88]*

This other Japanese method consists of relieving the operator from excessive need for attention by using simple tools based on the senses (vision, hearing) in order to prevent breakdowns: it is an anti-error system. It involves defining the equipment items that avoid (*yoke*) unintentional errors (*poka*), organizing himself, being imaginative and studying the work center in detail. The objective of Poka Yoke is to achieve “zero defects”. Poka Yoke was invented by Shigeo Shingo, the designer of the SMED system.

For example, Poka Yoke uses templates so that the worker positions his or her piece on the machining tool without having to take special measures; this saves him or her time and reduces the possibility of errors.

It may use specific fittings for fluid pipes to avoid contamination.

Alarms indicating the incorrect positioning of tools, work-pieces, and so on are put in place.

#### 10.4.6. *Human aspects*

It is difficult to give the name “tools” to the things that involve human beings. However, nothing can be done without methods and without active involvement of the players of the company. It is pointless to discuss quality if employees are not motivated and trained. Training affects team work amongst other things. This is the group which needs to be convinced that progress is necessary and knowledge must be questioned by “foreign” people in the group.

There is no doubt that the Japanese “miracle” owes much to the ability of the Japanese to work in teams, to accept “quality circles”, to progress and to fight for their workspace.

### 10.5. The American response

It was from the 1960s that America, which felt the upcoming Japanese threat, began to think about methods of production management. The APICS (American

Production and Inventory Control Society) was founded in 1957 in Cleveland [KER 89] and has more than 80,000 members today!

It is interesting to note that the word *Inventory* is included in its name. The American response would be at the source of management systems called MRP I and II (Material Requirements Planning and Manufacturing Resource Planning) respectively.

A similar method, the OPT (Optimized Production Technology) method, highly publicized by its inventor, develops the concept of constraints or bottlenecks.

*Re-engineering* was all the rage starting from the 1980s. We will discuss this in Chapter 13 “Change Management”.

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## Chapter 11

# Innovation in Chemical Engineering Industries

In the face of rapid evolution in our society and the rise of new competitors at the global level, and the relative decline of industry in the developed countries over the past 10 years, there are great uncertainties and concerns about the future of our society. The reaction to this destructive slow evolution is very frequently used: “innovation is essential”. As F. Barnu [BAR 10] emphasized, innovation appears to be the ultimate weapon for the West “to deploy” in the face of immense international competition.

From this perspective, innovation takes on an extraordinary dimension, but unfortunately it is also sometimes used as a catch-all response. Soon after the cry of “let us innovate” is uttered, everything remains to be done and nothing is achieved. There are approaches, however, that enable us to have a better understanding of innovation and to help us get our bearings, to act faster and ultimately give us more opportunities that lead to innovation.

Many of these methods are general in nature. Some of them have been adapted for the special features of manufacturing industries, services, or management of organizations. *There are some innovation methods specific to the chemical engineering industries and they are under constant evolution.* While making a connection between the market, technology and our discipline of reference, the chemical engineering, we can imagine that they will evolve considerably in the future.

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Chapter written by Oliver POTIER and Mauricio CAMARGO.

However, there is no “black or white” answer. The *pensée unique*<sup>1</sup> is poisonous to innovation. Innovation is a complex process and there is a large swath of possibilities. This is fortunate, because if there was a single response every time, then it would be very easy for our competitors to know our future implementations and the concept of innovation would become meaningless. Thus, *complexity is both the major difficulty of the innovation process, but also its major asset.*

Innovation cannot be confused with business strategy, but it must be integrated with it. It affects different levels of the company. So, within the company there are not people who must innovate and others who cannot, but on the contrary, it is a win-win process between the departments and leads to innovation.

Innovation has been with us for a very long time. Man has always innovated since the first tool or the discovery of fire, and western industry would not have reached its high level of development without innovations: innovation is synonymous with success.

The basic question about innovation is – what are we looking for? – at least to increase the survival capacity of the company (by retaining or growing its customers) and if possible, to increase its revenues. Ethical and environmental dimensions could be added, depending on the actors within each company. However, the evolution of the world, new needs, as well as what is represented by the third paradigm of chemical engineering [CHA 10, HIL 09], expands this concept of innovation by integrating the economic and social issues to the service of mankind, i.e. the integration of sustainable development issues: rational development of our industry, energy management, competition and international cooperation, health (notably emerging contaminants [RIC 11]), entrepreneurship, resource conservation, understanding society and its needs, preservation of industrial heritage, etc. This results in a growing demand for new processes: shorter implementation time (finding the solution faster), more flexible process units (reconfigurable, the product lifecycle becoming shorter and shorter), manufacturing of high quality products with a lower and safer ecological footprint, etc.

We must move towards a sustainable and competitive chemical engineering industry [CHA 07].

But before talking about innovation methods, let us recall what innovation is.

### 11.1. Definition of innovation

Innovation involves several levels of the companies and organizations. We thus have product, process, service, organization, or business model (for example, a

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<sup>1</sup> Here, a general meaning of this French expression, applied in several domains is implied. It highlights the fact of approach a particular problem, under a unique point of view.

recent innovation in the business model was the introduction in many countries of free newspapers and their mode of financing).

In the field of chemical engineering industries, it is clear that we are strongly concerned by the innovations of products and processes. However, other types of innovation may also have their places. The organization of the company can be improved or changed. For example, the introduction of *Open Innovation* (see section 11.4.4), is an organizational innovation that is contributing now to the creation of product and process innovations in some companies. Service innovation can also be an important leverage for some chemical engineering industries, for example by focusing on the functionality of certain products (e.g. physical or chemical properties) instead of talking about the products themselves.

It is interesting to note that sometimes the product sold may also be a process. This is the case in the field of equipment manufacturing; for example, a reactor of a wastewater treatment plant: this is a complex process sold as a product, which provides a service (to transform wastewater into clean water, which is meeting the requirements of regulations and which can thus be released into the natural environment). The concepts of product innovation and process innovation, and even service innovation, can thus sometimes cross over.

From the perspective of IP (Intellectual Property), the strategies to protect a process innovation can be very different if they involve a process innovation that can be kept secret within a company (and therefore closed to an outside view), or if they involve a process innovation sold as product, which will be found easily by contacting the competitors, and which may require patent protection.

It is also important to note that innovation is not invention. Innovation includes the concept of novelty (sometimes invention), which goes to the state of manufacturing (or of implementation for services and organizations), and which finally meets market success; innovation is therefore not just novelty.

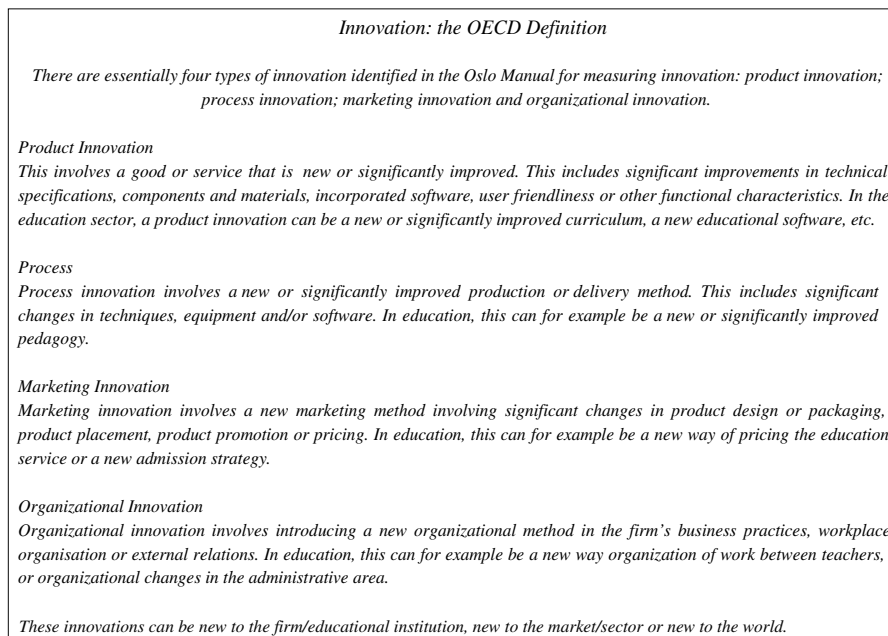
Innovation is a complex process that finds its advantage and purpose in the significant improvement or commercial success that it brings to the company.

There are several alternatives to the definition of innovation. One of the most famous is that of the OECD (see Figure 11.1). It highlights the concept of significant improvement. OECD recently insists on the concept of success; for example commercial success, for products [OEC 05].

To complete the definition, we can define innovation according to the importance of its effects: incremental innovation, which sees small progressive and almost continuous effects, or breakthrough innovation (or *radical innovation*),

which induces a dramatic change, and which can have significant effects on the company. They are often compared, because incremental innovation can strengthen the dominant position of a well established company in the market, and breakthrough innovation can allow a new company to emerge in the market, but can be difficult to manage for a company that already has a dominant position.

However, as breakthrough innovation is sought after (and sometimes difficult to obtain), these two types of innovation are complementary. And incremental innovations will often gradually improve breakthrough innovations (see Figure 11.2).



**Figure 11.1.** Definition of innovation according to the OECD

A more detailed description of the types of innovation was proposed by Henderson, Clark and Tushman [HEN 09]. For product design, they propose to take into account the different components constituting an “object” and the manner in which they are organized (connection between them), which they call the product architecture. For example, for a fan, the various components are the motor, the propeller, the foot, the debris guard, and so on. However, it should be noted that the combination of certain components can play on the architecture gathering them together.



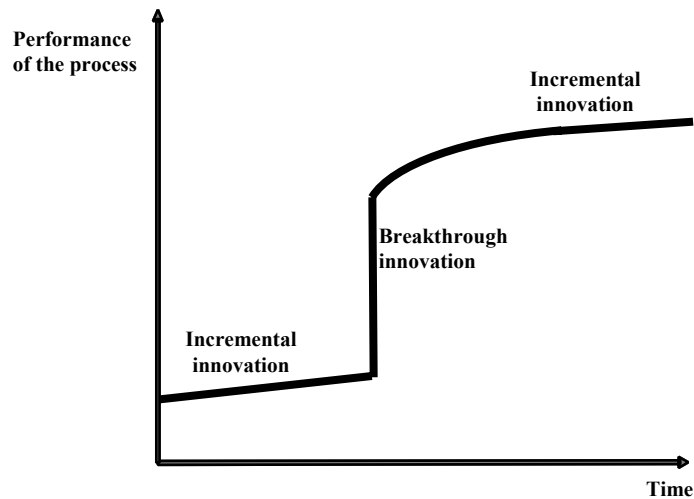


Figure 11.2. Breakthrough innovation and incremental innovation

We can thus define innovation according to two criteria: the evolution of one or more components and the evolution of architecture. We thus obtain four types of innovations that also include conventional types (incremental and radical):

- incremental innovation, small changes in the components and architecture;
- modular innovation, no (or small) change in the architecture but big changes in at least one of the components;
- architectural innovation, big change in the architecture, but not in the components;
- breakthrough innovation, big change in the architecture and components.

In the process industries, we can compare these types of classification with the process description by unit operations or processes. The process can thus be seen on different scales, the concept of component being associated with different devices:

- either on the one hand, various components constituting a unit operation (describing the architecture of the unit operation);
- or on the other hand, the unit operation representing a single component (describing the architecture of a workshop or a plant with several unit operations).

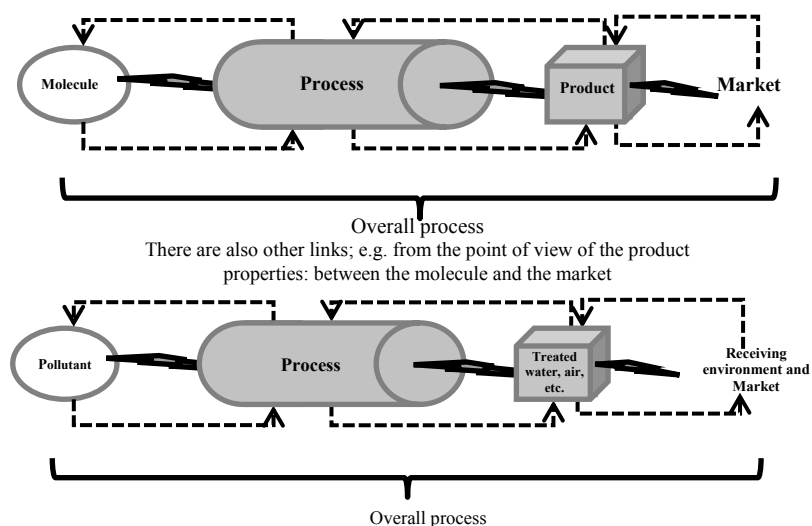
In this case, although the components cannot be associated equally, the architecture of process units can be studied from this point of view, for example to improve its flexibility.

Another type of innovation, often called disruptive innovation [CHR 97], affects the products (or processes, etc.), which do not provide real technical improvement (or even use inefficient technologies), but that finds by its characteristics (low cost, or very specific application domain, etc.) a niche market, and that finally meets success by progressively invading a large market. This is, for example, the case currently with the success of low cost cars in many countries.

Innovation is thus, in this case, more in the concept of use of the product than in the product (or the process) itself. For this reason, some refuse to talk about innovation here, even if there is a commercial success.

### 11.2. Field of innovation in the chemical engineering industry

The fields may differ depending on the type of innovation involved (product, process, process sold as product, service, organization, etc.). However, the broadest field of innovation is the one dealing with the product, starting from the evolution of the molecule and reaching the market, going through changes in processes (see Figure 11.3). We then realize the complexity of this process requiring staff capable of discussing among themselves and of understanding each other, from research and development department, the design office and so on, up to the marketing department. This requires a multiple, cross and multiscale approach, with more and more multi-disciplinary competencies as well as creativity. Here, each service should not allow its specialized competencies or be diluted in transversality.



**Figure 11.3.** Field of innovation, case of a chemical process from the molecule to market, and case of a pollutant treatment process

On the contrary, the goal is that each specialist remains strong in their own field, but they must be able to communicate and understand people of other services. This refers to the *T-shape* [IAN 93]. The vertical line of the T symbolizes the specialist, and the horizontal line, their ability to understand and communicate in other domains.

Some companies have embarked on this very effective approach, but now it is still common to see that conflict arise in some other companies between marketing and R&D departments; one accusing the other of not understanding customers, the other accusing them of not understanding the technological constraints. These problems can diminish the innovation capacity. Thus, an ill-defined concept of customer–supplier between R&D and marketing services can be a source of conflict. A department of the company is not at the service of the other, but both have to work together toward the same goal.

*The suppression of complexity may lead to conflict, but once better controlled, the complexity is also a great source of innovation.*

This transversal vision (and mutual understanding) within the company is now essential to develop a sustainable and competitive industry.

This new innovation, integrating the constraints of the changing world, requires what we call *Creativity Under Constraints* (scientific, technological, economic and sustainable development constraints, etc.) to reach new results that are adapted to multiple requirements (see section 11.4.1).

### **11.3. The need for innovation**

Most companies and countries are now investing more into innovation. At the end of the decade, despite the economic crisis of 2008, the amounts of investments in public and private R&D hadn't stopped increasing [OEC 10]. To paraphrase A. Hatchuel, we are in an innovation-intensive capitalism. Several factors determine nowadays this race for innovation. Among others, we can cite:

- the constant renewal of products, as a result of more demanding consumers, who are better informed and who demand a product and personalized associated services;

- the adaptation of the industry to this demand has led to new organizations in order to enable a quick response at a lower cost. For example, the modularization of the manufacturing systems has enabled us to reduce the development lead times of new products, while components, subsystems, or finished products end up going everywhere in the world before reaching the final consumer [BER 06];

– the convergence of technologies, as opposed to a mono-disciplinary vision, has allowed us to multiply the possibilities of products and to expand their field of application. For example, collaborations between nanotechnology and biotechnology are opening up a range of applications which have so far not been imagined in fields as diverse as health, environment, or industry;

– the constraints of energy security, which now force us to look toward new sources and to overcome the technological obstacles of current solutions; e.g. in the automobile industry, with the evolution of new (electric, hybrid, fuel cell) motorizations and the continuous improvement of the heat engine in terms of consumption and CO<sub>2</sub> emissions;

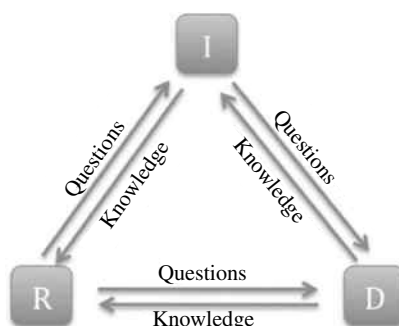
– the sustainability and environmental constraints, as a consequence of climate change that directly affects the productivity of agricultural lands and the availability of food for a constantly growing population.

All these factors together, and many other factors, mean that pressure and constraints on the company are permanent. In an uncertain context, innovation will take on an even greater importance as a key factor in the survival and growth of companies. In view of the R&D investments, companies and governments seem to be aware of this constraint. But the advantage cannot be limited only in quantitative terms of investments. New approaches that can increase the effectiveness of the innovation process prove to be necessary, because despite the efforts and progress in terms of creation and development of new products, the success rate of the innovating process remains very low (14%, according to a study by Cormican and O'Sullivan [COR 04]).

On the other hand, the traditional vision of R&D as being the only source of innovation in the company seems to reach its limits. Le Masson *et al.* [LEM 06] have proposed the emergence of a new feature of innovative design (I) within the companies.

In fact, they define Research (R) as a controlled process of knowledge production, and Development (D) as a controlled process that activates the existing competencies and knowledge in order to specify a system. The function (I), allows for the co-evolution of competencies and products. In other words; (I) must activate (R) and (D), which makes it possible to organize new cross-domain possibilities (see Figure 11.4).

The work of *Le Masson et al.* [LEM 06] illustrates, according to an account of *Hounshell and Smith* [HOU 88], how in the innovation of nylon 6-6 by the DuPont company, a result of the function (R) had to wait for several years so that a stakeholder, function (I), identifies the potential value of the result of this research by an application in the textile industry: nylon stockings.



**Figure 11.4.** Relations between R, I, and D (according to [LEM 06])

*Short history of nylon [ROB 83]*

*Nylon changed the history of the Dupont company forever and became the first entirely synthetic fiber, and also the first big success of this company. Used today for a wide variety of applications such as mechanical parts, guitar strings, parachutes, and all types of textile products. Here are some highlights of the history of its creation.*

– 1927: Dupont decides to launch a research program without any clear commercial objectives, which was dedicated exclusively to artificial materials in the department of Elder Bolton (he became the head of the chemistry department in 1930). In fact, he had a true prospective and commercial vision of the researches he would undertake, his goal being to replace natural materials, especially for the automotive industry, which was growing strongly. He hired external academic consultants. At this time, this was a first.

– 1928: Wallace Carothers, until then an assistant at Harvard, is appointed to run the technical team. He started the research about obtaining polymers from basic constituent elements. For this, he developed a process that eliminated the need for hydrolysis of synthesized molecules, which deteriorates the technical performances of finished products.

– 1930: a member of the team (Julian Hill) obtains a material for the first time, which is very solid after cooling.

– 1932: the research program is stopped, because the fibers obtained hitherto from aliphatic esters, presented more penalizing problems for a textile fiber: very low melting point and solubility or instability of organic solvents.

– 1934: Bolton refusing to give up, relaunches the program. Carothers decides to direct their researches more around polyamides. By relying on the results of

the team which indicated that the most promising monomers were those of the C5–C10 order, Bolton decided to use benzene, a raw material that was available in large quantities for industrial processes. Thus, adipic acid and hexamethylenediamine, both derivatives of benzene, were selected as raw materials for polyamides (future nylon).

– 1935: the first filaments and fibers of nylon 6-6 are made. Their melting point reaches 263°C, an acceptable margin to withstand ironing temperatures.

– 1938: patent filing and release of the first commercial product using nylon: toothbrush bristle.

– 1940: marketing of the first womens stockings; in the first year, 64 million pairs of stockings were sold in the United States.

– 1941: during World War II, most of the production was dedicated to the manufacture of parachutes.

– 1945: second launch of nylon stockings; thousands of people are queuing up in front of the shops.

*The creation of nylon was not only a technological and commercial revolution, but also a great scientific breakthrough, which required the development of new processes by Dupont.*

**Box 11.1.** *The saga of nylon*

#### 11.4. Methods for innovation in chemical engineering industry

Innovation methods adapted to the chemical engineering, or created especially for it, should take into account the technical and technico-socio-environmental-economic parameters, i.e. sustainable development which, in its global vision, also includes the problems of energy, health, etc.

The two most classical innovation strategies are: Market Pull and Technology Push. The first faces innovation and the business strategy through market analysis and its potentialities. The second strategy starts from the technological (and scientific) evolution in order to create new products to be supplied to the market. These two approaches can sometimes be very effective. They are opposed in their principles and applications. It can also result in an incapacitating opposition between certain departments of the company (see section 11.2). However, it is possible to overcome this opposition and combine these two methods, by not leaving the prevalence to one or the other, but by allowing for a real exchange between the departments: *the market analysis and research results taken together in a continual exchange, are together important sources of innovation.*

Other approaches can effectively lead to innovation. They are process approaches that we will develop further.

Nowadays, we teach these methods to engineering students, by integrating the concept of “Creativity Under Constraints”, in order to enable students to obtain this *T-shape* profile.

#### 11.4.1. Method of “Creativity Under Constraints”

Why have we added the term constraints to the term creativity, which represents a certain kind of freedom? This is not about a terminology only affecting mechanics, or that evokes unwanted developments. The term is to be taken as a whole (scientific, technological, economic and sustainable development constraints, etc.).

Creativity sessions often occur in two steps.

The first step, also called *divergence*, seeks to promote the emergence of new ideas, and for this, it is important not to cause any deadlocks by the criticisms that would make difficult the process of idea creation, such as: what you say is not realistic; it is not economically feasible; or we do not have the resources, etc.

This process is easy for some and difficult for others. Besides, this is not very surprising because, generally, people are not trained to do this. The selection and training process in Western economies is mainly based on convergent intelligence, which enables students to produce solutions (and to focus on them very quickly) from things that have been learnt; this is mostly favorable to reproduce the existing, but not for promoting the emergence of new solutions, then of innovation.

This first phase of free creation is thus fundamental. There are many methods such as Brain Storming, to facilitate the process. A good summary of the methods is presented in the *Techniques de l'ingénieur* [VID 98].

The second step of the creativity process, also known as *convergence*, allows for the criticism and selection of the ideas proposed in step 1. They are closely remained through different criteria such as scientific, technical, and sustainable development criteria, etc. Some of these analyses can be very fast, and others will require additional studies or tests prior to validation.

By applying these techniques in companies or during the training of students, over the last few years, it seems that these two stages are often not sufficient to create new and concrete ideas. On the one hand, the blocking process in step 1 is not always overcome, but on the other hand, paradoxically, it seems difficult for some

scientists and technicians to produce realistic ideas. We thus reach a dichotomy: on one side, ideas, and on the other, constraints, with no common ground leading to new and concrete ideas.

This is why we have set up a third step, the phase of *Creativity Under Constraints*, which corresponds to a production of ideas by taking into account, the scientific, technological, and social constraints, etc. The number of ideas provided in this step is less than those produced in step 1, but the proportion of concrete and achievable ideas is much greater.

Steps 1 and 2 are still necessary, as they gradually lead to the ability to generate ideas and to criticize them.

We can notice that during step 3, *the identification and study of constraints will often become a source of new ideas*.

This step of *Creativity Under Constraints* can be facilitated by also using other methods, for example by combining the market pull and technology push strategies (see beginning of section 11.4). In this regard, it would be better to generalize this second term into *Science and Technology Push*. More conceptual scientific dimensions can be added to this case as a basis of reflection; for example, constructal innovative approaches [TON 04].

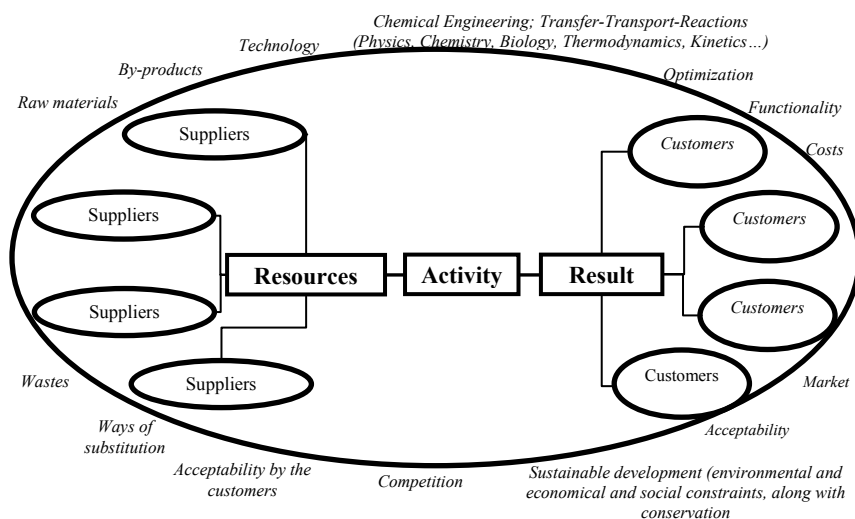
Another method can be derived from the RAR approach (Result-Activity-Resources) which represents the process operation, such as a workshop, a company, or even problem resolution. It is generally used to identify the activities, and then the necessary resources to achieve a goal: the result. This corresponds to the market pull approach.

This RAR method can also be transformed and integrated in different ways at the third step, for example:

- with our (financial, technical, etc.) resources and taking into account the market, what product can we make by changing few of our activities?
- or, by changing some of our resources (e.g. raw materials, new competencies) and part of our activities, what product can we make?
- etc.

RAR is often used as a simple tool for business strategy. Sometimes, it is integrated into the customer–supplier approach, but all the constraints can also be added to it (see Figure 11.5).





**Figure 11.5.** Example of generalized RAR to present different socio-technico-economic-scientific constraints

#### 11.4.2. Approach by the TRIZ method

In contrast to the above constructivist methods, for which the ability to generate ideas depends on the inherent creative competencies of the participants, the TRIZ method proposes a positivist approach, where the technological problems are reformulated, and analyzed from different angles or principles [CAV 99]. This is a method of creativity, whose Russian acronym means theory of inventive problem solving. It was developed by the Russian inventor and scientist Genrikh Altshuller (1926–1998).

Altshuller found, after analyzing hundreds of thousands of patents, that there is an algorithm for solving an engineering problem. He also proposed a set of generic creative principles. The TRIZ method is implemented at the beginning of a design process [BOL 07]. It is used:

- in a prospective manner, to explore new concepts on future products;
- to resolve recurring technological problems or deadlock situations on the existing products and;
- to anticipate the ways of product development [ALT 99].

In order to have a general overview, we will cite the five key notions on which the TRIZ method is based:

– *contradictions*: TRIZ prohibits any direct transition from the initial problem to the solution, as well as compromises. Thus, any problems that have to be solved with TRIZ should be stated under the form of a contradiction, which the search for solutions will have to face. A contradiction must be aimed at improving one parameter, without degrading others;

– *resources*: these are substances, energies, pieces of information, etc. necessary for a technical system;

– *ideal final result*: consists of describing what we wish to obtain in the ideal case. It is a fantasy of the mind, an unattainable dream destined to open the pathway for problem solving;

– *laws of evolution*: G. Altshuller formulated eight laws of evolution of technical systems. Their knowledge would help to solve invention problems, and even to anticipate their appearance. Any technical system goes indeed through four ages: 1) evolution toward a successful combination of its parts, 2) development toward the ideal via the priority perfection from the least-effective part, 3) acquisition of dynamic properties (combination or fragmentation of parts) and 4) transition toward a self-controlled system (automation);

– *psychological inertia*: preconceived notions, tried and tested use of solutions, expertise, professional jargon, etc. are obstacles to creativity. They lead to self-limiting.

Currently, the TRIZ method is increasingly used by companies as large as Motorola, Dow Chemical, Unilever, Siemens and Intel [JAN 06]. A significant number of companies are still skeptical because they see in TRIZ the quest for an equation for innovation, which removes its unique character. Others see it as one more approach, just like the Six Sigma or Lean Manufacturing, which helps to improve the performance and productivity of companies.

It should be noted that TRIZ is designed for the manufacturing industry. It takes care of different functions that are found, for example in mechanics, but it includes only just a few of the many processes of chemical engineering.

TRIZ, in its initial configuration is therefore not very suitable for chemical engineering industries, but its adaptation could be very useful. Its application therefore remains limited compared to other fields of engineering [COR 09]. However, we can cite the works of Hipple [HIP 05] on TRIZ applied to the analysis of process failures, or those of Le Lann [LEL 07], which explores the application potentialities in the field of processes, or still the works of Cortes Robles [COR 09], where the authors propose an innovation accelerator applied to chemical engineering. This accelerator consists of two parts: the first is focused on incremental innovations and based on knowledge management (case-based reasoning), and the second is focused on radical innovations and based on a TRIZ algorithm.

### 11.4.3. Management of the innovation process

#### 11.4.3.1. Technology: a complex system

Hammel & Prahalad [PRA 90] defined the core competencies (or technological competencies) of a company, as not only being the differentiating factor enabling the company to be competitive, but also as the most important component of the technological capital that must be managed to innovate.

Thus, controlling the evolution of the key-competencies of a company cannot be reduced to launching a research program or changing the equipment of a process unit. To remain at the forefront of technology, a patent, a machine, or a particular process is not enough; we must also be able to rely on the competencies of men and on managerial practices.

Later, Leonard Bauton [LEO 95] defined the nature of these core competencies as being constituted by four principle dimensions:

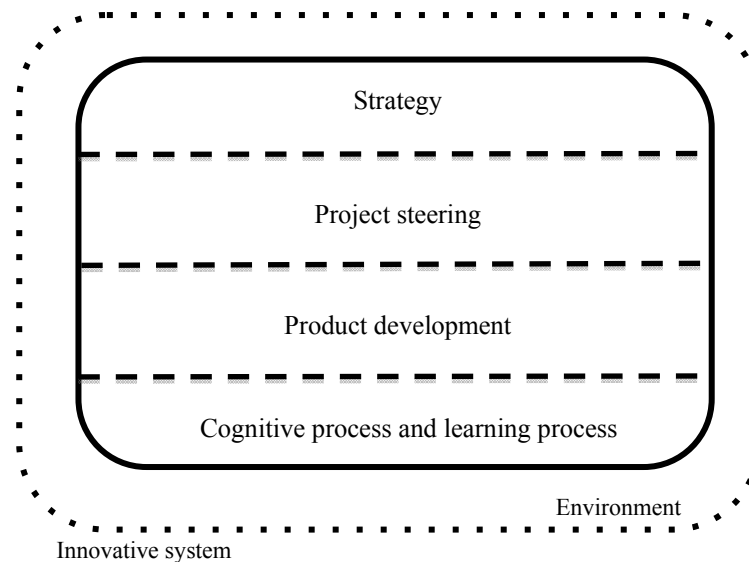
- physical systems;
- the skills and knowledge;
- the management systems encouraging knowledge creation;
- the values of the organization that guide and channel knowledge creation.

Any innovation process must take these dimensions into account. This idea is also reinforced by the concept of technological system [CAS 87], which expresses its competencies as being constituted by a core, which corresponds to the scientific and technical know-how, surrounded by a set of related competencies, such as financial, economic, managerial, or logistical competencies.

In all cases, the innovation process must be studied from a systemic point of view, as several levels of the company intervene in its implementation. This explains its interdisciplinary and multiscale nature. Indeed, the success of the process is ensured by the coordinated interaction of a set of stakeholders and tasks. These stakeholders must work in a synchronized way and their associated tasks are performed simultaneously and/or sequentially, with decision making at every levels. Boly and Morel [BOL 06, BOL 08, CAM 09] have defined four main levels: the *strategic* level, the *project management* level, the *product development* level and the level *of the individuals (cognitive process and learning)* (see Figure 11.6).

Every project fits in this innovation system, which will be more or less complex depending on the line of business and on the type of innovation to be marketed. However, taking into account the different levels will help to better control the innovative process, with the aim of reducing uncertainties.

- *Strategic level*: definition of the strategy.



**Figure 11.6.** *Intervention levels of innovation engineering*

This strategy is defined by taking into account the context in which the company evolves, but it should aim at defining the main lines that will determine the future and nature of the project, as well as the resources and effort that will be allocated to it. Thus, any new definition of an innovative project should be assessed with respect to this level.

The characteristics of a new project which will be defined at the strategic level are: the temporal space in which it can take place, the allocated budget, the technological and commercial risks involved, and the impact (customer and field).

Two main lines of projects can be differentiated: the current projects and the major projects. The current projects: they correspond more to a defensive development; thus the company will favor improvement projects (incremental innovation), short term projects, and projects with limited budgets. Major projects: correspond to a conquest development, in which preference breakthrough innovations will be favored, in the medium or long run, and which have larger budgets.

– *Project management level*: from an idea to a new technology.

This level concerns the ability and effectiveness with which the company system is able to market new products or new technological solutions.

It primarily affects the development of competencies, technical resources, and project management making it possible to follow the evolution of an innovation project and if necessary, to take the necessary decisions to make corrections [COO 05, KLI 86]; for example, the integration in the last few years of technologies enabling us to develop the products faster and to reduce the development cost. We can cite, among others, PLM (*Product lifecycle management*) systems, simulation and modeling tools (molecular simulation, process simulation) or platforms-products.

It also concerns the innovative ways to make the whole process more effective: for example, the valorization of intermediate products and use of external resources, as it is the case in open innovation, which has been today at the center of the innovation strategy of companies like P&G [CHE 03], or else the growing trend to integrate the user at the center of the design process, not only in a validation role, but also as a co-creator of the new innovation (user centered innovation).

– *Product development level*: an integrated vision.

Here, the word product is taken in the broadest sense: it concerns all that is affected by innovation. Thus, it can also be a process or an organization.

This level concerns a global vision of the product based on its constituent components (e.g. material), its architecture, its functional properties of use, or the acceptability criteria of the customer. This subject will be developed in section 11.4.3.2.

This level includes all the stages from the potentially innovative idea, by passing through the intermediate stages (e.g. test, model, prototype, or associated tools), up to the finished product.

– *Level of the individuals* (cognitive process and learning).

It reconsiders points seen previously, especially in sections 11.4.1 and 11.4.2, with the need of thinking differently, to analyze paradoxes and contradictions, to develop imagination and the creativity then associated with cognitive reframing, to take into account the parameters under different aspects of science and technology but also non-technical parameters, and in some situations, to use systematic methodologies of types: TRIZ, knowledge reuse, usage analysis, and prospective.

#### 11.4.3.2. *Product development: a new integrated vision*

The concept of innovation, beyond the design of a new product or its associated process, is fundamentally linked to its success in a given market. This success is now more than ever, determined by a set of economic, environmental, and social

constraints in constant evolution. As J. Villermaux [VIL 93] had anticipated, this complexity implies that a vision exclusively focused on the technical performances of the product or on the optimization of the process yield, is not relevant anymore.

Indeed, in process chemistry and engineering, the term product development was traditionally associated with synthesis, experimentation, and calibration at the industrial level of a product [HIL 09]. Most of the efforts are allocated to these stages. However, in other fields of engineering, the term product development is used in a broader sense that also includes the properties of use, perception of the user, or the study of the associated supply chain [ULR 08].

In the last few years, we have witnessed the rise of a new global and integrated vision of the design of chemical products in the scientific community [CHA 00, CHA 02, EDW 04, GAN 05].

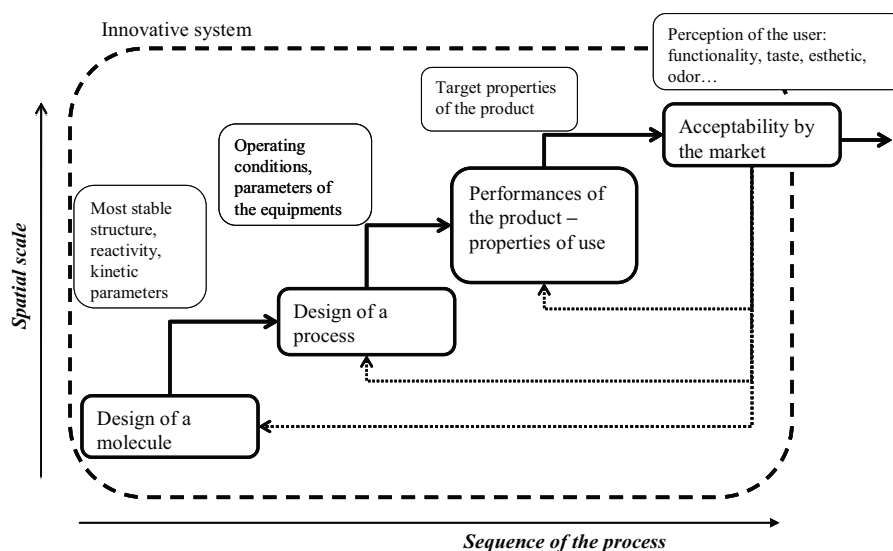
This dynamic will help us, in the forthcoming years, to better represent its complexity and therefore to get closer and closer to the reality of the innovation process.

This phenomenon was facilitated by several factors, including:

- the emergence of conceptual frameworks or metamodels, which allow logical bridges between different design fields. As an example, we can cite, the [SUH 01], in which product design goes back and forth between four related spaces: the space of consumer attributes, the space of the product functional requirements, the space of physico-chemical and biological properties of the material, and the space of the process variables;

- the level of the sophistication attained by tools such as the *Computer Aided Process Engineering* – CAPE tools, thanks by the development of process computation, simulation, and optimization capacities at different scales (from the molecule, by going through the industrial process, up to the associated supply chain). This makes it easier to establish and formalize the existing links between the different design levels and spaces and to seek an optimization of all of its components [GAN 05];

- advances in decision engineering by the integration of the decision maker, the point of view forms an integral part of this global vision. There are thus nowadays decision support techniques, in particular multicriteria analysis, and multiobjective optimization [AZZ 01, FON 04, MAS 03]. They enable the formalization of for example: user perceptions, the uncertainty of the measurement or to simultaneously handle the criteria belonging to different dimensions, such as ecology, product performances, or the efficiency of the associated process. Some of these techniques enable us to link the sought after product properties to the process operating conditions [CAM 11].



**Figure 11.7.** Overview of the innovation process

In Figure 11.7, we propose an overview of the whole process, of the spaces, variables, and associated interdependent criteria.

*Example of application for the optimal product–process design by using the multicriteria analysis.*

In the polymer industry, engineers always seek to obtain, with the highest productivity and the lowest cost, macromolecules with characteristics adapted for specific usage properties for a targeted market. The optimization of manufacturing processes thus takes on a multicriteria nature that will have to result in the best possible compromise.

This example concerns the optimization of batch polymerization in styrene and  $\alpha$ -methylstyrene emulsion; for more details please refer to [JOL 08, CAM 11]. The multicriteria optimization procedure chosen is based on the use of an evolutionary algorithm and on the concept of domination in the Pareto sense<sup>2</sup>. Thus, potential solutions, optimal in the Pareto sense, have been generated from a simulator of the process (including, in particular, material balances and stoichiometry).

<sup>2</sup> In a multicriteria problem, for which we seek to simultaneously optimize several contradictory objectives, this consists of finding all the points of the research space, so that there is no other better point on all the criteria simultaneously.

Subsequently, a decision support system, using a method of multicriteria analysis, has been developed to determine the optimum operating conditions taking into account the preferences of a decision maker with a view to obtain the target product.

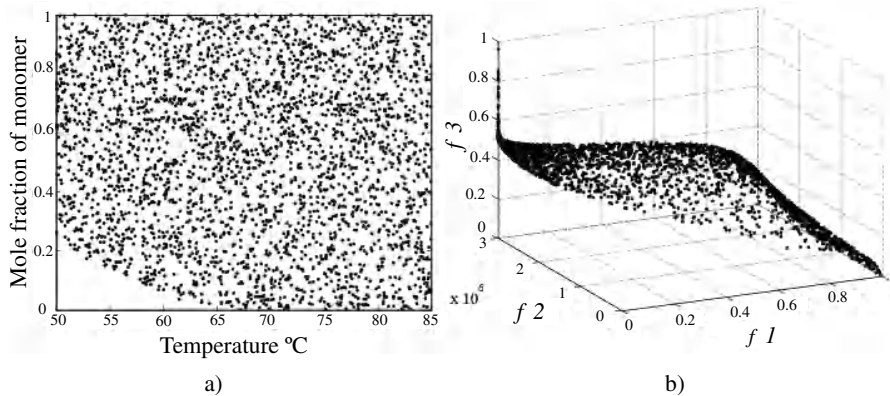


Figure 11.8. a) Pareto zone and b) Pareto front

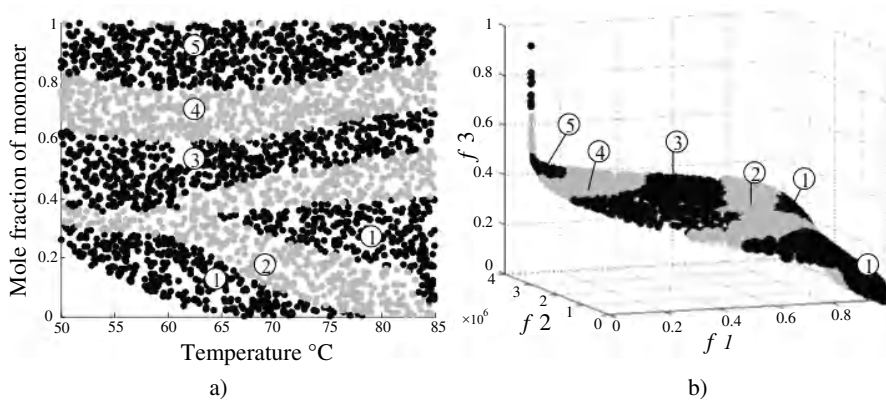


Figure 11.9. Classification of the best solutions by quintiles from 1 to 5 of the Pareto zone (a) and of the Pareto front (b)

The left-hand side of Figure 11.8 shows the Pareto zone of optimum points, a space of variables of the operating conditions of the process (temperature and mole fraction of the monomer). However, it covers almost the entire studied area. The right-hand side of Figure 11.8 shows the Pareto front a space of criteria of the use value of the product, which makes it possible to visualize the phenomenon by



presenting a surface in a 3D space. We note that it is absolutely impossible to simultaneously maximize the objective functions  $f1$  (monomer conversion) and  $f3$  (reaction yield), all the while minimizing  $f2$  (the difference between the target molar mass and the actual molar mass).

However, if the first phase of multicriteria optimization gives a very broad result, using a decision support system will help to give recommendations.

This approach makes it possible to take into account the experimental observations and the know-how of the product and production experts in order to determine, but also to assess the interactions between the variables. A classification of operating conditions, with the help of an overall assessment index, makes it possible to identify the most interesting parts of the Pareto zone (see Figure 11.9). In addition, obtaining a reliable classification subsequently helps to better integrate the consumer preferences, and also to determine the optimum operating conditions and new design spaces.

The study and application of multi-criteria analysis methods are useful nowadays, since decision-making in design is becoming more and more integrated with the dynamics and constraints of the entire organization. Thus, among others, the application of a decision support method takes into account:

- the various levels of analysis, to which a design object pass through before its industrialization (strategic, tactical and operational levels). The actions or resulting measures are developed through a long and complex process mobilizing many actors. In design, there is not one decision or one decision maker, but a series of strategies and compromises between different viewpoints, or between groups that do not share the same solution;

- often, given the complexity of the process, the taken decision does not respond to optimality, in the mathematical sense of the term, but rather to a satisfactory solution [GRA 96], which takes into account the maximum information (criteria) that brings the problem closer to reality;

- the aggregation stage is part of every multicriteria decision-making process where the assessment is performed according to several criteria and several experts, especially in subjective evaluation [GRA 96].

#### **11.4.4. *The company organized to innovate***

##### **11.4.4.1. *Open innovation***

On 7th July 2003, the Businessweek journal, entitled its front page “The P&G revolution” explained the breakthrough approach of the CEO, Mr. Langley, which

allowed P&G to significantly reduce its R&D expenditures, while retaining its innovation dynamics in terms of the introduction of new products in the market. In fact, this company is the largest producer of consumption products in the world, is more than 170 years old, and is recognized in the world for its technological capacity based on a powerful internal R&D. This company decided to incorporate more technology coming from outside.

The objective was not only to integrate the innovative capacity of its thousands of commercial and institutional partners, but also to enhance its own technological capacities toward the outside, such as selling royalties to other lines of business.

The strategy was setup through their C+D (Connect and Develop) program [HOU 10]. Thus, with the help of their Website, for example:

- inventors can visualize the current needs of P&G and propose their inventions;
- subcontractors may propose a specific cooperation to develop a new product;
- other companies can browse the list of technologies that P&G is offering for purchase.

The aim of this approach is to help P&G to get easily in touch with subcontractors or global inventors, who have technologies that can meet the requirements of P&G. In addition, due to the sale of patents and licenses to companies that do not compete with it, P&G collects additional funding; with a bit of creativity, there can be very many applications of their patents in other core competencies.

In order to better understand the concept of open innovation, let us look at how the innovation process was traditionally applied. In fact, this process is often represented in the form of a funnel (see Figure 11.10), in which a set of ideas and concepts are filtered in a systematic way until they obtain the product or service best adapted to the market. Usually, this process is carried out by the individual investment of a company, and by using its internal resources and keeping them within the company. This traditional vision can be called closed innovation.

In contrast to this traditional vision, H. Chesbrough [CHE 03] has proposed the idea of an open and distributed innovation process. In fact, he has identified several factors, which currently make the closed model no more effective (effectiveness in terms of the effort necessary to create a new product).

Among other factors, we can mention:

- the mobility of the most competent people;
- the worldwide distribution of knowledge (before it was concentrated locally);

– the information and communication technologies that facilitate the collaboration with the suppliers and partners, but also with the users.

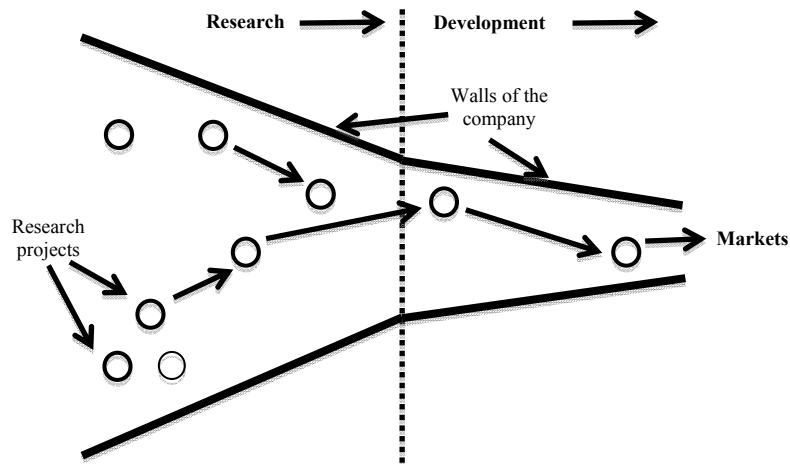


Figure 11.10. Traditional view of the innovation process [CHE 03]

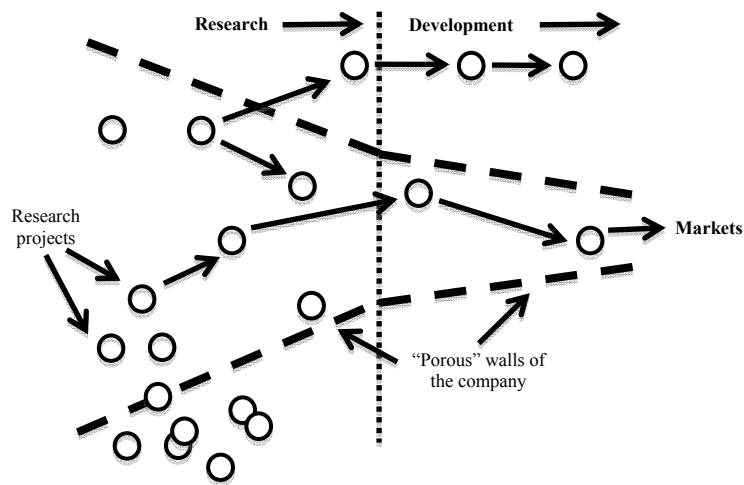


Figure 11.11. Representation of open innovation

This view naturally leads us to look toward the outside and to cross the walls of the company to engage external sources in the innovation process (see Figure 11.11). Thus, Open innovation is often described as the combination of

ideas and internal and external resources, in order to improve the development potential of new technologies.

In this vein, the external sources, processes, and infrastructure required to apply this approach take a fundamental role:

- sources: partners, spin-offs, universities, and users (communities or individuals);
- processes: all forms of intellectual property management, (in-out) licensing, patents, partnership agreements, and so on;
- the infrastructure: communication technologies, Internet in all its forms as well as its actors, virtual reality, simulation, etc.

In this vein, the control of intellectual property becomes a decisive factor in the success of the implementation of such an approach. Currently, many companies deploy initiatives to promote the implementation of open innovation. We can mention for example Apple, BMW, and Renault and Solvay in France. We are experiencing a growing dynamics around this subject, and the forthcoming years will tell us if *open innovation* has kept its promises in the entire process industry.

#### **11.4.5. Technical choices**

In the previous pages, even if it was not directly presented, the technical dimension was always underlying. There can be no innovation in the process industries without the involvement of a strong scientific and technical knowledge in chemical engineering, and/or chemistry, and/or biology, etc.

The new constraints of the modern world, lead us to the development of systems, which are often very sophisticated, to control the processes from the point of view of sustainable development and preservation of health. We are referring to the constraints, but we do not want to present it negatively. It is also a source of creativity and a necessary development path for our society. Our industry now sees its development through green chemical engineering and green chemistry [ANA 98]. And process intensification becomes an essential lever for process transformation. This is where most of the major innovations are found currently. However, innovation should not be limited to a very restricted area; a breakthrough innovation will overturn economic data even more if it is unpredictable.

As for intensification, it can be relocated according to the presentation of conventional definitions: process improvements will generally be from the domain of incremental innovations and even modular innovations, while the development of microprocesses is a technological leap and represents a radical innovation.

Such a document on innovation in the chemical engineering industries should reconsider a description of these technical development options. However, within the scope of this book, we can suggest readers refer to the chapters concerning these domains. However, we can now summarize the four options of development proposed by Charpentier [CHA 11]:

- total multiscale control of the process for increasing the selectivity and productivity: customized nano and microprocessing of materials with controlled structure;

- process intensification: design of new technologies and new equipment based on scientific principles, on new operating modes or on new methods and production scales;

- manufacturing of usage properties: formulation and manufacture of the product with special attention paid to complex fluids and solid technology (the green products/processes couple);

- application of modeling methods and computer simulation of chemical engineering to real situations: from the molecular level up to the production site, including the control and safety of the sustainable process.

### 11.5. Conclusion

Throughout this chapter, we have gone through the fundamental points for a better understanding of innovation in chemical engineering. Most of the subjects could, by themselves, be the subject of a chapter, and innovation in chemical engineering industries could be the subject of an entire book. Some points have been tackled and others could not be dealt with in the space of a chapter, such as the concept of risk-taking and its assessment by FMECA (failure mode, effects, and criticality analysis) methods, or the concept of scoreboard and criterion for the management and organization of the innovation process in the company.

Another issue that has only been discussed here tangentially is the concept of technology transfer, seen not only from the point of view of intellectual property, but also from our ability to transmit new competencies, especially from the research sector toward the industrial sector.

However, we hope to have clearly presented the different key fields of the innovation approach. It is neither only by chance nor only by inventiveness, even if creativity is essential. There exist approaches, methods, and techniques. However, there is always a risk of not being successful and there is no ready-made answer.

Technical and scientific skills are essential. A good organization of the company is also necessary, and we know that a poor organization and a bad work environment, can kill innovation. We need to go toward a sustainable and competitive process industry, and this forward movement is very complex, combining performance and fulfillment of societal needs, while taking into account its constraints. The concept of company actor, who, although a specialist, also to exchanges their ideas with other actors with very different profiles makes sense here. We find this T-shape concept interesting and necessary. And perhaps, we can paraphrase this old slogan, by saying, *innovation is everyone's business*.

Even if there would be enough information to fill an entire book, the formal study of the innovation process for the chemical engineering industries is still as its early age. *Thus, our job is not only just to exchange information on this subject, but also to continue building this new approach together for example, by creating more connections between management and technical disciplines, and also between the different technical disciplines that make up chemical engineering, by creating better tools to better synthesize the information from different researchers and industrialists, to allow everyone to create their own strategy, and by developing new teaching methods. Similar to the innovation cycle in companies, the development process of our discipline, innovation for chemical engineering industries, must follow a process of continuous improvement, such as the famous PDCA (Plan, Do, Check, Act).*

This challenge of innovation could also take us, beyond the present operation, to raise some other questions on the future of our society and on the connections between companies, research, and universities: *What are the links between research, transfer, and industry? What type of research for tomorrow?*

Many questions remain open.

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## Chapter 12

# The Place of Intensified Processes in the Plant of the Future

### 12.1. Process intensification in the context of sustainable development

In a January 2000 article, George Keller and Paul Bryan [KEL 00] estimated in line with the predictions of the “Technology Vision 2020” [TEC 96] report that the chemical plant of 2020 had to meet several important challenges, including the reduction of costs associated with the consumption of raw materials, energy and investments, the improvement of safety conditions, the best product quality, increasing environmental performances of (CO<sub>2</sub>), the reduction of stocks, and a greater flexibility of the production capacities.

In reality, these challenges are not different from those of nowadays, but we can consider that they will take a more and more significant place in the future plant.

The question is to know whether the technologies and current production methods can meet these major challenges. Currently a very significant part of the global chemical production in volume, and even more significant in value, is made in batch stirred reactors and this proportion does not seem to be decreasing [RIP 83]. According to Thomas Schwalbe [SCH 06], approximately 97% of organic syntheses are made in batch processes. This major share by batch processes is explained by several reasons. There are numerous syntheses of small annual capacities for which the conventional agitated tank offers great flexibility and versatility of process units. This is also the production tool that seems the easiest to adapt from manufacturing recipes developed in laboratories (apparent ease of extrapolation). Finally, the capital intensity

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Chapter written by Laurent FALK.

of the equipment is relatively reasonable and, in the case of fine chemicals, the cost of equipment changes according to the volume at the power 0.3, well below the commonly accepted value of 0.6 for other types of continuous processes [ROB 05].

However, it is striking to note that some high-tech products with high added values are derived from the manufacturing process units that are using relatively inefficient pieces of equipment. The latter have many disadvantages detrimental to both the quality of the synthesized products, to the environment by excessive consumption of energy or solvents, and also to the safety of installations and people.

Currently, we realize more and more in fine chemical industries that the manufacturing methods are in fact less efficient for a rather high operating cost. This is particularly true for intermediate chemical products, where the limitations induced by medium- and large-sized stirred tanks lead to potential losses of products by a low selectivity. Stirred tanks have limited thermal performances. This is why the implementation of rapid exothermic reactions in such systems often requires the dilution of reactants, which in turn necessitates a separation stage. The use of solvents is detrimental on many levels. A high consumption of solvents, whose recycling cannot be complete and which induces direct or indirect environmental discharges, is of course a first element. The need for separation processes of reaction products and the recycling of solvents are also stages requiring energy consumption, that become greater as the amount of solvent gets higher.

In addition, the rates of chemical reactions are directly related to the concentration of reactants, the dilution contributes *de facto* to a slowdown of kinetics and to longer synthesis durations that induce increased costs, and also increased energy consumptions.

Finally, extrapolation stages between the laboratory and the production unit, especially for new products, are particularly complicated. Using inefficient equipment, which is difficult to be extrapolated increases the durations of the industrialization and product marketing phases. The associated costs may be particularly penalizing in the context of high economic competition.

For many years, there has been a major attraction for the significant improvement of manufacturing methods through the replacement of conventional equipment by intensified equipment and by transforming the discontinuous process units into batch process units, where the operating conditions are more strictly controlled.

Process intensification consists of, through the development of suitable methods, techniques and devices, designing more efficient, more compact, and more economic processes, whose production capacity is several times greater than that of a conventional process. The implemented technical principles aim at getting rid of

the limitations of heat transfer (outflow and inflow), more generally of energy flows and material transfer, and also to change the thermodynamic limitations (solubilities, reaction equilibria), which slow down the overall kinetics of transformation and/or separation of a process.

The above applicable objectives are not new and evidently come under the general mission of the process engineer, but they appear in a constantly evolving context. Thus, the industrial accident of the Union Carbide plant at Bhopal in December 1984, now listed as the most significant industrial disaster to date (between 20,000 and 25,000 casualties according to victim associations), has raised awareness by putting the emphasis on the need to reduce risk factors by avoiding the massive handling of dangerous intermediate products. Let us note that already in the same year, T. Kletz [KLE 84] had indicated that process intensification was a way of reducing chemical hazards.

The intensification thus ensues from an essential need for the evolution of process engineering, particularly in the current context of trade globalization, of increased competition, and of a genuine concern related to sustainable development [CHA 07].

The answer to these objectives requires an integrated and complex vision of all the three principal components of sustainable development called the “3Ps” (process, people, and planet) or 3Es (environment, economy, and ethics):

- environmental component by the development of safer processes that are less consuming in energy, raw materials and solvents (resource conservation), which are less polluting;
- economic component mainly due to the gains in raw materials and energy and also due to the miniaturization that helps to reduce the capital intensity of processes (volume of installations and buildings), the duration, and thus the cost of design (high-output screening) and extrapolation phases (using the numbering-up technique);
- societal component coming from the technical and economical advantages that contribute to the competitiveness of the chemical industry. The decrease in the design and industrialization stages accelerates the marketing of new molecules and new products and can preserve the competitiveness of the companies. The intensified technologies also contribute to the improvement of the quality of life by small, clean and safe plants located close to dense urban areas.

The concept of intensification is closely linked to the concept of miniaturization of the pieces of equipment. In fact, the increase in transfer and processing rates enables us *de facto*, by reducing the residence time of fluids, to design more compact and equally efficient pieces of equipment. It is from this purely technical concept, developed in the 1980s by Colin Ramshaw [RAM 83], that process intensification [REA 08, STA 09] is seen nowadays as one of the founding concepts of the plant of

the future by developing new production methods that generate new business models (onsite production and production on demand, reduction of the stocks, reduced transportation of raw materials and products, and flexibility by the modular plant).

In this chapter, we will present the main technical principles of intensification and more especially the relationship between the intensification and size of installations. We will consider some examples of applications and developments, without, however, drawing an exhaustive list. In the context of sustainable development, economical aspects are essential. This is why it seems to be necessary to also address the problem of the real impact of intensification in economic terms, but also of business models, although this subject is generally difficult to deal with in a few lines, partly also because of the few published data.

## 12.2. Main principles of intensification

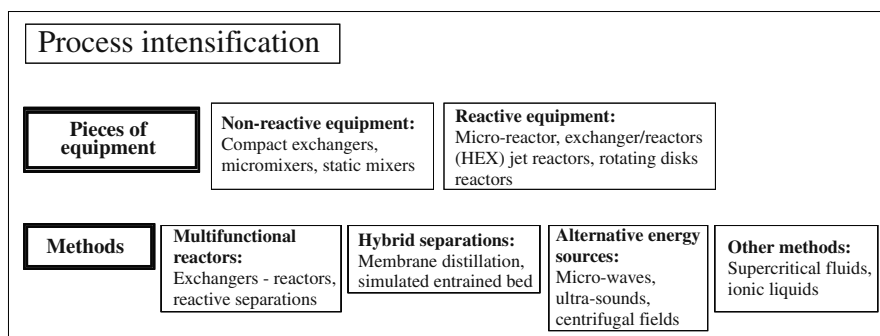
The first works on process intensification in the industrial world, date back to the late 1970s, when the ICI company had been the first to highlight that the concept of intensification was an effective way to reduce the investment costs of a production system by developing the HiGee technology thus enabling the separation of mixtures by centrifugation (the intensification of transfers helps to concentrate the equivalent of a large number of theoretical stages in a small volume). A very large-scale application of this technology has enabled the replacement of 30 m splitters operating under vacuum by rotary devices of 1.5 m in diameter for a single separation efficiency. However, the order of magnitude of this dramatic reduction has raised many questions among distillation specialists; Colin Ramshaw [RAM 95], one of the pioneers of process intensification was announcing reduction of factors 100 times or even more. According to Stankiewicz and Moulijn [STA 00], a factor 2 is considered to be within the scope of process intensification.

The basic idea of process intensification thus opens the way to many and diverse applications. Stankiewicz and Moulijn [STA 00] classify them according to the two lines of approach (methods and equipment) as detailed on the organization chart in Figure 12.1.

We have the following:

– the *methods* relative to process intensification represent a vast field of study and include multifunctional reactors (reactive distillation), hybrid separations (membrane distillation, etc.), alternative energy sources (microwaves), or different methods for measurement and control. The use of hybrid processes, and especially the multifunctional reactors, implement most of the time, in a single device, the reaction stages followed by the separation of products. In addition to the significant savings in operating costs and to the reduced installation size, these methods have one major advantage of overcoming the limitations of thermodynamic equilibrium by separating the reaction products as and when they are formed;

– the *equipment* that make up the alternative strategy of process intensification. Particularly, it involves playing on the structuring of flows, by adapting for example the geometric dimensions of the system to the characteristic times of the limiting processes. Microreactors and microswitches are part of these pieces of equipment, as well as static mixers, rotating disks, and exchangers reactor (HEX).



**Figure 12.1.** Process intensification and its components: classification according to Stankiewicz and Mouljin [STA 00] following the methods and pieces of equipment

This classification has the disadvantage of not being completely clear because the pieces of equipment are technological solutions obtained from the intensification methods. Therefore, intensification is best addressed through the methods that can remove some limitations, from where technologies and equipment originate. The processes of material and energy transformation involves multiple phenomena coupled at different spatial and temporal scales. The slowest processes have the highest characteristic times. This reflects the influence of the limiting phenomena. The means of action of intensification therefore vary depending on the nature of the limiting processes. These limitations are of four types: material and heat transfer limitations, thermodynamic limitations, energy limitations, and kinetic limitations.

### 12.2.1. Mass, heat and mixing limitations

In practice, these limitations can be partially removed by a transfer intensification, which is obtained by degrading a surplus of mechanical energy. However, this form of intensification is very penalizing. Let us consider a chemical reactor consisting of an stirred tank, in which we wish to increase the cooling capacities for better temperature maintaining. To increase the heat transfer coefficient in the stirred tank by a factor 2, approximately a 15 times greater mechanical power should be used by increasing the rotating speed of the agitator. An attractive alternative of intensification is to use microstructuration, where the stirred tank reactor is replaced by a continuous multitubular heat exchanger reactor

cooled by an external fluid. To simplify things, this heat exchanger-reactor can be seen as a simple heat exchanger, whose reactive fluid flows in laminar regime in straight cylindrical channels and is cooled by contact with the wall at constant temperature. In this case, the heat transfer coefficient is inversely proportional to the diameter of the flow channel. As the exchange area per unit reactor volume is also inversely proportional to the diameter, the cooling flow per volume unit becomes inversely proportional to the square of the channel diameter. The intensification effect is thus very significant as the decrease of the channel diameter by a factor 10 is enough to increase the bulk exchange flux by a factor 100!

We show [COM 04] that this major intensification effect is found in many other processes such as mass mixing and transfer.

With the considerable development of microtechniques, it is possible to produce microstructured reactors, mixers, and contactors of very small dimensions from about a few microns to several millimeters. By better controlling the conditions of flow and transfer, the secondary parasitic reactions can be removed, thus enabling the manufacture of very pure products with a high selectivity [LOM 06]. These objects provide new opportunities for transformation processes by allowing a selective intensification of physical and chemical processes: new synthesis possibilities producing less non-recyclable effluents, safer production units, lower solvent rates, new materials and products, etc.

### **12.2.2. Thermodynamic limitations**

The first class of thermodynamic limitations appeared in balanced chemical reactions. To shift the reaction equilibria, stoichiometric surplus of reactants are used, which induce several problems in conventional equipments. This leads to the acceleration of reaction kinetics, as well as to higher adiabatic temperature rise that can be difficult to manage if the cooling capacities of the reactors are inadequate. In addition, excessive reactants require the separation of downstream products and recycling, which can lead to sophisticated separation equipments that are costly in terms of investment and operation (separation and recycling energy). The multifunctional equipment, in which the reaction and separation are performed simultaneously, has the advantage of a potential significant decrease in equipment cost and of a reduced energy consumption thanks to heat integration [SAD 01, STA 03]. The most symbolic example is that of the production of methyl acetate by reactive distillation developed by Eastman Chemical Inc., which not only reduces the capital intensity of equipment by 5 (reducing the number of pieces of equipment from 28 to 3), but also the energy costs by the same factor [SII 95, STA 04]. There are many other principles such as reactors coupled with adsorption and absorption, membrane reactors, reaction-crystallization couplings, and precipitation [STA 03].

The second class of thermodynamic limitations is related to the solubility of the reactants and products that can lead to a decrease in reaction rates and selectivity rates or separation efficiency rates. The use of ionic liquids, whose scope is much broader than that of simple solvents (e.g. catalytic activity [FRE 07, MAR 00]), comes under this framework. For example, the Difasol process for olefin dimerization [FAV 05] proposed by IFP-Axens is a two-phase process using an ionic liquid phase and the organic phase. In comparison with the homogeneous Dimersol process, the ionic liquids of the two-phase process have the advantage of a lower solubility rate for octenes than for butenes. The significant reduction in consecutive octene reactions provides an increase in selectivity from 68% to 75%. The Difasol process also has the advantage, over the Dimersol process, of a 10-fold reduction in catalyst consumption, high compactness (four 120 m<sup>3</sup> reactors for one 50 m<sup>3</sup> reactor), i.e. an economic gain of 15% on capital expenditures (CAPEX) and 20% on operating expenses (OPEX).

Supercritical processes are also considered to be intensified processes, particularly due to the high solvent power of the media used. Supercritical CO<sub>2</sub> is thus an interesting alternative to many organic solvents and can be easily separated by simple expansion. Many reaction applications have been implemented [HYD 05], such as Friedel-Crafts alkylations, hydroformylations, oxidations, etherifications, and especially hydrogenations where, on the one hand, mass transfer limitations are eliminated as the supercritical medium is monophasic and, on the other hand, the solubility of hydrogen is infinite, thereby leading to substantial gains in selectivity (synthesis of 3-ethyl-cyclohexene by catalytic hydrogenation in supercritical CO<sub>2</sub>) [STE 03].

### **12.2.3. Limitation by energy input**

Another method of intensification aims at providing energy to the system unconventionally by playing on the modes of supply (microwaves, acoustic waves), the location, and the type of energy or dissipation.

In some processes using diphasic fluids, the gravitational force is an important parameter that determines the mixing, flow, or separation of phases. It is sometimes necessary to have large pieces of equipment to achieve higher efficiencies. One way to reduce the size of the pieces of equipment is to increase the field of gravitational acceleration by rotating the fluids, as it is done by centrifugation. But the application of these centrifugal fields can also be very beneficial to intensify mass and heat transfers by obtaining very thin liquid films, or very high specific interfacial areas. There are many uses of the rotating disk technology for reactive applications and for absorption, extraction, or distillation processes [REA 08b].



In some cases, the energy input by generation of microwaves also provides significant gains in efficiency and selectivity of reactions [LOU 06]. There have been studies in this field for many years but it is often the combined approach of microwaves and continuous processes (flow chemistry), which offers a significant gain compared to batch processes [HES 11, RAZ 10]. Microwave generators are also used for localized energy inputs in separation processes such as distillation [ALT 10].

Let us also note the intensification by acoustic generation, which by a very high energy contribution of several million of  $\text{kw/m}^3$ , enables a local increase of pressures and temperatures or the formation of radicals, which are favorable to transfer between phases and reaction kinetics [GOG 03].

#### **12.2.4. Kinetic limitations**

There are some reactive systems whose kinetics are relatively slow (characteristic time of reaction of several hours) and therefore not limited by mass or heat transfer. High residence times are hardly compatible with intensified reactors and very small microreactors. These classes of reactions have been, for some time, removed from the operating range of intensification [ROB 05]. Conventionally, we can of course accelerate the reaction rates by higher temperatures or working pressures, or even by increasing the concentrations. However, these activation modes are either difficult to control in conventional agitated reactors because the heating or cooling rates are limited (long durations to heat up or cool down the reactor which are detrimental to productivity), or because the equipment costs become prohibitive (high pressure). On the other hand, complex syntheses often involve thermally activated secondary reactions that are detrimental to the selectivity and efficiencies, and that are difficult to control.

The transition from the batch production mode to the continuous mode opens new routes because it is possible to work in new operating windows (high pressure and temperature) without bringing on a significant cost overrun of equipment, while significantly improving the reaction efficiencies [HES 05, HES 09a, KOC 09, LOM 06]. The principle of thermal activation of two parallel reactions is illustrated in section 12.3 on Figure 12.2.

#### **12.3. Connection between intensification and miniaturization**

In all of these means of action, the internal and external geometrical structure of the device plays a significant role, as it allows a better local piloting of phenomena by controlling the flow conditions, and heat (energy) and mass transfer conditions. This is an important problem of intensification, which conditions the possibility of extrapolation for high capacity processes.

The performance of any equipment (reactor, heat exchanger, mass exchanger, separator) can be represented by its efficiency,  $\eta$ . In a reactor, it is similar to the conversion, which can be defined as the ratio of the flow rate or the amount (mass or mole) of processed material to the flow rate or as the amount of material available for processing. In a heat or mass exchanger, in a separator, this efficiency is the ratio of the amount (the flow rate) of heat or material transferred to the amount (or to the flow rate) of potentially transferable material or heat.

As a first approximation in many cases of continuous processes, the efficiency  $\eta$  is an asymptotic relation of the ratio between the space time  $\tau$  (ratio of the volume of fluid in the equipment by the volume flow rate of fluid) and the global characteristic time  $t_{op}$  of the processes governing this process. The characteristic time is an indicator of the speed at which the transformations or transfers occur in the equipment; it is all the more short as the kinetics or the transfer rate is high.

Thus, in the simple case of a first-order process, the effectiveness, according to the type of flow considered (perfect mixer or plug flow), is given by the following relationships:

$$\begin{aligned} \text{Perfect mixer: } \eta &= \left( \frac{\tau}{t_{op}} \right) / \left( 1 + \frac{\tau}{t_{op}} \right) \\ \text{Plug flow: } \eta &= 1 - \exp \left( - \frac{\tau}{t_{op}} \right) \end{aligned} \quad [12.1]$$

We deduce from these relationships that for a given efficiency, the volume  $V$  of the equipment is directly proportional to the characteristic time of the process  $t_{op}$  and to the fluid flow rate  $Q$ :

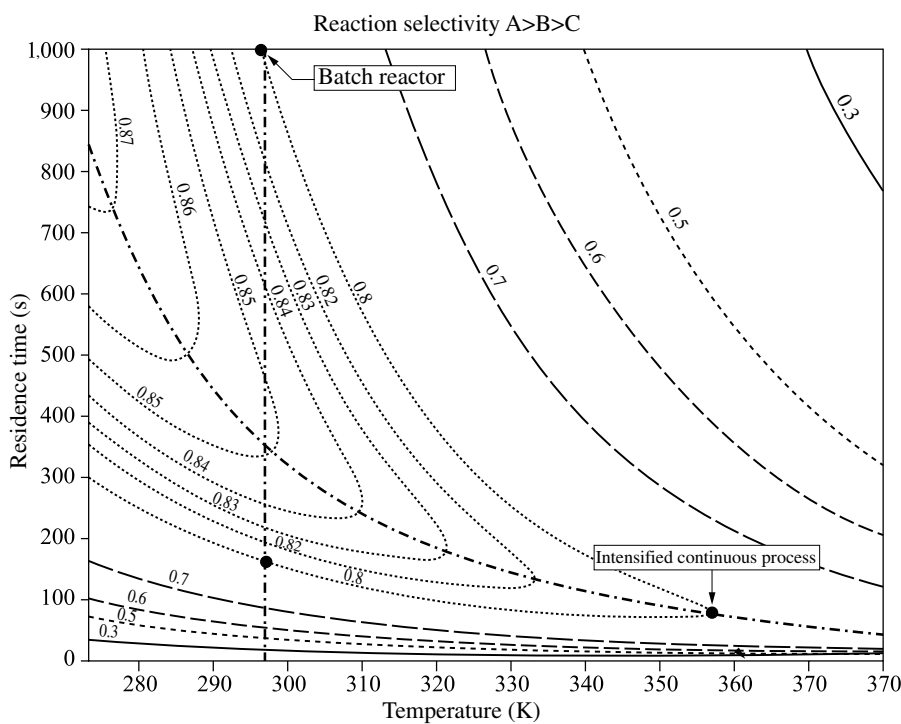
$$\begin{aligned} \text{Perfect mixer: } V &= t_{op} Q (\eta / (1 - \eta)) \\ \text{Plug flow: } V &= t_{op} Q (-\ln(1 - \eta)) \end{aligned} \quad [12.2]$$

This simple idea shows that process intensification, which consists of increasing process rates or, in other words, of reducing the characteristic times, especially by reducing the limiting phenomena, involves reducing the volume of equipment and/or increasing the processed flow rates.

In the case of processes limited by mass or heat transfer, the characteristic times are highly dependent, often by a quadratic relation of the characteristic dimension of

the channels in which the fluids circulate. That is why microreactors, micromixers, and microexchangers have amazing efficiencies for particularly low volumes.

To illustrate the close relationship between intensification and miniaturization, let us consider an example of exothermic synthesis, for which we seek to maximize the selectivity of one of the reaction products. Figure 12.2 shows the influence of the temperature and residence time in the reactor on the selectivity of an intermediate product  $B$  in the simple case ( $A \xrightarrow{1} B \xrightarrow{2} C$ ); the main reaction  $A \xrightarrow{1} B$  is exothermic and the secondary reaction  $B \xrightarrow{2} C$  is favorably activated by the temperature with respect to the first reaction.



**Figure 12.2.** Selectivity chart based on the temperature and residence time. Comparative analysis of operating points of a conventional batch process and an intensified continuous process

In a conventional agitated batch reactor whose cooling capacities are quite limited, the flows of reactants are slowly carried out so as to work at low temperature and prevent any thermal runaway detrimental to the selectivity

(e.g. Grignard reactions). In the example, the operating point of the semi-batch reactor at 297 K requires a long residence time of about 20 minutes (1,000 s) to achieve a maximum selectivity (selectivity  $S_B = 80\%$ ), which is detrimental to productivity. By using an intensified reactor with very good cooling capacity, it is possible to control the temperature of the medium and work at 357 K. The reaction kinetics being strongly accelerated, the residence time can be considerably reduced to a few dozen of seconds (70 s). This makes it possible to maintain the high value of selectivity ( $S_B =$  nearly 90%). For a similar production flow rate, the intensified equipment can be almost 15 times more compact than a standard stirred tank.

This equipment miniaturization, involves however several significant challenges, such as the risk of clogging by the introduction or formation of solid products and a very high pressure drop, which have long been seen as major obstacles to the industrialization of these compact piece of equipment.

The internal flows in these pieces of equipment are often in laminar regime. The impedance loss  $\Delta P$  can be estimated from Poiseuille's equation, which shows that  $\Delta P$  is inversely proportional to the diameter  $D$  of the flow channel at a power 4:

$$\frac{\Delta P}{L} \approx \frac{Q}{D^4} \quad [12.3]$$

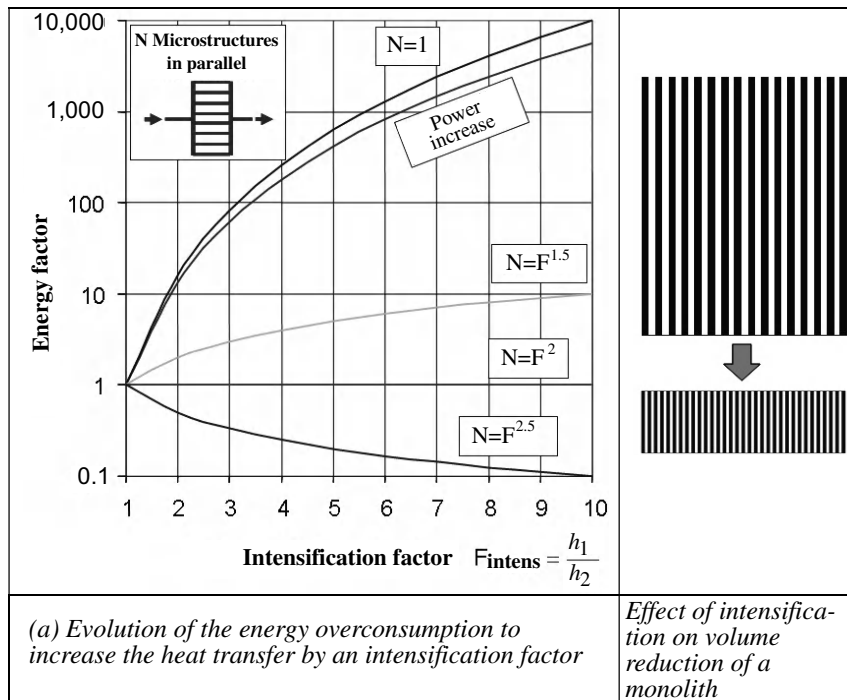
This equation indicates that sending the entire flow rate  $Q$  to be processed in a single channel of length  $L$ , is done at the cost of an impedance loss and thus of a very high energy consumption, on the contrary to the objectives of sustainable development in which the principle of intensification fits. An alternative would be to use multiple channels in parallel in order to subdivide the main flow rate into very low elementary sub-flow rates, thereby compensating for the increase of the impedance loss due to the reduction of the channel diameters.

In some cases (limitation by heat or mass transfer), the reduction of the channel diameter is accompanied with a significant intensification that reduces the length of the channels. This leads to very short multichannel equipment with an impedance loss much lower than that of a conventional piece of equipment [COM 04].

The chart (a) of Figure 12.3 shows, in the case of heat transfer intensification, the evolution in the energy overconsumption (energy factor) to be implemented in order to increase the heat transfer coefficient by an intensification factor  $F$ . In this chart, several possible strategies are shown: the "power increase" curve corresponds to the laws of heat transfer in stirred tanks, for which it is found that the increase in the heat transfer by a factor 2 requires close to 13 times more mechanical power. In the case of a laminar flow in a single channel, we obtain a very similar behavior that show that intensification is very energy consuming.

By choosing to subdivide the flow into  $N$  parallel channels, it is possible to significantly reduce this overconsumption. Thus, for an intensification factor  $F = 2$ , the separation of the flow into three channels ( $N = F^{1.5} \cong 3$ ) leads to an energy overconsumption by a factor 2 when compared with a single channel; the four-channel separation ( $N = F^2$ ) does not require any overconsumption and the separation into six channels ( $N = F^{2.5}$ ) even allows a reduction by a factor 2. This flow structuring strategy however requires designing a distributor and a collector that ensure a perfect flow distribution.

Figure 12.3(b) illustrates the problem of the size reduction of a multichannel catalytic reactor, while maintaining the same effectiveness and impedance loss at identical flow rate. The decrease in the internal channel diameters by a factor 2, reduces the volume of the monolith by a factor 4 [COM 04].



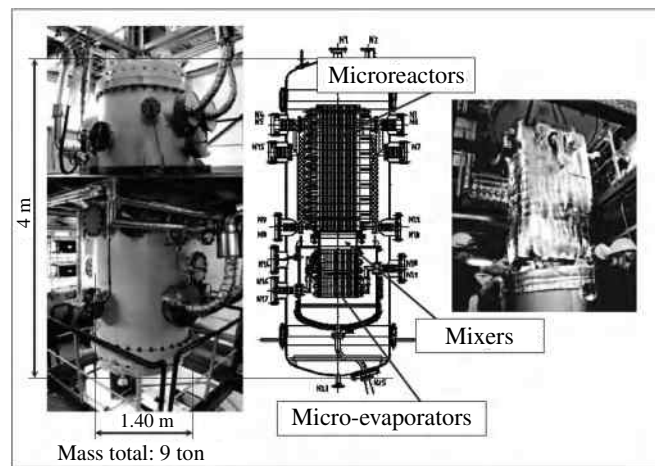
**Figure 12.3.** Intensification by microstructuring. Relationship between intensification, energy consumption, and equipment volume

This principle of flow structuring has given rise to the concept of micro- or multistructured equipment, which corresponds to large pieces of equipment for handling high flow rates, in which the internal flow structuring allows intensification,

miniaturization, but a moderate impedance loss. The typical example is the plate reactor-exchanger; an industrial example proposed by Degussa is the DEMIS (*Demonstration Project for the Evaluation of Microreaction Technology in Industrial Systems*) process of catalytic epoxidation of propene [MAR 05] which is illustrated in Figure 12.4.

The important potential innovation brought by process miniaturization lies in the possibility to extrapolate by multiplication and parallelization of equipment, all the while avoiding the various problems of conventional extrapolation by scaling up. This concept of ideal parallelization, which requires, however, a perfect equidistribution of the flow down to the smallest geometric scales [LUO 05, SAB 09], infers that if the optimum operating conditions at the smallest scale (elementary channel) of an equipment can be determined in laboratories, then the operating conditions of the industrial reactor are identical. It is then enough to optimize the operating conditions in laboratories or on a small pilot scale to define the operating conditions of the industrial system. This underlies the complete review of the classical methodology of process engineering, where we proceed in steps (determination of chemical and physical intrinsic kinetics, characterization of coupled transfers, etc.), so as to build a model enabling extrapolation by calculation.

We can foresee that this extrapolation technique (known as scaling out or numbering-up) would contribute to significant savings in the costs and development times of an industrial process.



**Figure 12.4.** Presentation of the multistructured reactor of the DEMIS project [MAR 05]

However, it is necessary to modulate this advantage by the fact that, in reality, the network of multiple scales in large structures creates new couplings depending

on the size of the system (e.g. heat transfer). In addition, the distribution of flows in a network of channels of different sizes, especially in two-phase flow, is not yet a fully resolved problem.

## 12.4. Applications

### 12.4.1. *Intensification for safer processes*

Intensification is involved in many ways to improve process safety. Initially, the significant increase in heat transfers can very efficiently cool the chemical reactors and prevent the formation of hot spots and the runaway of reactions [ANX 08, BEN 08, ETC 97]. Equipment miniaturization is also one of the key elements in improving the safety provided by process intensification. As Trevor Kletz [KLE 91] very simply puts it, “What you don’t have, can’t leak!”. The reduction in volumes reduces the severity of impacts in the case of leakages or accidents. This volume reduction results in lower storage volumes of reactants and products, smaller reactors and pipes, thereby reducing the potentially stored energy, and facilitating containment.

For example, a batch reactor producing an organic intermediate can contain a potential energy by thermal degradation of the equivalent of several tons of TNT. A small continuous intensified reactor, which is nearly a thousand times smaller than the batch reactor, reduces this TNT equivalent to a few kilograms.

The reduction of the pipe diameters also reduces the size of toxic clouds. For example, the rupture of a chlorine pipe of 2 inches diameter requires setting up a blast area (20 ppm of chlorine in the atmosphere) of 5.5 km; with a diameter of 1 inch, the distance is reduced to 700 m and 0.5 inch to 80 m [HEN 00]. For small installations, the solution of containment in a bunker becomes possible as the building costs are considerably reduced. This ensures a very high passive safety and that is why intensified processes are often associated with intrinsically safe processes.

Another application of intensification and miniaturization involves the production on site and the demand for hazardous intermediate products used in the manufacture of secondary products. It thus eliminates the need for any storage and transportation of hazardous materials. This concept is not entirely new, but the volume reduction of installations provides an additional important element. Let us quote the example of the synthesis of Caro’s acid used as a powerful oxidizing agent, formed from sulfuric acid and hydrogen peroxide, in a tubular reactor of 20 ml volume at a rate of 1 ton per day [WHI 92]. Alternatively, the direct synthesis to the demand for phosgene that has reduced the amount of storage from 25 tons to only 70 kg [HEN 00]. The AET Group has developed a small synthesis unit of 4 kg/h phosgene for applications in fine chemicals [AET 10], which are illustrated in Figure 12.8.

However, the intensified processes often operate under higher conditions of temperature, pressure, concentration, or energy density than conventional processes, thereby increasing the potential hazard. It can therefore be a contradiction in stating that the intensified processes are inherently safer. Etchell [ETC 05] thus lists some of the important elements which in some cases show that intrinsic safety is not ensured. An important point concerns the human factors to be considered in risk analyses of intensified processes. The new operating conditions may be unusual for untrained operators. Similarly, the complexity of processes can be greater (multifunctional equipment, start-up and shutdown procedures, more complex control systems).

The reaction rates are often higher because of strict operating conditions (pressure, temperature, concentrations), or because of the removal of limitations on mixing, heat and mass transfer. The phenomena are thus very fast and there is a need for rapid and sophisticated online measurement and control systems. In risk analysis, it is therefore important to consider these specific dynamic aspects. Finally, despite the small size of the equipment, fluid flow rates can be high; if the process does not operate in normal operating conditions, off-spec products or hazardous by-products may be formed. It is necessary to store them rapidly at the line output and then to reprocess them. We are confronted again with the problems associated with some batch processes with high material accumulation.

Another important point is that in some cases, only one of the pieces of equipment of the process is intensified, whereas the other devices are conventional. This is particularly true during the rearrangement of batch processes to continuous processes in fine chemicals, where we replace the conventional stirred tank with an intensified reactor operating at a higher pressure. We were able to identify [FAL 10, MAC 10], in a HAZOP comparative analysis between an intensified process and a conventional process, that the risk lies in the phase downstream to the reactor (separation device in glass that cannot withstand high pressure). This shows that if intensified equipment can be intrinsically safer, this is not necessarily the same for the entire process.

#### **12.4.2. Intensified processes for energy**

The intensification of heat and mass transfer phenomena by the microstructuring of flows (structured monolith or plates) and catalytic depositions (thin film depositions by wash-coating) potentially allows a considerable reduction of the reactor size. In some applications, the limiting process becomes the chemical reaction itself and it is necessary to improve the formulation and the catalyst deposition. Velocys and Oxford Catalysts have therefore developed new Fischer–Tropsch catalysts for microstructured reactors that accelerate the kinetics by a factor 10–15 in comparison to conventional reactors, and that enable conversions of about 70% per



pass (against 50% for a conventional reactor). The size of the Fischer–Tropsch installations may be reduced by almost 90% over a conventional installation [LER 10]. A direct application involves the GTL (*Gas to Liquid*) installations established by the TOYO and MODEC companies on the offshore FPSO (Floating Production Storage and Offloading units) platforms in 2012 [GER 10].

The miniaturization of catalytic processes opens, due to the equipment cost reduction, completely new perspectives of distributed small capacity units, in order to meet the local energy requirements (production, valorization, and storage) but also for the production of synthetic gas and hydrogen for chemistry and processing industries.

There are many potential applications and it is impossible to provide an exhaustive list here. The following can be cited as examples:

– *valorization of flare gases*: according to the World Bank, the discharges of flare gases were about 100 billion m<sup>3</sup> per year in 2002 [WBG 04]. The costs of different gas valorization techniques (liquefaction, gas pipes, electrical energy generation, etc.) can help us to define, for each of them, a field of application based on the gas flow rates and on the distance between the production site and the use site. Velocys [LER 10] thus estimates that conventional GTL methods are economically viable only from a production of 10,000 barrels per day, which covers only 6% of the total emissions. The profitability of small GTL valorization units based on microstructured reactors would be demonstrated for productions between 10,000 and 2,000 barrels per day, representing nearly 40% of the gas sources;

– *hydrogen production*: the hydrogen market for energy and chemical applications is rapidly developing but is also complex. A study by the European project Roads2HyCom [HYG 09] shows that there is an onsite production market with a demand for hydrogen of a capacity ranging between 30 and 800 Nm<sup>3</sup>/h. In the case of production by methane reforming (SMR process), it is, however, still necessary to reduce the costs by a factor 2 with respect to the high capacity units; a hypothesis that seems to be realistic. Currently, the costs for onsite hydrogen production by reforming are not competitive with those for transportation.

### 12.5. New economic models implied by process intensification

Process intensification offers new perspectives for a cleaner and safer sustainable chemical plant of the future. Improved performances in terms of efficiency and selectivity also lead to economic gains in operation (raw materials and energy), which can be significant, depending on the sector.

In addition, miniaturization equipment, underlying the intensification, naturally leads to the concepts of chemical and modular mini-plants which, thanks to units

with a greater flexibility, can further enhance economic performances. Although not entirely new, the concept of modularity, encountered in the oil industry, is reinforced by compactness equipment and opens up new economic perspectives for the chemical industry.

### 12.5.1. Assessment of operation cost reduction

The fields of applications of intensification are very vast and the disparities among the various examples are sometimes significant. It is therefore difficult to draw general laws on the economic operational gains.

It is, however, possible to approach the problem in a simple way by estimating the return on investment time coming from the financial gain brought by the productivity gain associated with the technological change (transition from the conventional process to the intensified process). This estimation can be made by the following simple calculation:

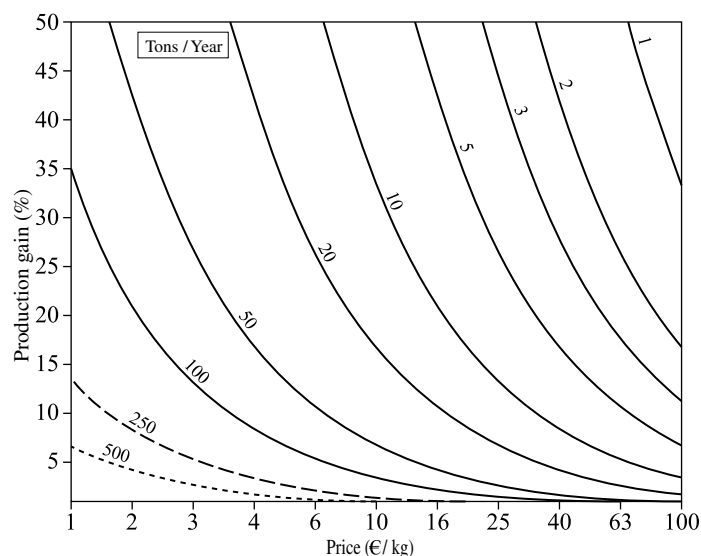
$$\text{ROI Time} \cong \frac{\text{Total amount of investment (€)}}{\text{Annual financial gain (€ / year)}} \quad [12.4]$$

with:

$$\left( \begin{array}{c} \text{Annual financial} \\ \text{gain (€ / year)} \end{array} \right) = \left( \begin{array}{c} \text{Annual nominal} \\ \text{production (tons / year)} \end{array} \right) \times \left( \begin{array}{c} \text{Price of the} \\ \text{product (€ / ton)} \end{array} \right) \times \left( \begin{array}{c} \text{Productivity} \\ \text{gain (\%)} \end{array} \right)$$

From this relationship illustrated in Figure 12.5, we show the production gain necessary to amortize an investment of 100 k€ in 3 years depending on the price of the manufactured product and for different production capacities (in tons/year).

We can notice that technological innovation mostly favors pharmaceutical processes (products with high added value and low tonnage), because even with a small overall gain in the productivity by a few percent, we obtain a short return on investment (ROI) time. The innovation for intermediate products at a few dollars per kilogram and of higher annual tonnage requires a substantially higher overall productivity gain. For a higher investment of several hundreds of k€ (to use the figure, the value of the nominal productivity at constant gain, or the gain at constant nominal productivity must be multiplied accordingly), we find that the expected gain on the entire production line should not be incremental, but must at least reach several dozens of percents, which is a much more difficult objective. The simplifying assumption made here, which considers that the financial gain is entirely supported by the productivity gain, shows the need to find other gains on operating costs in order to reduce the ROI time.

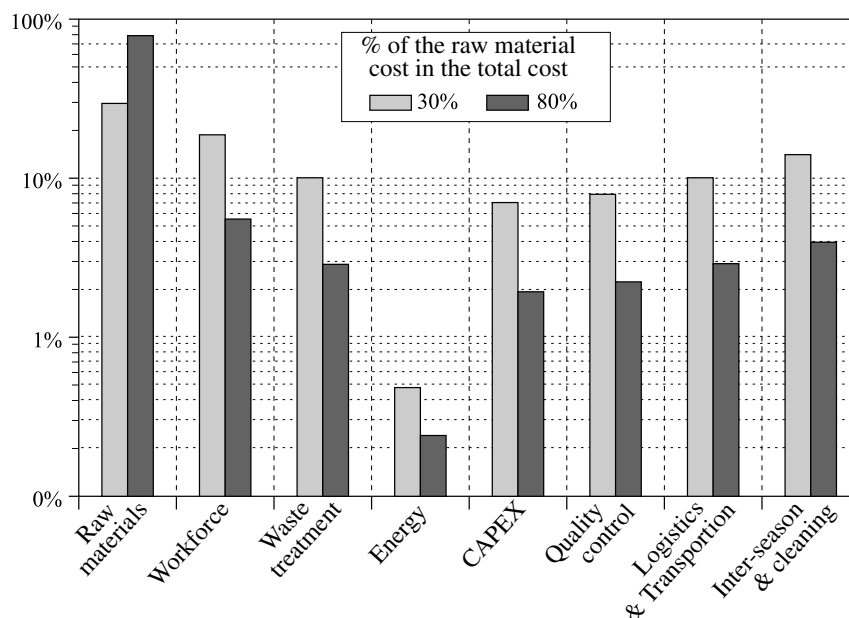


**Figure 12.5.** Production gain required to amortize an investment of 100 k€ in 36 months based on the price of the manufactured product and for different production capacities (tons/year)

The gain in operating costs brought by intensification is not evenly distributed over all the items and the impact can be very different based on the type of product. Figure 12.6 shows the distribution of different items in fine chemical and pharmaceutical products, according to two different proportions of the raw material cost in the total cost (average values taken from [HES 06, KRT 06, ROB 05, ROB 08]).

For these high added value products, the impact of intensification of the reaction conditions may be significant due to the gain in raw materials provided by the increased reaction efficiencies and selectivities.

In addition, intensification often requires the transformation of fine chemicals plants from the batch mode to the continuous mode and allows de facto a greater automation of production modes. It is thus estimated that the cost of workforce per mass of product manufactured by a highly automated continuous process, can be reduced to about 50% in comparison to a batch process unit [PET 03, ULR 88]. The intensification can also help us to reduce the number of synthesis steps: this is also a factor for reducing material handling costs [PIS 11, ROB 08]. Corning, producer of intensified processes, estimates that the rate of reduction in labor costs can reach about 20% [PIS 11]. Following the various examples reported in fine chemicals, the gains provided by intensification are on average about 15–25% [HES 09b, PIS 10, ROB 08, ROB 10].



**Figure 12.6.** Distribution of different items in the total cost of a fine chemical and pharmaceutical product according to two proportions of raw material costs (30% and 80%)

For the other sectors of chemical industry, the proportion of energy in the operating costs can be much higher. Thus, for the Dow Chemical company, energy costs represent about 50% of the incomes (\$54 billion in 2007) [PRI 10]. Intensification comes as a support of other methods such as heat integration (pinch method), management and organization of production methods, thermal insulation, and equipment improvement and renovation (burners, compressors, etc.).

According to the recent studies conducted in the United Kingdom and the Netherlands [REA 08], it is estimated that the reduction potential of the energy consumption in the chemical industry and subsidiaries, thanks to intensification reaches 40 PJ per year, i.e. about 1 million of ton oil equivalent/year (1 PJ = petajoule =  $10^{15}$  J =  $2.38 \times 10^4$  TEP). The projections for the chemical and food industries will provide figures of about 50–100 PJ/year by 2050 for the Netherlands.

The modes of action offered by intensification primarily focus on two points. The first point concerns the improvement of reaction efficiencies with a better control of operating conditions for efficiency and selectivity gains [MOH 11,

WAL 03]. These gains in efficiency lead to reduced energy consumption during the downstream separation operation. To illustrate this case, the impact of the conversion gain of the reactor over the specific energy consumption in Joule per mole of output product in a fine chemicals plant has been considered.

The hypotheses correspond to the classical case of a process unit where the column is currently in existence and unchanged (20 theoretical plates) and the degree of purity of the product at the head of the column is fixed at 99%. Depending on the input composition of the column (reactor outlet), the power of the boiler and the rate of recycling  $R$  are adjusted to satisfy the constraints of composition at the column outlet. We examine two cases, depending on whether the separation (ideal mixture) is easy (relative volatility  $\alpha = 3$ ) or difficult (relative volatility  $\alpha = 1.5$ ).

The results illustrated in Figure 12.7 show that the energy gain is significantly different depending on the separation “difficulty”. For an increase of about 30% of the reaction conversion, the gains in separation energy are about 25–40%.

The second point concerns the intensification of separation processes such as reactive distillation and distilling columns with partitions for which we can achieve energy savings up to 30–40% in comparison to the conventional units [EMT 01, HO 11, SCH 02, TRI 92, WOL 95].

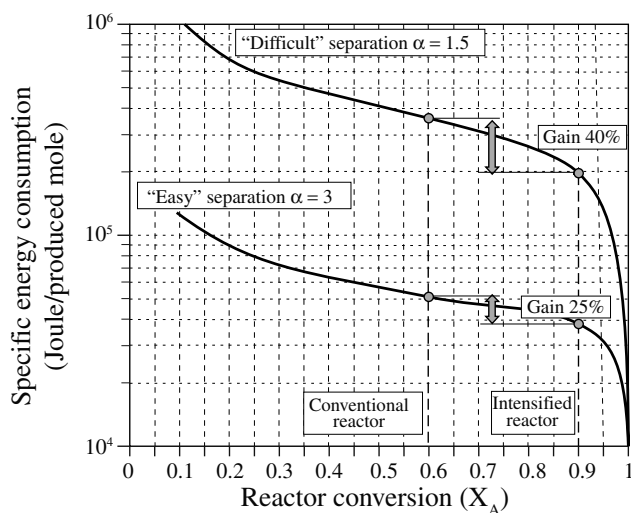
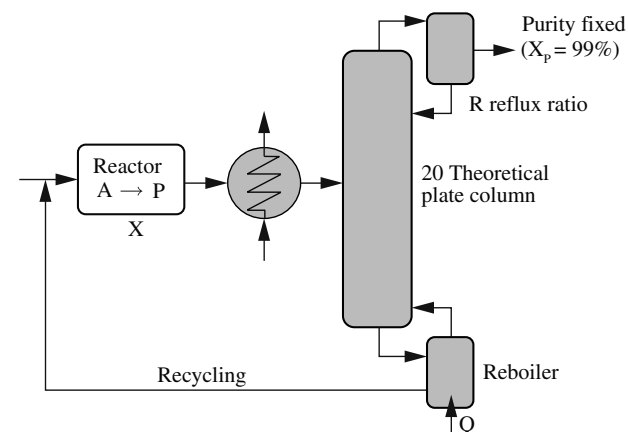
### 12.5.2. Assessment of the investment costs of intensified processes

The concept of chemical and modular plant miniplant opens up new economical perspectives for the chemical industry.

The economic advantage of small, modular production units is however contradicted by the traditional rules of the industrial development, where it is commonly accepted that the investment costs are proportional to the production capacity, i.e. equipment volume at the 0.6 power [PET 03], or less in some cases (0.3 power for a fine chemicals batch process unit [ROB 05]). This promotes the development of high capacity units and disadvantage *de facto* the use of intensified technologies that cannot profit from this scaling law.

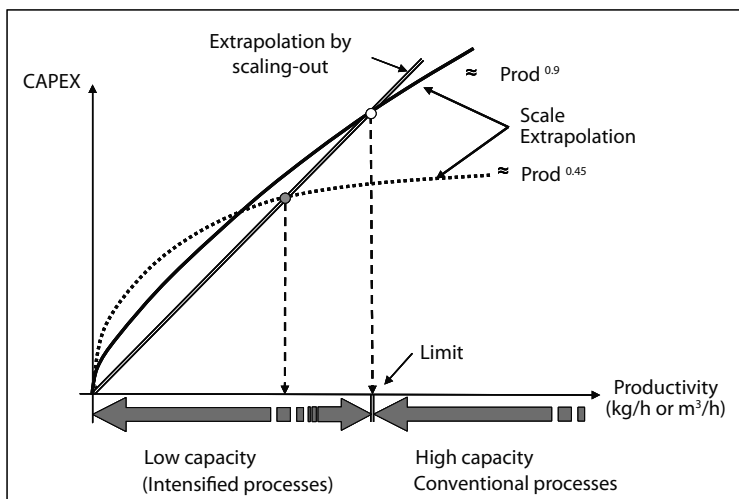
In fact, in this comparative approach, it is necessary to consider the fact that the production capacity of a conventional piece of equipment is not always proportional to its volume, as is the case, for example, for a reaction limited by heat transfer, where the productivity of a batch stirred tank is only proportional to the  $\frac{2}{3}$  power of the volume. In this case, the equipment cost becomes proportional to the 0.9 (0.45 in the case of a fine chemicals batch unit) power of the productivity,

thereby indicating a less marked scale effect. Figure 12.8 compares the extrapolation rules in size (scaling law) and number.



**Figure 12.7.** Impact of the intensification of a reactor on the downstream separation energy consumption by distillation. Influence of the "difficulty" of separation (relative volatility  $\alpha = 1.5$  and  $\alpha = 3$ ) (fixed data: 99% purity, 20 theoretical plate column, enthalpy of vaporization  $L_v = 25$  kJ/mole)

The duplication in number by paralleling the equipment and peripheral systems (pumps, sensors, and actuators) is detrimental to high capacities and shows that the intensified units are kept for low production capacities; the limit depending on the type of manufactured products can be estimated at several dozens of tons/year.



**Figure 12.8.** Evolution of the investment costs according to the production capacity. Comparison of approaches of extrapolation of size and of extrapolation by duplication in number



**Figure 12.9.** Comparison of a continuous intensified reactor RAPTOR<sup>®</sup> with a batch stirred tank with the same productivity (AET Group)

In reality, this approach needs to be revised significantly as the productivity per volume unit of intensified equipment is often higher by several orders of magnitude in comparison to conventional equipment (see example of selectivity). The AET

Group has thus developed a very compact intensified reactor (RAPTOR<sup>®</sup>) [AET 10] of less than 1 liter, whose production capacity is that of a several cubic m<sup>3</sup> stirred tank, but for a reduced investment cost.

This proves that the cost of an intensified equipment can, in some cases, be significantly lower than that of a conventional equipment, but there is no general rule. As a whole, the market of intensified equipment is currently not fully mature, and it is estimated that many prototypes are made at high costs that should decrease. However, we have to keep in mind that in general, in a complex process, the reactor accounts for only about 10% to a maximum of 20% of the total cost; even for a significant reduction by a factor 2 in the reactor cost, the overall gain in investment is only 5–10%. The significant reduction in the CAPEX (*Capital Expenditure*) is mostly due to the impact of intensification on the entire production line, as shown in some examples of fine chemicals using tested technologies (IMM, Corning). One of the arguments often identified with the reduction in investment costs is the reduction in the number of stages (reaction or separation) in comparison with a conventional process [MAC 11, PIS 10, SCH 10, ROB 05, ROB 08]. Depending on the cases, intensified processes allow a CAPEX gain of about 15–25% in comparison with a conventional unit.

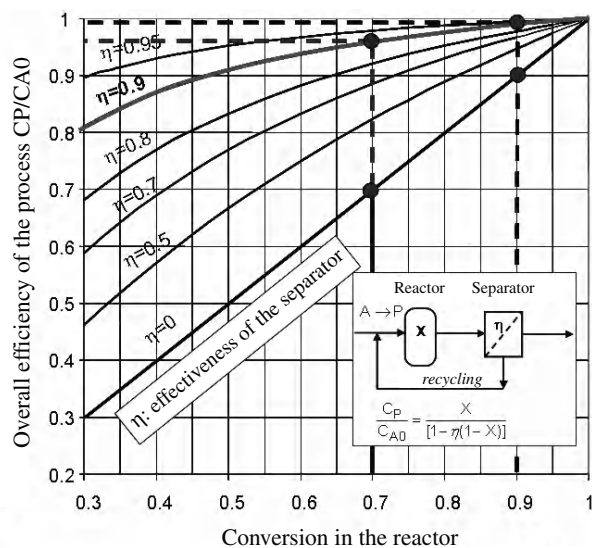
This notable difference between the investment gains, estimated on the reactor itself and the process as a whole, illustrates the difference in strategic choices between the application of intensified equipments to improve an existing process or to create a completely new unit. Let us consider in the case of an extremely simple process consisting of a reactor followed by a separator enabling us to recycle part of the reactants at the reactor inlet (Figure 12.10). The overall efficiency of the transformation process of a reactant *A* into a product *P*, depends on both the conversion *X* in the reactor and the efficiency  $\eta$  of the separator, and is given by the equation  $C_P/C_{A0} = X / [1 - \eta(1 - X)]$  illustrated in Figure 12.10.

Let us consider the two different scenarios of the improvement of an existing unit and of a new unit.

*Improvement of an existing process:* the process uses a low efficient conventional reactor (conversion rate  $X = 70\%$ ), followed by a 90% effective separator, to achieve a total efficiency of nearly 96%. By replacing the reactor with a more efficient intensified technology ( $X = 90\%$ ), the overall efficiency of the process increases to almost 99% (the same separator is retained).

The choice of the technological change estimated by calculating the ROI time is conditioned by the operating gains brought about by the reactor intensification (productivity and separation energy). The separator being already available, its investment cost is not involved in the calculation of profitability.





**Figure 12.10.** Comparison of the overall efficiencies of a conventional process and of an intensified process

*Setting up a new unit:* we must choose the technology corresponding to the economic optimum of investment and operating costs. Let us assume that the desired overall efficiency is 96%. On the one hand, if a low efficiency reactor (conversion rate  $X = 70\%$ ) is chosen, it is necessary to invest in a separator with high effectiveness ( $\eta = 90\%$ ), whose energy consumption can be quite substantial. On the other hand, by choosing an intensified reactor with a high conversion rate ( $X = 93\%$ ), a separator with a lesser effectiveness ( $\eta = 50\%$ ) is sufficient, which is much less expensive in terms of investment and operating costs, to achieve the overall efficiency of 96%. In this case, it is necessary to take the separation into account; an element that depends largely on the proportion of the cost of energy in the final cost of the manufactured product.

This example shows the complexity of the choice of the layout of intensified technologies in the processes according to the industrial sector considered. This explains the difficulty to draw up general application rules.

### 12.5.3. Technico-economic advantages of the modular plant

The concept of process units or modular chemical plants, which have drawn more attention in the last few years, results from the compactness of the intensified equipment associated with the possibility of extrapolation by duplication.

This increased attention is motivated by a combination of factors such as the difficulties of very strong international competitiveness, the reduction of product lifecycle (between launch and decline) and a high volatility of markets, coupled with an excessive rise in energy costs, which lead to particularly poor economic forecasts. In this difficult context, the plant of the future must become more flexible to adapt itself better to the market demand.

However, it seems that the economic models set up after World War II, based on the increase in mass consumption, are becoming less and less suitable. The economies of scale associated with high production capacities require very high investments, which, in a fluctuating market, lead to increased risks and a reduced net present value. According to S. Shah [SHA 07], the investment costs of a process unit or a plant, which represent about 4–5 times the equipment cost (Lang's index), and which are too high, are due to a too specific design of each manufacturing unit, even for an identical manufactured product.

There are many reasons, such as the age of installations that can be different and some units may have benefited from technical improvements or local constraints (supply of raw materials, specificities of the product market, and regulatory market). Shah foresees that a modular plant, based on identical, reusable, standardized, and mass-produced modules, would considerably reduce the investment costs and make these modular plants fully competitive in comparison with the large units benefiting from economies of scale.

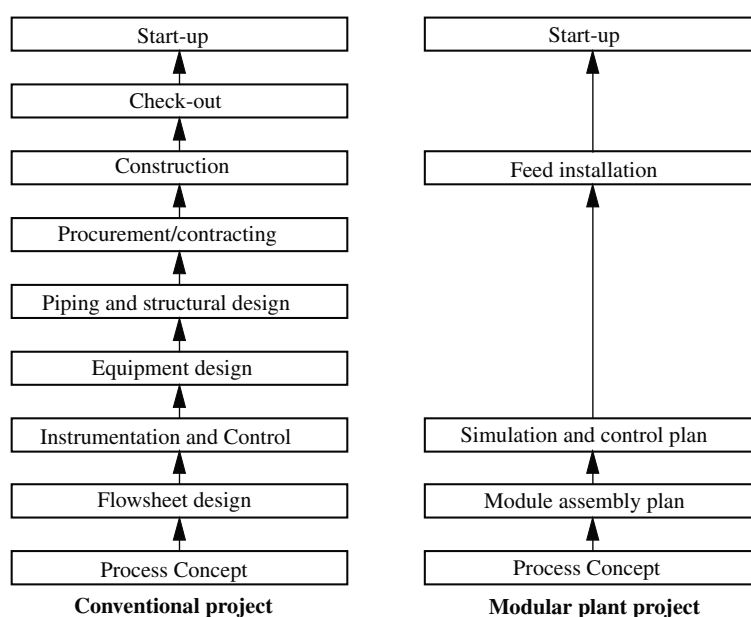
Figure 12.11 illustrates the economies of stages in the design and implementation of the modular plant. This design is based on the reusable mass-produced modules that can be easily interfaced and connected to other modules (decrease of the connection costs). The modules are not specific but are considered to be functional and versatile elementary parts that can be used in different types of processes. For a maximum reduction of the costs, each module meets a standard (size, connector technology, throughput, etc.) in order to facilitate assembly and interconnection procedures.

In the case of an alkylamine synthesis unit, Shah believes that a 36 ktons/year modular plant helps to achieve overall production costs 10% lower than those of a conventional plant with a five time higher production capacity.

There is also another significant advantage to modular plants related to their ability to adapt to market demand. Lier and Grünwald [LIE 11] have thus shown, based on studies of various scenarios, that the modular plant has a higher net present value for the first 10–15 years in comparison with a conventional plant.

In fact, in the investment or the construction phase, the smaller and more effective modular plant in comparison to the conventional plant can be developed more quickly. It therefore helps to generate income and to take market share more quickly.

This is a notable advantage for a company that makes new products with a relatively short lifecycle requiring considerable efforts in research and development. Moreover, the staggering over time of capital expenditures is a substantial advantage in comparison with a high capacity conventional plant, whose entire efficiencies allowing real economies of scale, will be achieved several years later.



**Figure 12.11.** Comparison of design and construction approaches of the modular plant compared with the conventional plant (according to Shah [SHA 07])

The flexibility of the modular plant has other advantages, whose non-exhaustive list is given in Table 12.1.

The first concepts of modular plants for the chemical and pharmaceutical industries emerged in 2000 and are now implemented.

Figure 12.12 shows an artistic rendering of a miniplant mounted on a truck, proposed by [BHR 10], which enables onsite production and production on demand for some production campaigns. The AET Group proposes small capacity continuous units (4–40 kg/h) for the onsite and demand production of phosgene [AET 10], which is immediately consumed in a downstream continuous reactor, by reaction with a second reactant (e.g. with an alcohol to form chloroformates or carbonates, or with an amine to make carbamoyl chloride, isocyanate or urea) for on demand synthesis applications.

Advantages	Disadvantages
Development, investment, and construction phase	
Fewer extrapolation steps Shorter development times Shorter time for entering the market → decrease in terms of time for incomes and market shares. Separation of the manufacture and operation stages of the modules. → growth of production capacities adapted to demand; no excessive capacity. Production of modules in series. → gain of experience and learning effect in favor of reduced costs for the following modules. Investments spread over time. → increase of liquid assets.	Material surplus Space necessary to set up modules  → loss of efficiency
Operational phase	
Flexibility of the production capacities: unit start-up and shutdown. → adaptation to demand. Each unit operates in optimum conditions of efficiency and energy. → material and energy gains. Ease of maintenance.	Each unit operates independently.  → additional need for workforce → more complex measurement and control systems and procedures.

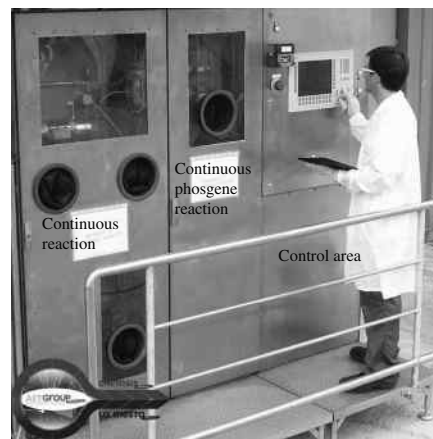
**Table 12.1.** *Advantages and disadvantages of the modular plant [LIE 11]*

In the field of pharmaceuticals, there are currently many important developments on the transformation of batch process units into continuous, intensified, and modular process units [FLE 10, HUW 10, NIC 10, SMI 04].

These real benefits of the modular plant require however flexible and interchangeable modules, whose dimensions and connector technologies must be standardized in order to facilitate assembly or interconnection procedures. The main objective of the European project F3Factory [F3F 10] is to design and develop such modules based on intensified and automated pieces of equipment that are assembled on a backbone facility delivering utilities from a dedicated platform. The advantage of a multipartner platform is to share the investment and operating costs.

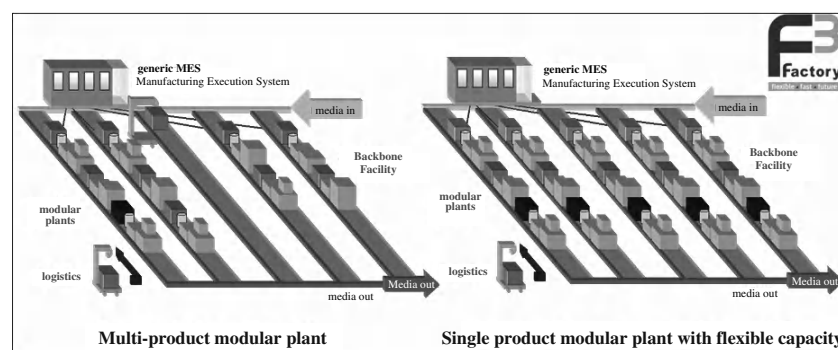


(a) Concept of self-supporting skid-mounted miniplant (artistic rendering, [BHR 10]),



(b) Continuous and on-demand phosgene generation module [AET 10]

**Figure 12.12.** Examples of skid-mounted modular systems



**Figure 12.13.** Concept of intensified modular plants developed as part of the European project F3Factory (FP7) (<http://www.f3factory.com/scripts/pages/en/home.php>)

## 12.6. Conclusion

In this chapter, we have provided some examples that show the different possible applications of intensification. These few examples do not constitute an exhaustive list of all the possibilities. Readers can refer to the specialized scientific literature.

If intensification is a concept which has been created with a very specific purpose, which was original at that time, of equipment miniaturization, then nowadays, we can see that intensification covers a much broader field of “modern” process engineering that aims at developing processes for the sustainable chemical plant. It becomes an integral part of process engineering so that everyone “makes prose without knowing it.”

Intensification involves however two very important concepts:

- transition (very often) from batch to continuous production equipment (which does disclude the concept of batches, as we can produce by campaign);
- equipment miniaturization, which necessitates extrapolation by paralleling the channels and/or equipment, if we wants to process high capacities.

This mode of extrapolation by duplication is a major revision of methods for the design and improvement of devices, since in principle, it is enough to optimize the operating conditions on a basic part in laboratories or in piloting, in order to define the operating conditions of the industrial equipment.

However, it would be unrealistic to state that, by means of intensification, all future plants will be small, clean, safe, and confined units. The basic products with large tonnage will continue to be produced in large plants. Moreover, in many processes, solid products are handled (catalysts, dissolution of solids, formation of precipitated or crystallized products): thus remains a challenge for some intensified processes implementing small equipment volumes. In addition, the intensification potential is not the same for every process; some processes may benefit from significant technological breakthroughs, whereas others might not. Finally, depending on the total amount of investments to be made, it might be better to retain more conventional installations that have been improved, modernized, and debottlenecked, rather than to build completely new units. Finally, there are some processes that have been hardly addressed by intensification, such as bioprocesses whose reaction kinetics are slow and microorganisms, highly sensitive to all “intensified” operating conditions, are thus more stressful. Yet, the stakes for processes of treatment and transformation of biomass are essential for the plant of the future.

Despite the difficulties outlined, intensification brings about innovation concepts that can redefine the conventional production modes and renew the economic models of enterprises.

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## Chapter 13

# Change Management

The depletion of natural resources, particularly fossil fuels, population growth, and pressure that it puts on the environment, climate disruption, globalization, and the emergence of “giants” such as China, India, and Brazil which result in imbalances, and the vital issue of water will lead to unprecedented social upheavals especially in developed countries. The changes required will result in technological challenges that researchers, engineers, and technicians must solve; *process engineering* has a major role to play.

*The 21st Century will be a century of transition!*

The company in this changing world must constantly adapt and look for forms of reliability, set up a protective “shield” both organizational and technological. The “technological shield” is one of the tools provided by the SMS (Safety Management System) described in Chapter 2.

*Running a business is managing risks.*

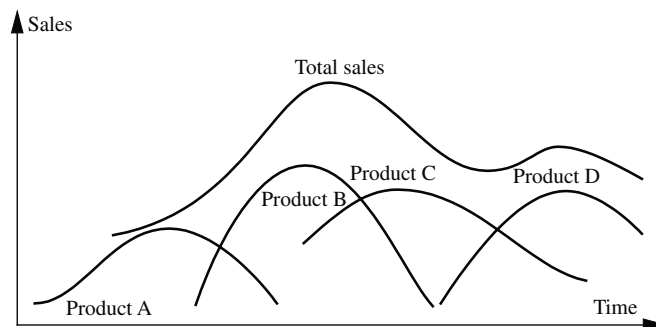
In the 1980s, Change Management was developed/created in the United States. It is the basic package of many consulting firms that offer companies “support” in what can be a perilous exercise. Any major change is difficult and results can be disappointing or even contrary to the objectives set.

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Chapter written by Jean-Pierre DAL PONT.

### 13.1. The company: adapt or die

The turnover of a company consists of sales of its various products, each in their respective phase of their lifecycle, which is illustrated in Figure 13.1. The products are born, and reach their plateau of maturity, whereas others die of old age or of sudden death as they are dethroned by competing products more popular among the consumers. The life of the product only decreases in this competitive world of ours.



**Figure 13.1.** Contribution of products to the total sales

The company is therefore obliged to develop new products; research, engineering, and production have contributed to innovating, adapting, creating, and editing of the existing system. It is the same with the production tool, as we have discussed in Chapter 3, from which Figure 13.2 is extracted.

Since 2006, M. Goshn, CEO of Renault, said that his company lacked new models. In 2010, Renault focused its strategy towards electric cars and small cars.

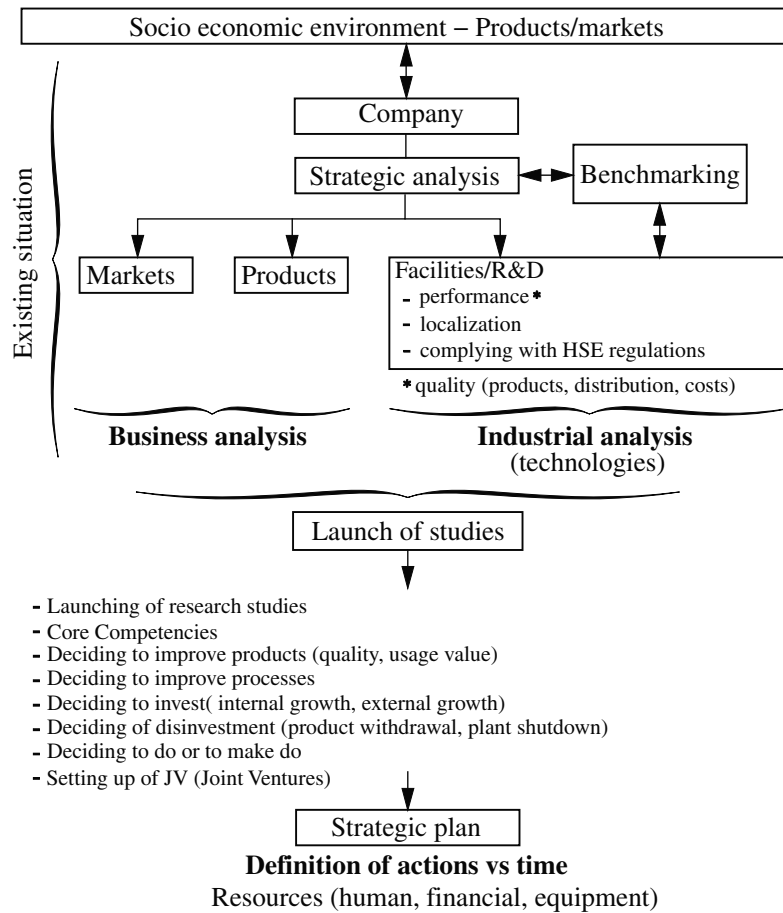
*The contribution to turnover and profit generated by new products is a good indicator of the quality of the research of a company and its innovative spirit.*

### 13.2. The company: processes and know-how

Management of change requires knowing the business processes, and assessing its expertise and *core competencies*.

#### 13.2.1. The company, a multitude of processes (processes, methods, procedures)

A *process* can be defined as an activity implemented by people with the help of a means to achieve a certain goal (e.g. payroll or hiring an engineer). *Everything is a process!*



**Figure 13.2.** Strategic plan of the company – industrial aspects

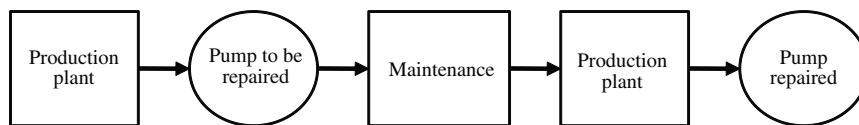


**Figure 13.3.** Illustration of a process

The goal of process industries is to transform raw materials and energy into finished goods and services. Let us cite chemical industries, companies involved in energy supply, pharmacy, metallurgy and so on. All of them make use of a process, i.e. a set of skills of methods and technologies.

A *procedure* is a *written* document that reports specifically on how to perform an activity. A production manual recollects all SOPs (Standard Operating Procedures), i.e. methods involved in a specific process like manufacturing phthalic anhydride, sulfuric acid etc.

*Let us consider an example of a repair process of an electric pump in a plant.*



**Figure 13.4.** *Repair process of a pump (very simplified)*

Such a process is a sequence of operations which brings into play a number of services. A person qualified in electrical servicing isolates the motor of the pump and shuts off the supply from the motor control center (MCC). The production service isolates the pump, drains it, cleans it, and documents the work order (WO). The maintenance department dismantles the pump, repairs it, sets it back, allocates the cost of the expense, and maintains/updates the pump record data sheet. The production department puts the pump into service, and signs the WO after the performance review.

The oversimplified process above involves different trades. The difficulties arise at the *interfaces* as shown in the following example.

The *Piper Alpha disaster*: the oil platform Piper Alpha in the North Sea exploded followed by a fire accident on July 6, 1988. One hundred and sixty seven men died, and 61 saved their lives by jumping into the sea. The platform was destroyed. The cause of the disaster was the routine repair of a pump. The investigation report accurately determined the cause: poor general organization, maintenance processes of poor quality, lack of written procedures, lack of staff training, and so on.

### 13.2.2. *The expertise of the company – core competencies*

The expertise of the company is its greatest asset, and is its first capital. This is the greatest wealth of companies in developed countries which are quantified as *science- and technology-based societies*. *This is their chance of survival*.

Ikujiro Nonaka [NON 98] made the following observation: “*In an economy where the only certainty is uncertainty, the one sure source of lasting competitive advantage is knowledge*”.



*Knowledge management* (KM) is a set of practices meant to assess the knowledge of individuals, organizations, and identify the essential knowledge of the company to maintain its technological lead. The protection of know-how is an essential component of KM; years of work and research can be squandered in a few moments especially in recent times where information can be exported at the click of the mouse.

KM uses the cognitive sciences, sciences for understanding the mechanisms of human or animal thinking and includes among other disciplines, psychology, linguistics, organizational theory, anthropology, neuroscience, artificial intelligence and so on.

One goal of KM is clearly to ensure the continuous training of employees knowing that “Every 5 years half of the technical knowledge base becomes obsolete” (AIChE, American Institute of Chemical Engineers). Another of its missions is to spread knowledge at the company level, knowledge that must be adapted to those who receive it; a maintenance worker does not need the skills of a CPA (Certified Public Accountant).

The know-how of the company is diffused and is not confined to its boundaries. It may include:

- an external part: KM within its customers, suppliers, business partners, and so on;
- an internal part: KM within its patents, trademarks, company structures, production, sales, and so on.

The know-how may also be classified based on the nature of the knowledge:

- *explicit* knowledge encompasses all that is formal, written, and these are the procedures, protocols, and operating manuals. In an analytical laboratory, operating procedures are described step-by-step and the materials brought into play are perfectly defined; these methods can be exported without any difficulty;
- *tacit* knowledge covers the skills that are often the result of a long time of learning in the field or the ability of people; it takes years to train a glass blower, and he can't become one over night. The quality of a dish depends more on the quality of the CHEF than of a cookbook.

The know-how of a plant can be scattered between:

- the researchers who developed the process;
- engineering firms that built it, with a special mention for process engineers, key players of process review meetings, and process safety reviews. They are at the

beginning of the process flow diagrams (PFD), process and instrumentation diagrams (PID) and process equipment specifications (see Chapter 9);

- successive manufacturing personnel (engineers, supervisors, employees) (*special mention to those who started the plant*);
- maintenance and laboratory personnel;
- the actors in the *supply chain* who have knowledge of suppliers, customers, the use of products, and distribution channels;
- the after sales service, the applications laboratory.

#### 13.2.2.1. Core competencies

The term core competencies includes the knowledge that the company cannot do without because they are part of its expertise. They can be handled by an individual, with the risk that this represents, a set of individuals with very similar skills, or group of people with complementary skills.

In the case of start-up of a process unit abroad, the entity that has exported the technology will be called on to send staff for manufacturing, maintenance, instrumentation, laboratory, and so on.

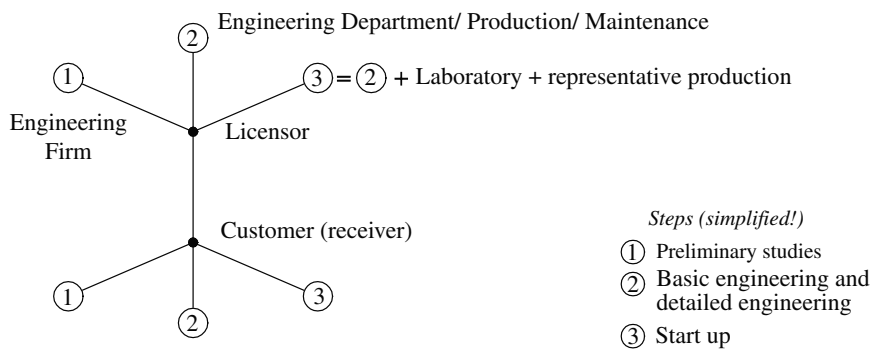
The *core competencies* can be described as strategic [TAR 98] because the company's future depends on them. In general, the company's business will evolve with its activities; some skills will become obsolete or will become common as the know-how has become widespread; the company can find the equivalent on the employment market. It takes a lot of flair to identify new skills and new competencies that will support the activities from the medium- to long-term.

*Focusing its activities on expertise or management* is the question that every professional is made to ask in the course of his career by questioning what works best for him, what allows him to grow and reinforce his "employability". The latter reflects the ability of a person to keep his job, and to increase his chances of finding another depending on what happens to his employer or on the evolution of the market. Knowledge about the skills relevant to the job performed, and the new skills to acquire to stay at the "top level" should be part of everyone's questions.

Beyond the cliché "an expert is someone who knows everything about nothing and a manager knows nothing about everything", everyone has to question his field of expertise.

### 13.2.2.2. Technology transfer

Let us consider the case of the construction of a plant abroad based on an existing technology. A licensor decides to build a plant abroad following a technology that belongs to him. In general, the licensor has at the beginning of the process one local contact (Figure 13.5).



**Figure 13.5.** Steps in technology transfer

The process of transferring the know-how follows the stages of industrialization as described in Chapter 9. The transition from feasibility studies to a “basic plan” will involve increasingly licensor specialists (representatives of the production, maintenance, laboratory, research department, etc.). A multitude of plans and procedures are exchanged. The receiver appropriates all the vast information that is given to him. One day, he will be alone with the industrial tool of which he would have acquired!

Let us note that transfer of *identical* technologies is practically impossible: regulations, quality of raw materials, finished products, plant capacity, weather conditions, the need to purchase equipment different from that used at the licensing agency without forgetting the cultural differences that will require adjustments and changes in the processes. Surprises often occur at start-up, and it is necessary to face them!

Let us see some real-life cases:

– *Plant in Texas:* a large plant lays off a portion of its staff to safeguard its *bottom line* (profitability). Due to numerous breakdowns, the employer is forced to rehire a majority of those dismissed.

– *Buncefield disaster:* on December 11, 2005 (Hertfordshire Oil Storage – United Kingdom), 300 tons of gasoline spilled out from a storage tank within 40 minutes (450 t/hour!!!). The safety features did not work and the damage was enormous.

Trevor Kletz, a British security expert, analyzed the accident and noted that the feedback did not play a part “*Organizations have no memory. Only people have memories and when they leave they take their memories with them*”;

– *Transfer of technology from France to Indonesia*: the factory licensor subcontracted the maintenance of his control system to an outside company. He is no longer the master of his expertise! It is in the hands of a very small company whose small size makes it vulnerable; licensor put him at risk. The transfer of technology is done in poor conditions;

– *Flixborough accident* (September 1, 1974): the reaction system of the Nypro Works at Flixborough (UK) consisted of six reactors in series [KLE 94], cyclohexane is oxidized to caprolactam, intermediate of nylon 6-6, with air at a pressure of 9 bars and at 155°C. About 250–300 m<sup>3</sup>/h of reaction mixture flowed from reactor to reactor: the reactors were connected by a pipe of 28 inches (711 mm). Following a crack in the reactor 5, it was by-passed and a *provisional* 20-inch pipe was put in place to connect the reactor 4 to reactor 6 by using two existing expansion bellows.

*This makeshift job was carried out by people who were not aware of the complex technology of expansion bellows.* Due to improper mounting, a bellow ruptured. A cloud of cyclohexane spread, lit up and exploded. There were 28 deaths and considerable damage.

The Flixborough accident highlights the expertise inherent in the design of the pipes. In a plant such as Flixborough, given the size of equipment and severe service conditions the *piping* should be considered as a *core competency*. A disaster could have been avoided.

### 13.3. Human aspects of change

It is difficult to use the name “tools” when referring to humans. However, nothing can be done without methods and without active involvement of the players of the company. It is pointless to discuss the quality if the employees are not motivated and trained. Training affects, among other things, the teamwork. It is the group which needs to be convinced that it is necessary to move forward and challenge the existing way of doing things at the request of “strangers” to the group.

In what follows, we will address matters dealing with a good working ambiance, quality of the visitor experience, and some “tips” that can be useful for first level supervisors.

Change can be seen not only as an opportunity for improvement, progress, and consolidation but also as a source of disorder, and a threat to the future. It can cause anxiety, fear, demotivation, animosity, rejection, and conflict.

The first step is to “unfreeze” a situation, an existing state of mind (unfreezing), and to overcome inertia. The second step is the stage of change itself. In the third and final phase, a new mood sets in, this is the “refreezing”.

Any change requires:

- a fight against the inertia inherent in any system: the NIH (*Not Invented Here*), and the NIMBY (*Not In My Back Yard*) have been proven: these are proven brakes to change;

- the support of most stakeholders (there will always be opponents!);

- interest to be greater than the disadvantages and constraints (there are always some!);

- a favorable “ambiance” and a feeling of trust supported by adequate internal communication;

- the players of change to be accepted and recognized as competent, eager to do well and not seen as inquisitors. They must develop methods and appropriate tools both technical and human, methods of group work, communication techniques, and methods of conflict resolution and problem-solving;

- the change team to be supported at the highest level of the company.

As such, the executive committee must include:

- the establishment of a project team specifically identified and managed by a project director with *appropriate resources*, who must report to the management, is a *sine qua non* condition of credibility;

- the definition of objectives to be achieved;

- monitoring the progress of the project from the cost and time perspective.

*Change can be a major source of conflict.* There is *ipso facto* the operational management versus entrepreneurial management conflict which was discussed in Chapter 2. One of the first questions asked by the “executives” is whether the business line can lead the change by themselves or whether outside help is needed, thereby generating additional costs and ... conflict.

### **13.3.1. Creating a feeling of trust**

Creating a feeling of trust requires a few simple rules (the following list is not exhaustive):

- *respect people*, to recognize what has been done (not all is bad!);

- *define the work* of each to make him/her feel comfortable in the organization;

– encourage each agent of change to ask himself the following question: *what do I expect from the upstream (information, products, etc.) and what does the downstream expect from me (information products)?*

This *minimalist* management tool is extremely handy: it allows each person to position himself in the organization and set his added value:

– make the system visible, transparent: the need for change as well as the team in charge of it are announced at the highest level. The process decision must be clear and must define the liability of everyone who is in charge, who is responsible?

Common case: a team “invades” a production plant for making improvements. How to ensure that the manufacturer responsible for the plant, and who has liability, does not feel bypassed; that he agrees to do the tests that are required which can present operational risks and customer risks;

– *inform and involve* all stakeholders at their level; no one should feel forgotten or overlooked.

To create this atmosphere in the manufacturing sites, factories, or plants, it is recommended to use both the techniques outlined below: visual management and *brainstorming*.

### **13.3.2. Visual management**

Chapter 10, “Japanese methods”, deals extensively with this concept; the following is intended as a simple addition.

Employees spend most of their lives in the workplace, increasingly visited by customers. An architect involved from the outset in the design of the company will give a nice “look”; the paint, green spaces and flowers that will decorate the workplace is only a tiny fraction of the amount of investment.

The company logos, billboards of safety results and site objectives will create an environment that the employees will appreciate, providing them with a *sense of belonging*. Many companies involve their employees in setting-up their environment (offices, cafeterias, break rooms, etc.); an initiative to be encouraged.

The procedures must be known to all. An adequate “*reporting*” takes into account the degree of progress of the successes and challenges and work ahead.

### **13.3.3. Brainstorming**

*Brainstorming* has its own rules, in contrast to what one might think. If, as a first step, it is necessary to leave complete freedom, so excluding the constraints and

ensorship, the ideas, even the best, then can be organized, reviewed, and reformulated. The flip chart is an essential tool of the organizer or the secretary.

### 13.4. Basic tools for change management

#### 13.4.1. *Systems analysis*

Von Bertalanffy is considered to be the “father of systems analysis”. The Austrian-born biologist immigrated to the United States before the war and in 1945 published his book *General Theory of Systems*. According to Von Bertalanffy, a system is a set of items in mutual interactions.



**Figure 13.6.** *Ludwig Von Bertalanffy (Vienna, 1901 – New York, 1972)  
the “father of systems theory”*

During World War II, the American mathematician Norbert Wiener introduced the concept of feedback in ballistic studies. These reflections were the source of his concept of “cybersystems” aimed at “*the study of communications, control, and command in organized systems*”.

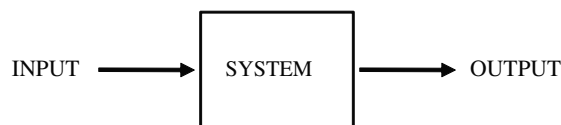
The French representative of this school of thought was the biologist Joël de Rosnay, who in 1975 published *Le Macroscopie*. Joël de Rosnay defines a system as “a set of elements in dynamic interaction, organized according to one goal” [LUG 05].

During the 1970s there emerged a third-generation systems analysis that was made necessary by the difficulties met in its application of cybernetics in social systems. This new approach, developed by P. Checkland and K.E. Weick [CHE 81, WEI 85] in the UK, is particularly suited to organizations regardless of their nature or size: companies, teams, families, economic systems, political systems, the world, and so on.

It is used primarily to build the preliminary projects of organization, development, change (strategy, management, etc.) by providing strategic analysis, construction, and project management tools.

A system can be schematized as in Figure 13.7.

The difficulty in defining the system is to define its borders, components, and their interactions. Everything is a system!



**Figure 13.7.** Schematization of a system

Here is what a representative of the European Parliament says about French agriculture:

“Environmental pollution, pollution of groundwater, monocultures for the production of so-called “green” chemicals, the depopulation of the countryside and quality of life are piled up, and to top it all, one talks about the difficulties associated with the economic calculations of prime costs, European grants, not to mention the climatic changes looming on the horizon!”

If we consider French agriculture as a system, what inputs should we choose? Farmers, the environment, livestock production, tourism; and what scope?

Let us consider the case of *biofuels*. For an agricultural country like France, it is legitimate to consider its biomass as a source of fuels substituted for fossil fuels. This is based on the fact that carbon dioxide, a greenhouse gas, which is released by the combustion engine, will be absorbed by the plant during growth. The systemic approach to this problem involves considering all the environmental impacts of the biofuel industry.

Lifecycle Assessment (LCA) of the biofuel industry shows three major stages or sub-systems: culture of the plant, transport, and plant biofuel processing. A first study done on biodiesel [DEN 98] shows not less than eight environmental impacts associated with the production of biofuel. Moreover, it is observed that the generation of greenhouse gas emissions takes place at each stage and is not limited only to carbon dioxide.

Paul Crutzen, who received the Nobel Prize for Chemistry in 1995 (for his work on atmospheric chemistry in collaboration with Mario Molina and Frank Sherwood), challenged the validity of this industry and has shown that a “systems analysis”



which includes the emission of nitrogen oxides associated with the production and use of nitrogen fertilizer gives a negative greenhouse gas balance. Nitrous oxide has 300 times the impact of carbon dioxide!

#### 13.4.1.1. *Systemic analysis of a company*

The company has been analyzed in depth as a system, which is nothing more than normal because of its importance.

It is considered as an economic subsystem of a high level of complexity in the world connected by a multitude of interactions. This is an “open” system whose purpose is the production and exchange of goods in different markets. This allows for better management of the complex transactions in the economy than by single individuals. It consists of elements of different natures: people (staff, suppliers, and customers), materials (raw materials, finished goods), money, information, and so on, which are grouped into subsystems to exchange flows of the same type.

The company-system is subject to different mechanisms of homeostatic regulation (“remain constant”) that tend to stabilize it: regulation with the environment, regulation between internal subsystems, and so on.

J. Mélése [MEL 95], a pioneer in the application of systems for companies and public services calls for “the modular analysis of systems” to represent the company system. The sociologist Edgar Morin is now considered to be an expert in the analysis of open systems, and the reader can benefit from this work [LUG 05].

#### 13.4.1.2. *Control of process modification*

The modification of a manufacturing process can have favorable, desired, or sometimes unfavorable consequences, as can be imagined. Changes to the manufacturing process may represent both a major opportunity and a very high risk, especially if they are performed on the job by the staff who do not have the history of previous activities. The proposed flow chart below (Figure 13.8) comes under change management. It is very simplified. A change in the process may involve the whole company, if the commercial product resulting therefrom is modified (hopefully improved). If so, samples must be sent to the customers, this phase can last for months. In the pharmaceutical industry or in the plant protection industry, a change process gives rise to a protocol very heavy with registration.

##### 13.4.1.2.1. Success story

Rhodia in collaboration with Michelin has developed the “green tire” where precipitated silica has partially replaced part of the carbon black. The reduction in friction leads to significant fuel savings. Given the extreme importance displayed by the manufacturer for safety, control tests lasted for years before final acceptance.

It is very important that any idea of modification for a change, any proposal is the subject of a cross-sectional information that affects all functions of the company concerned. The flowchart in Figure 13.8 can be considered as the beginning of decision-making. Its first merit is to consider the stakeholders. It often requires much to-ing and fro-ing.

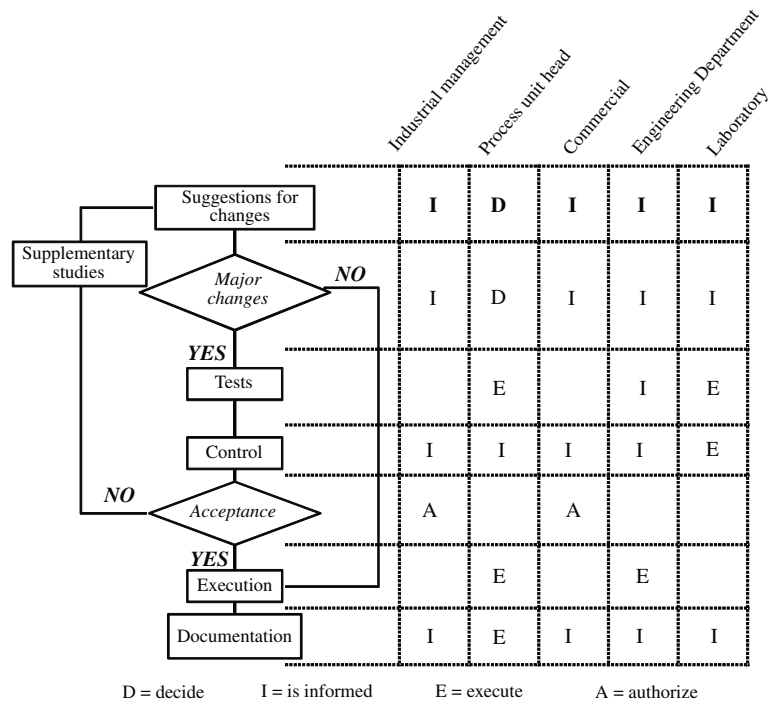


Figure 13.8. Flow chart illustrating the decision-making process in the modification of a manufacturing process

13.4.2. Continuous improvement, the PDCA, the Deming wheel

NOTE.– An overview of Deming’s life and his work is given in Chapter 10.

The company that decides to have a quality approach will establish a quality management system (QMS) an absolutely transverse process involving the support of all business partners (*stakeholders*). It should be considered as a business project because it involves organizational changes, and as such, its objectives, content, scope, and planning must be defined.

Easy to remember, the PDCA (*Plan-Do-Check-Act*) synthesizes its own basic principles of quality management as part of a continuous improvement process. The

method involves four stages, each stage leads to another, and aims to establish a virtuous circle. These stages are as follows:

- *P* for *Plan*: first of all, this is a step to choose the targets in accordance with the company strategy and its diagnostics, the requirements of customers (and business partners) and the criteria for profitability and then to implement the resources, adequate financial means necessary for achieving these objectives and ultimately to develop performance indicators;

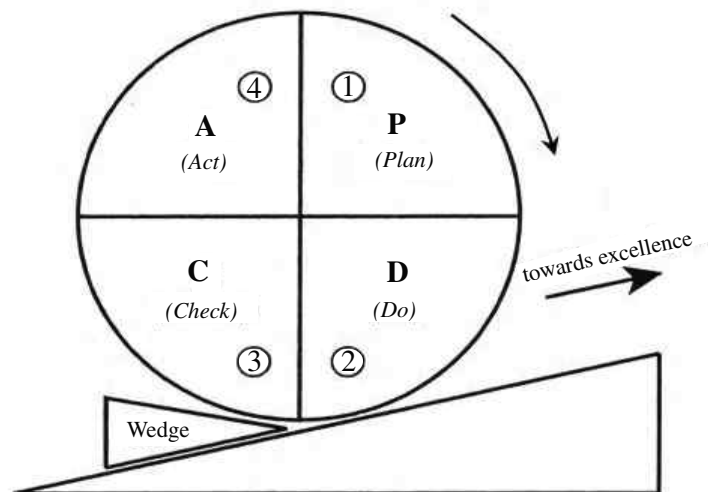
- *D* for *Do*: this step consists of executing the plans or projects defined in *P*;

- *C* for *Check*: the results obtained over time should be monitored to assess what will work and what will not work;

- *A* for *Act*: the last step consists of stabilizing parts of the system that work well, especially by writing the procedures attached to the process, as well as correcting or improving the solution implemented.

The *Act* step therefore brings a new project to be realized, so a new planning has to be established. It is a cycle that is represented with a wheel, the famous Deming wheel (Figure 13.9). At each stage, the wheel progresses a quarter turn. This move represents the action forward. A spin can take months or even years.

To avoid “going back”, a wedge is placed under the wheel, which prevents it from going back. This wedge represents the system of quality management, integrating part of the overall process of company management including preventive measures and corrective actions.



**Figure 13.9.** The Deming wheel illustrating the PDCA method

### 13.4.3. Pareto analysis

This refers to the Pareto law or the 80–20 rule; 20% of the causes produce 80% of effects. For example, 20% of customers account for 80% of sales, 20% of certain faults cause 80% of failures etc.



Vilfredo Pareto was an Italian economist who finished his career as Professor of political economy at Lausanne. During the studies that he conducted in Milan in the late 19th Century, on the distribution of wealth, he realized that 20% of people control 80% of the wealth. Later, this observation was extended to other areas.

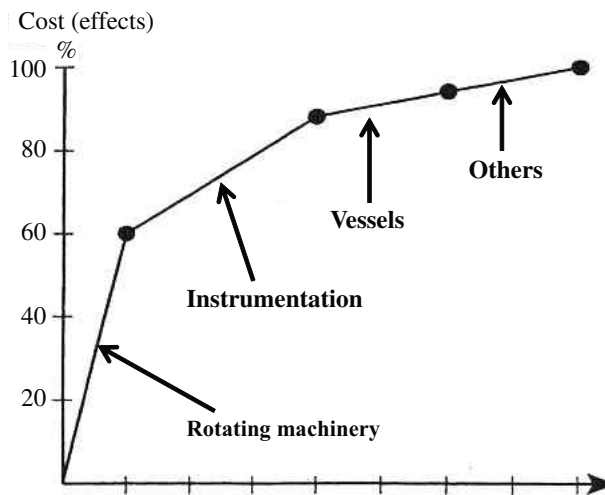
**Box 13.1.** *Vilfredo Pareto (1848–1923)*

The method ranks the causes by decreasing order of importance and measures their contribution to the final effect. Pareto analysis is significant because it determines where to focus its efforts to obtain the best results, thereby creating value with the greatest chance of success.

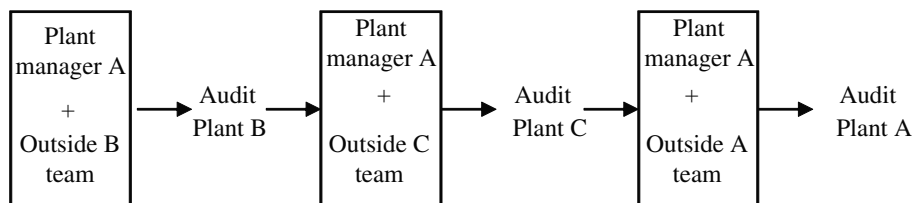
Figure 13.10 shows a Pareto chart applied to the maintenance cost of a plant. The analysis of this cost shows that rotating machinery (pumps, compressors, and agitators) represent 60% of costs. It is necessary to focus on this type of equipment. Pareto analysis of rotating machines may indicate that it is the centrifugal compressors which represent 80% of the cost of rotating machines; it is this type of machine which is to be considered first.

**13.4.4. External audits**

A method has been used in some very large companies that extensively uses the same technologies in different sites. The manager of plant A audits plant B with a team of people from outside B. The director of B audits Plant C, and so on, as shown in the following diagram.



**Figure 13.10.** Pareto chart applied to the maintenance cost of a plant



**Figure 13.11.** Particular method of auditing valid for large groups

This is a particular *benchmark*. The practices of each other are compared confidentially, the auditors have access to all the information since they belong to the same company!

Each entity may discover a better practice than it currently uses and use it to its advantage.

### **13.5. Changes and improvement of the industrial facility**

*Industrial practice shows that any system can be improved.* The process industries are industries, where experience and observation are essential. However, any system has its limitations: it is about whether to continue to improve the existing process or seek new technologies, i.e. look for what is called a technological *breakthrough* [RAN 93].

#### **13.5.1. Continuous improvement and process control**

The improvement of production tools may include, but are not limited to, the following:

- efficiencies;
- productivity gains;
- quality improvement;
- reduced manufacturing costs.

The process engineer and production assistant are at the heart of the system. They do not have the constraints of the person in charge of the operations. They have time to use the process engineering tools in order to model, simulate the system, check the performance of equipment using computer codes, and carry out the tests on the plant if possible or by using pilot facilities.

The first priority of the plant manager is to take care of his personnel day-to-day operations and customer satisfaction, and also to hunt for raw materials misuse, operations improvement, energy conservation.

EXAMPLE 13.1.– A fermentation plant comprises 15 fermentors of 130 m<sup>3</sup> each. A model of the stirring system using CFD (*Computational Fluid Dynamic*) shows that the transfer of heat and matter can be improved. Pilot runs confirm the potential gains. An industrial fermentor is changed; and full scale tests lead to a significant improvement in productivity of around 30%. The modified agitation system is extended to all the fermentors.

##### 13.5.1.1. *Statistical process control (SPC)*

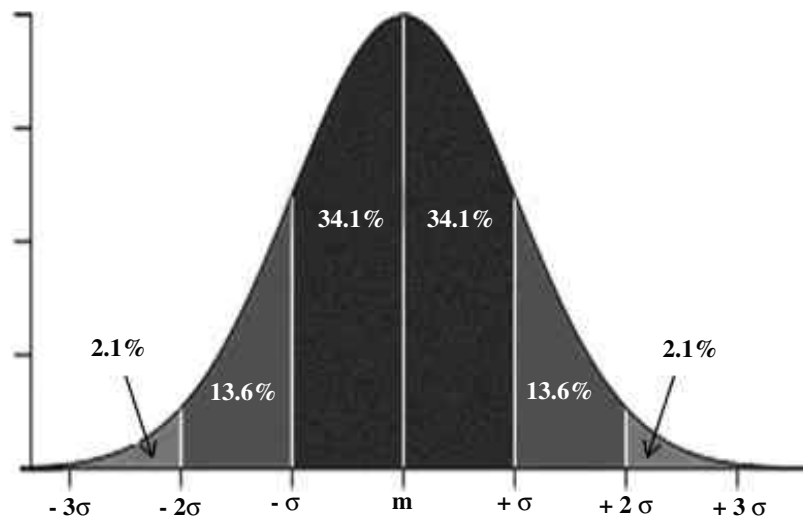
*Statistical process control (SPC)* was developed and used heavily during World War II. Edward Deming was one of its promoters. SPC has been at the beginning of the development technique called Six Sigma that will be mentioned later on.

These preventive methods are based on sampling and control of raw materials and products being manufactured, finished products, and the analysis of the physical parameters of the process (temperature, pressure, flow rates, etc.).

In the 1920s, the *statistical processing* of these values was the source of quality control. The aim was to ensure that the process did not drift and that the product characteristics remained within acceptable limits. *The ultimate goal is to prevent non-conformities*. This is the basis of SPC.

#### 13.5.1.1.1. Some reminders on statistics

Let us look at any variable of the process denoted by  $x_i$ . Sampling is performed and this value is measured  $n$  times. If the sample is representative, then the  $n$  measured values follow in most cases what is called a Gaussian distribution, a bell curve as shown in Figure 13.12.



**Figure 13.12.** Gaussian distribution and normal statistical law

The  $n$  measured values are distributed around their mean  $m$ :

$$m = \sum_{i=1}^n x_i \quad [13.1]$$

A value that represents the distribution of values around this average is the standard deviation  $\sigma$ , which is defined by:

$$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - m)^2} \quad [13.2]$$

If the distribution is normal as shown in Figure 13.12, then statistically:

- 68.2% of values are in the range of  $[-\sigma, +\sigma]$ ;
- 95.4% of values are in the range of  $[-2\sigma, +2\sigma]$ ;
- 99.6% of values are in the range of  $[-3\sigma, +3\sigma]$ , if  $6\sigma$ .

### 13.5.1.2. The SPC in manufacturing

Any process tends to drift either to identifiable but unpredictable causes (power failure, error of raw materials, setting error), or for random or unknown causes, also known as non-identifiable, which depend on the process (slight variation of raw material composition, malfunction of a metering device, etc.).

The aim of statistics is to collect, organize, and interpret data. Many product characteristics have normal distributions and are plotted by the famous bell curve (Figure 13.12).

The characteristics of a product must be between a tolerance of upper specification ( $T_S$ ) and a lower tolerance ( $T_I$ ). The products out of tolerance are reported as defective and rejected by the client.

The *capability* ( $C_p$ ) of a process defines its ability to focus on the average specification of the product required by the client, between  $T_I$  and  $T_S$ . The capability is a unitless number indicating the ratio between the tolerance range and the dispersion (variability of the process). It is calculated by:

$$C_p = \frac{T_S - T_I}{6\sigma} \quad [13.3]$$

The greater the number, the more “capable” the process is. As shown in Figure 13.13, one can simply decide whether a process is capable or not.

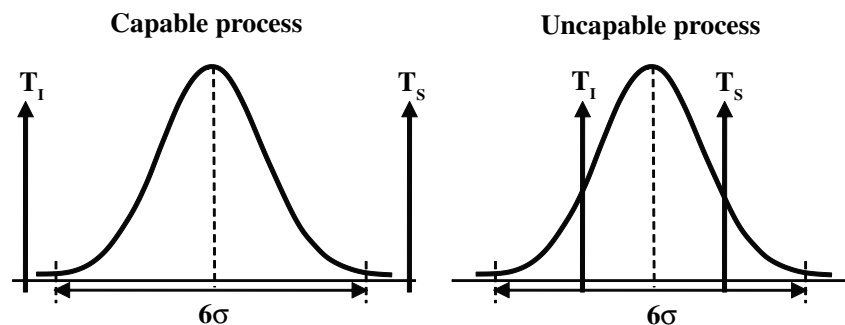


Figure 13.13. Criteria of a process capability



Another factor, widely used, is the  $Cpk$  index. This index reflects the offsetting of the distribution with respect to the average expected value in the range of specifications. It is calculated by:

$$Cpk = \min\left(\frac{T_s - m}{3\sigma}; \frac{m - T_l}{3\sigma}\right) \quad [13.4]$$

Many industries specify a  $Cp$  greater than 1.33. Motorola goes further and imposes a  $Cp$  and  $Cpk$  larger than 2 and 1.5 respectively.

The SPC uses control charts to monitor all the parameters that an Ishikawa-type analysis (diagram causes/effects) has identified as influential on the process. These methods are complex, it takes skill to work with them. Let us not forget the history that claims a statistician who drowned in a water depth of 50 cm on average!

#### 13.5.1.3. *Six Sigma method*

In the 1980s, the Six Sigma method was used and developed by Motorola in the U.S. The fact that General Electric announced that its use had earned them *hundreds of millions of dollars* ensured its promotion to major corporations.

It is structured in five stages called DMAIC, standing for *Define, Measure, Analyze, Improve, and Control*. As its name implies the statistic is at the heart of the technique; Six Sigma means six standard deviations.

Its objective is to eliminate defects and non-compliance of finished products.

99.99966% of the products of a “*Six Sigma*” process meet specifications. In other words, there is *statistically* only 3.4 defective parts per million.

*Six Sigma* has been extended to administrative processes of large companies beyond the manufacturing process itself. High-profile, it is implemented by experts and *black belts* and assumes a major infrastructure typical of the implementation of a quality system; it is primarily suitable for large companies [BRE 99].

#### 13.5.2. *Looking for a breakthrough*

The analysis of a manufacturing process, *benchmarking* (see Figure 13.2), that is to say comparison with a similar process, can lead to the sometimes difficult conclusion that the process in question has become obsolete.

Continuous improvement often conducted with the means at hand is not enough, one must review the situation and change the scale. The company then has to create a multidisciplinary team, generally constituted of representatives from research, processes, engineering, and general subject matter experts.

This method is cumbersome because it requires the allocation of dedicated resources for many years. It is therefore an expensive method! *It is a method that involves project management techniques.*

In some companies, the team thus formed is called the Process Improvement Team (PIT) The implementation of what can be called a Process Improvement Team (PIT) should follow some basic rules:

- a multidisciplinary team of five to seven people from outside and inside the plant, competent in the subject area;
- a leader selected from the people not inside the plant, recognized and supported by senior management;
- allocated resources (in various required disciplines from specialized laboratories, from engineering departments);
- a budget;
- a well-recognized methodology;
- short-term and long-term challenges clearly displayed (Pareto analysis);
- progress measured, monitored, and coordinated;
- recognition of the success of the team (hopefully!).

Some errors are to be avoided:

- persons engaged in PIT but in fact not available due to other priority assignments;
- people not recognized and accepted by people in the plant;
- a PIT leader with no or little expertise in the domain under study;
- inadequate resources;
- loss of momentum;
- a lack of interest of senior management;
- no budget for the study.

#### 13.5.2.1. *The case of IT*

IT (*Information Technology*) is essential in industrial processes. Its significance is only growing. It may be the best and the worst thing: *there is absolute need to know the process before computerization.* It is particularly recommended to proceed by steps to implement specific “pilots” as far as possible before going to full scale

hardware. Benchmarking of similar experiences might of course be of considerable importance and save time and money.

#### 13.5.2.2. *Change impacts – systems reliability*

Again: “*Entrepreneurship is managing risk economically*” [BAR 00]. The *risk management* of the company covers all risks of the company. It has become a business function.

Every business is vulnerable; all its functions are sources of risk. Production tools can be the cause of catastrophic technological accidents (SEVESO, BHOPAL, AZF, etc.). According to insurance companies, 70% of SMEs that have a serious accident such as a fire disappear in the 2 or 3 years that follow.

The safety aspects have been widely discussed in Chapter 2.

The notion of *robustness* of a system can be considered as an extension of the concept of dependability that covers the terms of reliability (R), maintainability (M), availability (A), and safety (S). It is often referred to by the acronym RAMS which can be considered the characteristics of a system that allows us to place justified confidence in it [MOR 05].

In the case of a change, the problem is to assess the “resilience” of the system. The notion of “resilience” stems from metallurgy: resilience expresses the aptitude of a sheet of metal to resist an impact.

It is with this notion of resilience in mind that we will briefly describe some risks involved in change management.

#### 13.5.3. *Corporate risk*

*The staff is the primary asset of the company!* Changes in people may have different origins; as for example:

- attrition by retirement, resignation, illness, and so on;
- transfers, promotions, social or family issues and so on.

The change in executives or in high level of control is an important source of risk. *A director who runs a plant of 200 people may be ill-suited to manage a plant of 500 employees. The style is different, the atmosphere is no more familiar. It is no longer possible to know everyone!*

*The critical mass of an organization* is the staffing levels, below which, a company may be at risk by lack of resources in case of key people leaving. Very small plants require special management, one person can be in possession of much

of the know-how, have many “hats”; his departure can cause some unpleasant issues.

*Time:* It usually takes 2 years for an executive to “get a hold” on a position, the first year he is floundering, the second he feels comfortable, and he can instigate from the third. Ill-timed transfers do not promote creative stability.

#### 13.5.3.1. *Product-related risks*

Performance products pose the most complicated case: often only the client appreciates the impact of a change in the product that they are buying.

Traceability has become a fundamental concept, in particular, for products of animal or plant origin.

#### 13.5.3.2. *Risk related to changes in the process*

We have already mentioned the need to implement appropriate procedures. Let us consider two real life cases for illustration.

Case 1: the productivity of a plant manufacturing an insecticide is increased by raising the reaction temperature by a dozen degrees centigrade. After a period in which the expected results are achieved, an explosion destroyed the plant and causes the death of two operators. The origin of the accident lies in the formation and the accumulation of an unstable by-product, the accumulation resulted from the failure of the “reactor-loop” recirculating pump. The cause of the accident is the *ignorance of work* during the development process, the formation of an unstable by product beyond a certain temperature was well documented!

Case 2: a manufacturer of allyl methacrylate decides to change his process in order to reduce production costs. Samples are provided to the major client whose testing is very brief. A new plant is built, and the old one is closed. *Ultimately*, the new product is refused, a small difference in composition leads to the products being deemed non-compliant! This example shows the need to know perfectly the use of the product made by the client and assess the impact of any change in quality.

#### 13.5.3.3. *Risks associated with changes in working plants (revampings)*

The project risks were discussed in Chapter 9 “Project Management Techniques: Engineering”.

Changes to existing plants are generally much more difficult than building new plants. This is what is colloquially known as *revamping*.

These difficulties have multiple origins.

The *calculation codes* have their limitations. When “it is new” it is easy to make safety margins in the case of uncertainty. In the case of a *revamping*, it may be necessary to ask the question about the capacity of a distillation column, its capacity can be increased from 100 tonnes to 120 tonnes/day by changing the fractionation trays! Conservation gains of a shell and its annexes are to be compared with the commercial risks if the capacity is not reached!

The determination of the *capacity limit of a WWTU* (waste water treatment unit), and its ability to process a new pollution load is difficult to evaluate. Some specific and at times difficult pilot tests must be performed.

The *cost estimation* is often very approximate. Let us take the case of piping; sometimes pipes, expected to be reused, have to be replaced by new ones due to their state of corrosion.

The *implementation phase* must take into account the issues related to the duration of shutdowns; customers have to be supplied.

It must also consider *safety* issues when changes are made on a working plant; fire orders absolutely mandatory to perform welding raise many questions. Operators are not ready to deliver them!

The *amount of contractor hours* (on workshop) are difficult to assess, everything is subjected to additional cost.

### 13.6. Re-engineering, the American way

Amongst all others, two American books have ignited the world of management in the 1990s:

– *Re-engineering the Corporation – A Manifesto for Business Revolution* [HAM 93];

– *Liberation Management – Necessary Disorganization for the Nanosecond Nineties* [PET 92].

The following quotes are taken from the two books and allow the reader to get an idea of the explosive content of their contents:

– *forget what you know about how business should work. Most of it is wrong!*;

– U.S. companies operate on the old principles which are 200 years old, mainly on the principle of division of labor highlighted by Adam Smith (1776). It is necessary to replace tasks with processes;

– a *Business Process* is a collation of activities that takes one or more kinds of input and creates an output that is of value to the customer;

– we live in a world regulated by the 3C's: Customers, Competition, and Change;

– *re-engineering* is the fundamental rethinking and radical redesign of business processes to achieve dramatic improvement such as cost, quality, service, and speed;

– *re-engineering* is different from restructuring, downsizing, reorganizing, and automating;

– why do we do what we do? Why do we do it the way we do?

– *values & beliefs*: the views of employees, those they stick to or those they reject;

– *People, Jobs, Managers & Values are linked together. Processes not organizations are the object of re-engineering!*

These quotes for the less vigorous reflect both a certain “American way of re-engineering” and what we can expect from the re-engineering of some companies run by outside consulting firms. These radical changes spread quickly!

In Japan, it took 10 years for Taichi Ohno to convince his company TOYOTA to adopt His system of JIT. Please refer to Chapter 10 “The Japanese Methods”.

Other countries, other customs!

### 13.7. Conclusion

We are on the verge of unprecedented transition. Sustainable development (the 3Ps) and competition require new concepts, and new technical and managerial approaches for industrial companies. Any company and everyone within it must be prepared to change.

Changes take time, patience and energy, the mastery of technologies involved, and the tools they own.

In terms of stubbornness and tenacity, didn't Edison say: *Invention is 10% inspiration and 90% perspiration!*

The concept of robustness is a fundamental concept: do the changes improve or decrease the robustness of the system? A well-conducted systematic analysis can help greatly to avoid disappointment.

The process engineer has a considerable role to play in these developments. He knows how to make balance sheets (material, enthalpy), he can visualize the

process, make it understandable to his colleagues from research, engineering, production and he is the person who can have a systemic approach and therefore see all the aspects of the projects.

He is the person at the interface of multiple disciplines, he has returned to play the role of conductor, and we hope that this will serve to teach him the different parts.

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## Chapter 14

# The Plant of the Future

Developed countries must owe their prosperity to the Industrial Revolution, to the machinery that the “capitalist” companies have been keen to create.

Currently, worried about their standard of living, developed countries look for ways to respond to the challenges posed by the depletion of fossil resources, water stress, climate problems like global warming, problems related to the environment, energy, globalization, increasing world population, the enormous disparities between rich and poor countries and the de-industrialization of developed countries.

De-industrialization, synonymous with unemployment, is consistent with the invasion of the products *made in China* and other emerging countries, and the relocation of the means of production from the developed countries toward countries with cheap labor.

The emerging countries, driven by growth dynamics, do not have the same questions as that of the developed countries; as for the poor countries, they try to survive in its *strictest sense*.

These problems, already mentioned in this book, are closely related to *consumption* and to industry which serves it by using multiple technologies; some rich countries have to start questioning them.

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Chapter by Jean-Pierre DAL PONT.



This is currently the case with the nuclear industry after the Fukushima (Japan) disaster in March 2011. Countries like Germany, hardly 3 months after this disaster, banished the nuclear industry from the horizon for a few decades.

NOTE.– In France, 75% of electricity comes from nuclear sources as opposed to 20% in Germany.

This single example is enough to pose the crucial problem of interface between the company and its production facilities and the technological choices that give rise to fear and distrust such as GMOs, nanoparticles or genetic engineering.

#### **14.1. Developed countries – companies – industrial firms**

Interviewed by the *Straits Times*, a newspaper in Singapore, Lee Kuan Yee, founder of this city-state with about 5 million people, defined a developed country as a country made up of interacting systems. Educational, banking, industrial, health, civil protection, defense, transport, and food systems, a system related to everyday life, welfare, recreation, and so on.

The need for *governance* of such systems, as well as their *vulnerability* is obvious.

##### **14.1.1. France – heat wave of 2003**

In August 2003, a heat wave aggravated by peaks of nitrogen oxide and ozone, due to the lack of wind, led to excess mortality, estimated at about 15,000 people particularly among the elderly. The mortuary rooms were saturated, a cold room from the Rungis international market and refrigerated trucks were requisitioned.

A political crisis followed! It is surprising that a country as organized as France could be the location of such events: the lack of coordination between different administrative bodies and the lack of governance was incredulous.

The power outage of New York in August 2003, the devastating effects of hurricane Katrina in New Orleans in August 2005 that raised questions about the design of levees of the Mississippi; and the catastrophe of Fukushima reflect the vulnerability of our *complex* societies.

Jacques Repussard, director of the IRSN (the French Institute for Radiological Protection and Nuclear Safety) [REP 04] analyzes the perception of the French regarding the industrial risk that they believe is primarily related to chemical risks, nuclear risks, waste management, air pollution, and so on.

The French worry about “the increasing dependence of our society toward the more and more inevitable technologies and networks that they generate (energy, transportation, telecommunications, hospital facilities, etc.)”.

Peter Senge [SEN 08] states that we are entering the ground floor in the post Industrial era. He observes that all the ages have an end “*from the Iron Age to the Bronze Age, from the age of the Renaissance to the Reformation ....*”. “*The Industrial Age which has shaped our life styles and our world view for generations, is no different*”.

It highlights American consumerism, 5% of the world’s population consumes almost half of the drugs and 25% of the fossil fuels ... “America is addicted to oil”, stated president G. Bush.

The companies, from the Industrial Revolution, that has shaped and maintained them, are central to the debate as creators of wealth and their impact on society. We have already highlighted this.

The concept of sustainable development that emerged in the 1960s has slowly but surely impacted on the industrial companies. In a kind of irony, the industrial disasters (Seveso, Bhopal, etc.) and environmental disasters (uncontrolled and excessive use of pesticides including DDT, etc.) have precipitated this movement [SEN 08].

The discovery of the chemistry of the atmosphere by Kreutzen *et al.* and the ozone hole created by fluorinated compounds, the impact of GHG (greenhouse gases) on the climate have evoked an international awareness that is about to disrupt the corporations, questioning its goals.

The book by Elisabeth Laville [LAV 06], *L'entreprise verte*, has the subtitle “sustainable development changes the company to change the world”. In France, an eponymous ministry came into being. The major companies are rated on these aspects by Vigeo, founded by a renowned former French trade unionist.

E-commerce is growing at a rapid pace and fairtrade is also moving with it at a brisk pace. The citizen wants to know if his T-shirt was made by children or by *slave workers*, how much was paid to the distant producer for coffee and whether the benefits are equitably distributed among the players of the chain, which ranges from plantation to distribution.

Therefore, the company is forced to review its products and the services which are its goals! It is also equally constrained by more and more stringent regulations, such as REACH in Europe.

#### 14.1.2. The ISO 26 000 standard

This was the first international standard on the social responsibility of organizations published on November 1st 2010.

It is based on the three pillars of sustainable development: economic, environmental, and social. It is a standard of governance whose objective is to clarify the responsibility of the company, facilitate dialog with its *stakeholders*; in the broadest sense, it takes into account human rights and the impact of the company on the environment.

The developed countries are left with the *ease of importation*: the need to produce no longer appeared to be necessary ... nor rewarding! Marketing and finance have found favor with the new graduates who neglect the production system.

Some significant countries advocated a *service* society! Even though services cannot bring their added value only to what has been produced!

Wealth is created by *manufacturing*, a term which appears to be more driving than production.

*The profit of the company, its wealth, begins at the plant!*

For having forgotten it, the United States, which brought the Industrial Revolution to its pinnacle, sank into an unprecedented deficit.

From the early 1980s, Hayes and Wheelwright [HAY 84] have sounded the alarm! They described back then the *vulnerability* that U.S. companies face with their competitors, mainly Japanese competitors. These authors developed the concept of *manufacturing strategy*, which we have dealt with in this book and which we can summarize by the need to maintain *cohesion* between the needs of the market in a long-term vision and the production facilities.

Manufacturing has become a *competitive weapon*.

The same authors later joined Kim B. Clark [HAY 88] and resumed developing the same ideas 4 years later, observing that the United States were declining more and more, while the whole world had admired their incredible industrial epic during World War II. At that time, factories were converted in record time to make planes, tanks, means of maritime and land transport, not to mention the Manhattan Project for the construction of two atomic bombs.

The *Liberty Ship*, by itself, symbolizes the power and quality of the American war industry; it implemented new manufacturing methods, it used standardization, methods

of continuous improvement that reduced of the duration of construction from 250 days to 50 days. Innovative training methods educated those who worked on them.

*Rosy the riveter* is a popular icon that symbolizes the 6 million women who participated in the war effort: among them was a certain Norma Jean Mortenson, who is better known by the name Marilyn Monroe.

To understand the production system, we have to first try to define it.

#### 14.2. Typology of means of production

The typology of means of production is a complex subject, given the extraordinary diversity of technologies used and the products derived from it, the amount of their investment, their location, staff who implement them and how they do it.

The manufacture of an Airbus A380, of 1,000 tonnes/day of ethylene, a drug whose synthesis involves a dozen steps, and the assembly of cars in series, involves completely different concepts. What about an oil platform in the North Sea or a paper pulp plant on a barge in the jungles of Borneo?

*Joan Woodward (1916–1971), an English sociologist, laid the foundation for a classification in the 1960s [DAL 07a, HAY 84]; since then, manufacturing systems analyses have been developed [CHA 90].*

The approaches are different, sometimes contradictory; the words do not always have the same meanings, especially when there is a translation. It is important to emphasize at the outset that *the organization of work, management of the production facility and the concept of manufacturing are closely linked*: one does not go without the other [DEC 80].

We will use the classification of Hayes and Wheelwright [HAY 84] by simplifying it. The authors distinguish the following production methods: project-based, job shop, assembly line, and continuous production.

– The *project* generally refers to a single object, usually a prototype. This is the case of civil works (dam, airport), very large pieces of equipment (ship, power press), or even a new plant. The project is assigned to a project team that executes and enforces a number of tasks according to a predetermined plan. The organization of work uses PERT or other software packages (we have discussed this in Chapter 9).

– The *job shop* where single parts are produced usually in small batches, for example, a set of machine tools, a printing plant are typical of this type of industrial organization. The part to be manufactured can move from machine to machine. Some machines can be grouped into specialized cells to perform a number of additional tasks.

– In some types of job shops, the *batch* undergoes several transformations, by passing successively from process unit to process unit. This is the case of fine chemicals plants where a raw material will react with other raw materials in successive reactors: for example, the oxidation process unit is followed by nitration, which is followed by hydrogenation in specific process unit.

– *The process unit* consisting of successive online work centers.

The final object is to be assembled by the supply of components at each stage. It moves from station to station at a determined speed. This is the invention of Ford in the automobile industry at the beginning of the last century.

– *Continuous process units*, this is typically the petroleum industry, heavy chemical industry. The continuous process unit differs from the assembly line by the fact that the product to be transformed is “continuous” and not “discrete” (we speak of 51.8 tons of kerosene but not about 51.8 cars!).

NOTES.– Some authors refer to the *production process* as continuous process units. In fact, this designation only applies to the process units of physical or chemical transformation of matter which, of course, is often implemented in the continuous process units!

Others call *mass production*, the production of large volumes of “discrete” objects in very short cycles, such as the manufacture of screws or plastic objects coming from injection molding machines.

Others still fail to distinguish between the continuous flow process manufacturing and the industrial *fabrications* or “discrete” manufacturing that produces individualized objects.

#### *VAT analysis*

Another classification is based on the analysis of the flow of raw materials and semi-finished products up to their final stage of finished products (Figure 14.1) [CHA 90].

We distinguish the basic models and V, A and T. While keeping the same term, we have added the model I:

– *model I or a single line*, for example an installation line of single electrical appliances (a case receives different components during the passage of assembly through stations in series);

– *model V or divergent model*, for example a steel mill (the steel is processed into beams, rounds, wires, steel reinforcing bars);

– in the process industries, a basic raw material results in a product tree; currently, this is the case of bio-refineries, where plant starch leads to a multitude of byproducts;

– *model A or convergent model*, such as a mounting of an aircraft in an assembly hall;

– *model T (convergent/divergent)*: a basic product manufactured according to model A is the source of byproducts; for example, a model of a basic car is differentiated by its accessories or the color of its body.

In chemistry, *master batches* are sent to various places, to undergo local transformations; various ingredients, such as perfumes or dyes, may be added to detergents.

We can deal with a combination of these basic models very easily.

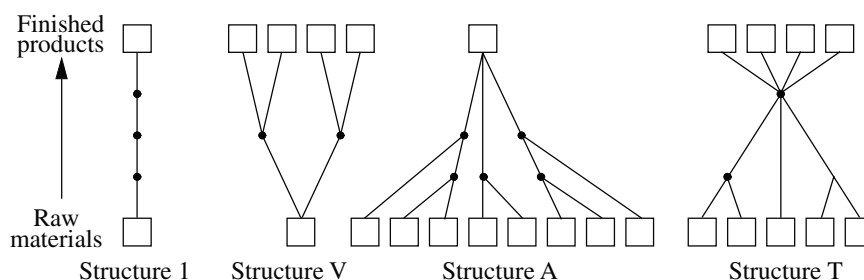


Figure 14.1. VAT analysis [DAL 07a]

**14.2.1. Industrial facilities reviewed in the light of the supply chain – flows**

The company is the seat of four major flows, symbolized in Figure 14.2:

- material flow (raw materials, work in progress, finished products, waste);
- financial flow (purchases, sales, production cost, etc.);
- information flow (customers, suppliers, production facilities);
- human flow (management of human resources).

The flow of energy does not usually appear in this classification because until now, in developed countries, energy was taken for granted. Will it be there in the future? The flows of energy can be negligible in fine chemicals, and dominant in heavy chemicals.

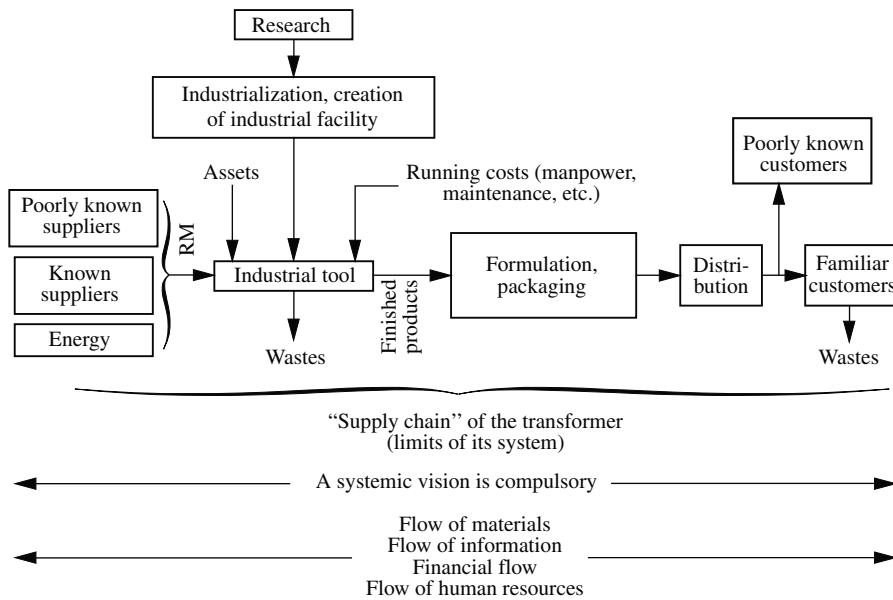


Figure 14.2. Flows related to production

This concept of flow appeared about 15 years ago [CHR 92, DAL 07], it is the basis of the concept of the supply chain (Figure 14.3), which sheds new light on the whole set involving transportation, purchase, management of manufacturing tools, management of raw materials stock, finished goods, work in progress inventories and distribution. This is a strategic vision that places the customer at the heart of the productive system.

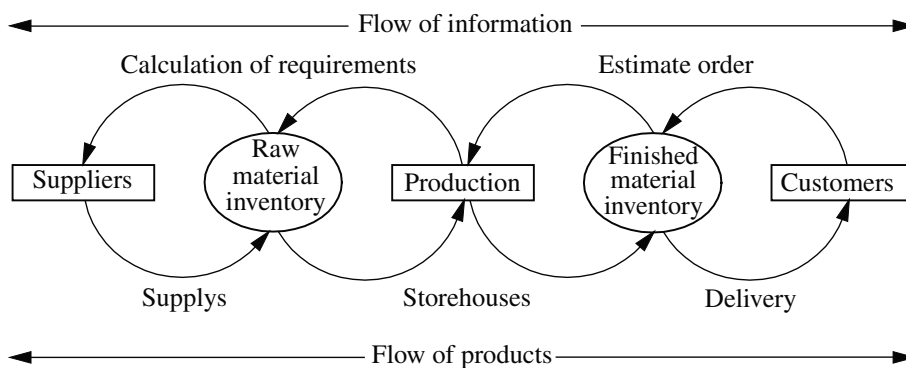


Figure 14.3. Visualization of the concept of supply chain

The purchasing function, distribution, and stock management are the key links of the *supply chain*: these are all processes that need to connect with the production itself:

- conditioning and packaging must be part of the design process, the presentation of the product may have an essential business impact (e.g. bottling of perfumes);
- the handling takes on very different methods that concern pallets, industrial trucks, conveyor belts, loading cranes, and so on;
- storage and transport also involve a variety of techniques that are sometimes very complex; a cold chain, the bulk handling of powders, air or maritime transport, to name but a few.

In some companies, the management of physical flows calls for ERP (*Enterprise Resource Planning*); the stock situation and customer orders managed in real time thus make it possible to optimize the management of production facilities and reduce working capital needs. The company can have a global vision of its activities, improve procurement planning and product traceability, and optimize the use of both physical and human resources.

The purpose of the *supply chain* concept is to integrate all the internal and external stakeholders of the company in order to accelerate the information flows and the materials flows.

The effectiveness of the *supply chain* is measured in the reduction of all the times of its processes. We move from a management pushed upstream, to a management driven by the downstream.

### **14.3. Product and plant design**

Products, production tools (process units, plants) must be designed for the customer and for the company in respect to ethics whose essential foundation is sustainable development.

*Man and his habitat must be placed at the center of the industrial plan.*

#### **14.3.1. Products**

Product design has been described in Chapter 7 (this concept includes the principles of *Green Chemistry* and the *Green Engineering Process* taken up in the book coordinated by Martine Poux [POU 10]).



Chapter 11 provides some tools to stimulate the indispensable innovation condition so that the company can have a competitive advantage.

The *win-win* client/supplier integration is a key idea; each party having knowledge of the others' businesses and its strong points. It concerns more and more the partnership that involves a *chain of knowledge*.

The period when Henry Ford told his customers "you can have the car in any color that you want, as long as its black" is over.

The industrialist appears more and more like a service provider with an added value. He contributes to the value created by his customer; the customer has to know this.

The concept of the 3Rs [LAV 06] "reduce, reuse, recycle" is an essential concept. It can be considered as an extension of the concept of *product stewardship*; products are managed *from cradle to grave*.

A *closed circuit* can be established between the customer and the supplier; waste and used products can be returned to the manufacturer for reuse.

Recycling is about to change the nature of some industrial sectors, it already heavily impacts on the appliance and automotive market.

#### **14.3.2. Processes**

What has been previously said for products applies for all processes at the heart of the eponymous industry.

*Technology is the basis of everything.*

Good management will never replace obsolete technology. Technology is now a weapon in the global economic war and must be managed as such. It must be continuously assessed and protected.

#### **14.3.3. The plant of the future**

This term, which is highly-publicized and with fears of plant relocation and thus of unemployment, is a carrier of hope and a number of contradictions.

What do we dream of? Of a plant using abundant (low carbon) renewable raw materials, which consumes little energy, a plant that respects the environment, that is to say, whose environmental foot-print is low, whose investment (CAPEX for

*capital expenditure*) and operating expenditures (OPEX) leaves a comfortable gross operating margin on growth markets!

We dream of a profitable plant, and hopefully a sustainable one!

As we have emphasized, for sustainable development, the concept of a plant of the future is a *compromise* between multiple criteria. It is necessary to have appropriate benchmarks. Catherine Azzaro Pantel makes this point in Chapter 8.

For example: we can build “cheap” by limiting instrumentation devices, automation and robotics, if labor is cheap. We have a transfer between CAPEX and OPEX.

We can buy cheap equipment, but what will be the cost of maintenance: not having a backup pump, what will happen to the reliability of the installation?

Electrical energy and water can be cheap and plentiful as in Canada; there are colossal coal reserves in China. Each case is a theoretical case or a special case.

NOTE.— Philippe Tanguy, at the time of the European Congress of Chemical Engineering that was held in Prague in August 2010, highlighted the relationship between water and energy. What will become of some French nuclear power plants if drought settles in?

The *location* of plants is taking on more and more importance in economies that are trying to be “circular” [PIP 10], that is where the products and energy from an installation will feed downstream installations. The new concept of the bio-refinery can be a preface for this.

We are witnessing the emergence of a concept of *regionalization* of the industry.

*Energy* is often of particular importance: from degraded energy, like from low pressure steam coming from HP steam may have multiple uses; process units and organizations can benefit from them.

Synergies between the process units of big industrial platforms such as those established in Germany in the 19th Century are obvious: utilities, treatment of effluents, and transport can be shared. But can we conceive it in socially unstable countries where a “minority” can block everything?

The location is strongly linked to the society, to transport *mobility*, to the quality of life (see Chapter 6).

Transportation accounts for about a quarter of global CO<sub>2</sub> and eco-mobility has to be taken into account.

#### 14.3.3.1. *Other considerations of conceptual order*

##### 14.3.3.1.1. The plant seen by the customer

The plant is made in order to serve the customers and *stakeholders*, which include the customers, they are the ones who bring it to life!

Grua and Segonzac [GRU 99] suggest looking at the factory “upside down”. Instead of starting as usual, from the raw materials and coming down toward finished products, the plant is designed starting from the warehouse!

The customer is placed at the center of the productive system.

EXAMPLE.– A senior executive used to only visit administration offices and the warehouse when visiting a plant. He told the stupefied technicians that the technique was their job, what interested him was the customer.

##### 14.3.3.1.2. Flexibility, recyclability

The *risk* related to the investment is a major risk of the company. This is the case for the highly capital-intensive pharmaceutical industry, where the risk related to the product itself (side effects) is very active before and after the start-up.

This type of risk can be mitigated by subcontracting, with *modular process units* that can at least partially be reused for other productions.

Flexibility must take into account the changes in manufacturing and raw materials. *It is no longer build for the long-term*. Philippe Escande in *Les Echos* [ESC 11] highlights the fear of companies faced with an outsider who is capable of innovating to the point of knocking down the established order. The fear is the breakthrough innovation rather than incremental innovation.

*Process intensification* is the subject of Chapter 12, written by Laurent Falk. This approach calls for miniaturization, aims to make the equipment parts multifunctional, and to move from batch mode toward continuous mode. We are at the clearing stages knowing that there are already *success stories* in fine chemicals.

##### 14.3.3.1.3. Equipment and architecture

To transform raw materials one needs equipment! Distillation columns, reservoirs, tanks, pumps, exchangers, filters, dryers, pipes, structures, instruments of control, wastewater treatment plants, and so on, are an integral part of the industrial landscape and represent a significant part of the total investment.

An item of equipment is a functionality and should be viewed in this aspect. Its integration with what can be called the *architecture* of the installation, should be

considered not only under process aspects, but also under the aspects of maintainability and ergonomics.

An item of equipment may be the process itself; this is the case in industrial chromatography. The synthesis of ammonia, no doubt the greatest industrial revolution of the 20th Century, was made possible by new high-pressure compressors.

We can question the impact of shortage which is looming on the horizon of some raw materials for the plants in the future.

Copper has risen from 3,100 dollars/tonne in early 2005 to 10,050 dollars/tonne in early 2011; what are the consequences to be expected if the phenomenon intensifies?

#### **14.4. Management of production and operations (MPO)**

The term “management of production and operations” is broader than production or manufacturing. Besides production, it includes all that relates to staff who coordinate, support, and manage it. It also includes purchasing, maintenance, processes, planning, management, performance analysis, and so on.

##### **14.4.1. Essential tasks**

The essential tasks are as follows:

- satisfaction of customer and stakeholders;
- maintaining the *cohesion* of the group and harmonious management of the operational and entrepreneurial mode;
- maintaining the *reliability* of the system (see Chapter 13);
- the maintenance of ethics;
- control to prevent major accidents, and damage to the environment and people;
- continuous improvement, quality, and cost reduction.

##### **14.4.2. Tools of the MPO**

- Cost accounting.
- *Scorecards* and performance indicators in the broadest sense, which range from output analysis to the occupancy rate of process units, to absenteeism, and the frequency rate of accidents.

The analysis of deviations compared with the established standards, which can be that of the budget, is of particular importance.

– All kinds of audits; those concerning the QHSE aspects have process analysis as a common point. A well-managed process unit, in terms of safety and which will be equipped with an adequate SMS (safety management system) will not have too much difficulty in obtaining ISO certification.

– The project management techniques widely described in this book.

However, let us note that the question of performance of a plant is a complex question because it is necessary to decide the measurement standards and determine the context in which the question arises: does it concern an audit of administrative procedures, a balance sheet, an evaluation of a process or an audit prior to a purchase? A very clean plant, without any accidents, can delight the corporate safety engineer, and its poor performance may discourage the financial analyst.

*There is no management without measurement*

– *Traceability* is becoming more and more compulsory in companies. Its objective is to know the history of a product, its origin, to identify the stages of its manufacture, and to recognize its integrity. It uses tools such as RFID, barcodes, DNA chips, and so on.

– RFID was already used during World War II to identify aircraft of friends or foes.

– In the biotechnology industry, the operating conditions of fermentation “batches” must be archived for 10 years.

– Other applications of traceability:

- location of parcels, means of transport, people;
- fight against composition fraud, falsification.

Traceability has become an inseparable part of the *supply chain*.

#### 14.4.2.1. *Lean manufacturing*

The term “lean manufacturing”, publicized by many consulting firms, implies the practices that are aiming to reduce the production costs to control the production facility, and to increase productivity in a spirit of continuous progress.

Ironically, we can say that it is a fight against *fat manufacturing* synonymous with excessive overheads, superfluous stock, and waste.

*Lean manufacturing* is particularly all the techniques that are related to Toyotism described in Chapter 10, often with the Western “touch” provided by the Six Sigma method. Its interest lies in the attention paid to the production function, very often neglected by many companies.

Americans point out that Henry Ford and Frederick Taylor were the first to lay the foundations of the modern plant that has replaced the mill. Value analysis, invented by L. Miles, has contributed to put the customer on the front of the stage.

The terms of *World Class Manufacturing of lean enterprises* cover, according to the companies, all the methods of *re-engineering* to improve profitability.

#### **14.5. The IT revolution – IT management**

It has changed the methods of engineering, facilitated calculations that took infinite time when they were made by hand, changed project management, and enabled modeling and simulation in process engineering. In the latter field, CFD (computational fluid dynamics) makes it possible to visualize the flows, transfers in dryers, fluidized beds, reactors and so on.

IT has invaded the management of the company and its facility and modified the methods of product design.

The CAx, that is to say, all that is computer-aided, gained momentum in the 1980s [BLO 99]. They paved the way for robotization which is strongly established in the manufacturing industry including the automotive industry.

The list of CAx is long! Let us cite computer-aided production management and computer-aided maintenance.

Data management, whether it is the data that a process unit continuously emits, or the information emerging from analytical instruments that detect infinitesimal doses, are possible using increasingly efficient statistical methods. It is about selecting the right methods and using them wisely!

NOTE.– A biotechnology plant of 100 million dollars has about 5,000–10,000 points of measurement. What about a refinery!

Peter Drucker [GRE 97] estimates that e-commerce is still in its infancy and it will bring a new revolution in the mode of customer/supplier relationships.

The advent of social networks is already changing the relationships between individuals profoundly and possibly between the states and individuals (see the Arab rebellions in Spring 2011). These networks will help to change the company due to the fact that nothing can be hidden for long!

#### 14.6. And the individual?

It is individuals who “do things” that bring the company to life, who operate the production facility, albeit by remote control.

Industrialization should consider the operators, the human factor in its design phase, and in its architecture, to reuse a term which is already used. Taylorism from its aspects analyses of tasks is still valid.

We cannot think of a flexible, versatile, and agile plant if the operators – from the laborer to the executive – do not have these qualities and if they do not have the means to implement them.

The fact that the company must become an open system has changed the situation and made it more complicated.

The increasing complexity of technologies requires a continuous effort in training. The lack of growth, visibility, and the race for efficiency cause stress and eventually psycho-social risks.

It is necessary to rethink the production facilities as a source of wealth. This is not the *dirty part* [HAY 88].

Edison said a century ago: *factories or death*.

Drucker said that, in the past, knowledge was at the top of the organization, but now it is at the *bottom* with the *knowledge worker*.

For this international consultant, innovation is the key: “some think innovation is a ‘flash of genius’, not a systematic, organized, and rigorous discipline. The Japanese are organizing innovation. So are the Koreans ...”.

Speaking of South Korea, Drucker points out that after the Korean War in 1953, the destroyed country had no industry. Currently, it is a leader in many areas ... The management of knowledge is the key as we have strongly emphasized.

*It seems to us that the integration system of research and the industrial system are a basic concept, a “key idea” upon which we must build.*

François Dehecq, chairman of Sanofi-Aventis, in a speech that followed the General Assembly of the Chemical Companies Association on April 22, 2010, emphasized that “there is no research center without a plant!”

During the tests conducted by Elton Mayo at the Hawthorne plant near Chicago in the 1930s, it became clear that staff motivation was improved if the staff were recognized and had a sense of belonging to a group; and from then on productivity increased.

EXAMPLE [DAL 04].– The establishment of a safety management system (SMS) in plants located in different countries of the Asia Pacific has helped all kinds of people to adhere to “a value system”. The result was spectacular both in terms of safety as well as productivity and quality.

People want to be recognized!

With all due respect, to many, Fayolism and its monolithic structure seem to be more outdated than Taylorism.

The management of change is highly significant (see the introduction to this book).

It exerts an increasingly greater pressure on the managers and their assistants [GRU 99]. This “climate of agitation” is very often a source of inconsistency, and plans after plans do not succeed. Let us remember that Toyotism took 10 years to set up itself and not without difficulty!

#### 14.7. Conclusion

The production system spearheading the industrial company is a source of wealth and, as such, it should receive the attention that it deserves under all the specific aspects of the management, be it technical, human, or commercial [GAT 09].

Producing has become a social act [DAL 07c]; producing necessitates questioning oneself on the type of growth that will exist in any country. China cannot have the same number of cars per capita as in the United States, unless maybe the US come down to the current rate of China. Why not after all?

Industrialization, which must define the plant of tomorrow or of the future, whatever name we give it, must design a tool whose products and/or services satisfy its *stakeholders*, including customers, by implementing the principles of sustainable development with particular attention to the problems of raw materials and energy. Raw materials and energy must be available in time, in price and quality.

There is not just one plant of the future, there are many of them, even for those that make the same product. Location, capacity, and technologies implemented will influence the “*design*” of the installation.

*It is easy to make up fairytales.*



EXAMPLE.– In the case of a transfer of technology in China, the author had to compare two very similar process units between Japan and France. The cost comparison seemed to be inexplicable, but the result was there! The Japanese process unit had a particularly low manpower. Undoubtedly, the social conditions were not the same but the Japanese process unit seemed to be simple! The French process unit seemed to be complicated but the pumps of the Japanese plant had no spares! In the Japanese plant there were two maintenance shutdowns each year when everything was overhauled. What a lesson!

The process engineer, has a significant role to play in the industries of transformation of matter and energy, industries that will shape our very near future at a time when an international awareness seems to be emerging.

“*We are in the right profession*”, said Dr. Richard Darton, President of the EFCE (European Federation of Chemical Engineering), who wrote the preface for this book.

The process engineer, in order to be effective, must have a systemic vision, know the geosciences and the machinery of the modern company.

After the technical engineer of the 19th and 20th Centuries, the era of the *citizen engineer and manager* has arrived.

This book is dedicated to him.

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