ytics Business Analytics Business Analytics Business
ess Analytics Business Analytics Business Analytic

Operations Research
in Business Administration and Management

Concepción Maroto
Javier Alcaraz
Concepción Ginestar
Marina Segura

Operations Research
in business administration and management

Concepción Maroto Álvarez
Javier Álcaraz Soria
Concepción Ginestar Peiro
Marina Segura Maroto

EDITORIAL
UNIVERSITAT POLITÈCNICA DE VALÈNCIA

http://tiny.cc/edUPV_rea

The publication of this book has been approved by the Department of Applied Statistics and Operations Research and Quality of the Universitat Politècnica de València (Spain)

Academic book collection

To cite this publication please use the following reference: MAROTO ÁLVAREZ, C., [et al] (2014) *Operations research in business administration and management*. Valencia: Universitat Politècnica de València

First edition, 2014

Authors: Concepción Maroto Álvarez
Javier Álcaraz Soria
Concepción Ginestar Peiro
Marina Segura Maroto

Cover design by Carmen Lloret

Of this edition: edUPV / www.lalibreria.upv.es / Ref.: 6176_02_01_01

ISBN: 978-84-9048-242-1 (print version)
ISBN: 978-84-9048-241-4 (electronic version)
DOI: https://doi.org/10.4995/REA.2022.617602

To our students: never lose the hope to do things better.

Acknowledgments

We acknowledge the support of the Faculty of Business Administration and Management of the Universitat Politècnica de Valencia in preparing this book for Operations Research teaching.

We also thank Stephen and Dogan for their infinite patience with the English proofreading.

CONTENTS

CHAPTER 1

THE NATURE AND METHODOLOGY OF OPERATIONS RESEARCH

This chapter begins with an overview of the origins and evolution of Operations Research in order to understand its current and future interest in Business Administration and Management studies. Due to the lack of a generally accepted definition for the discipline, several definitions are presented in section two of this chapter, in an attempt to cover the traditional approach as well as some more recent approaches. Section three describes some applications in Business Administration and Management. Lastly, the methodology of Operations Research is presented, including an in-depth analysis of the problem formulation, modelling and implementation.

1.1. THE ORIGIN AND EVOLUTION OF OPERATIONS RESEARCH

The term "Operations Research" or "Operational Research" (OR) was first used in the UK, when in 1936 a group of RAF scientists was established to study how to operate radar. This group was called the Operational Research Section, as it was more concerned with the operations of the new equipment than with the development of radar itself. This first section was so successful that by the time World War II was over other allied nations already had similar support groups for their military operations decision making (Keys, 1995). However, Kirby (2000) places the formal birth of Operations Research in 1938.

The positive impact of Operations Research during World War II brought about its subsequent smooth introduction into the industrial and commercial sectors on both sides of the Atlantic. In England it was concentrated in two industries, coal mining and the iron and steel industry. Paradoxically, the teaching of Operations Research started in the United States sooner than in England. The first textbook on the subject was written in the USA: Churchman, C. W., R.L. Ackoff and E.L. Arnoff (1957): *Introduction to Operations Research.* John Wiley, New York. In the 1960s American industry was therefore receptive to Operations Research techniques due to the preparation of its managers (Kirby, 2000).

It should be noted that these origins of Operations Research represent the official history accepted by the majority. Other authors such as Professor Bueno (1971) expand on this and argue that there are three basic sources that influenced the appearance of Operations Research: economic models, military operations and mathematics. Thus, he finds evidence in, amongst others, Walras's general balance model, which outlines the production balance with a system of linear equations, the Tableau Économique of Quesnay (1758) and in Input-Output Analysis by Leontiev (1936). However, the special relevance of Operations Research to 20th century economic thinking becomes evident as many Nobel Prizes of Economy (which started in 1969) have been awarded to authors who published works in the area of linear programming and other quantitative techniques and nonlinear programming and games theory. Among these Nobel prizewinners are Samuelson (1970), Leontiev (1973), Kantorovich (1975), Simon (1978), Solow (1987), Markowich and Sharpe (1990), Selten, Nash and Harsanyi (1994), Aumann (2005) and Hurwicz (2007).

Keys (1995) considers the period 1945-1975 as a period of growth and stability that he calls the “Golden Age” of classic Operations Research. During this period the institutionalization of Operations Research is seen in three aspects: as a support to management in industry and other organizations, in the creation of professional associations and in the establishment of academic programs.

The historical work carried out by Kirby (2000) emphasizes the rapid dissemination of Operations Research techniques after the revolution of information and communications technologies during the 1980’s. Thus, in the early 1990’s, spreadsheets implemented linear and nonlinear programming codes, and their performance has improved a lot since then. This situation of Operations Research offers new challenges and opportunities for business administration and management. For example, nowadays millions of Microsoft Excel users can create and solve models that allow them to improve business decision making at operative, tactical and strategic levels. Moreover, the Operations Research techniques are and will continue to be part of the applications for helping decision making techniques known as *Decision Support Systems (DSS)* and *expert systems*.

1.2. THE NATURE OF OPERATIONS RESEARCH

From its beginning, there has not been a generally accepted and precise definition of Operations Research and, throughout its evolution, its methodology has been extensively discussed. The main characteristics of Operations Research appeared in the first OR textbook published in 1957. Specifically, there is an emphasis on the scientific method, the interdisciplinary teams, the decision making, obtaining the best solution and the global approach.

For Assad, Wasil and Lilien (1992) Operations Research - Operations Research/ Management Science (OR/MS) - is the application of the scientific method to decision making or to professions that approach the best way to design and operate systems, usually under conditions where allocation of scarce resources is required.

Keys (1995) considers Operations Research as a technology. Operations Research uses the scientific method on which its observation, modeling, thinking, experimentation and logical and systematic investigation are based. However, it does not use these methods with the same purpose as science. Science is descriptive, Operations Research is prescriptive. The objective of Operations Research is to provide information and to design ways to improve the effectiveness of organizations.

The two basic characteristics of this **technology** seen from this new model are their **objectives** and their methods. The objective of Operations Research is the **production of information** about the systems that facilitate improvement in the effectiveness of the organization. The **methods** used to produce this information are of a **scientific nature.** That is to say, they are based on measures, analysis and validation rather than likes, intuitions and opinions. If we consider that technology is in charge of designing systems, physical as well as abstract, Operations Research **is a technology that designs abstract systems** that consist of useful information for the planning, the control and the other necessary activities to manage an organization.

According to Keys, **Operations Research is a technology that designs abstract systems, by scientific means, to improve the effectiveness of organizations**. The implications for teaching and learning Operations Research take into consideration two components. On the one hand, formal means must be used to teach useful working ways, such as quantitative analysis and application of scientific methods. On the other hand, it is necessary to complement this education with the application of the previous skills to real problems. This textbook considers this approach as the most appropriate in areas where Operations Research is taught, which are, Business Administration and Management studies.

Robinson (2000) defines Operations Research as the application of the scientific method to improve the effectiveness of operations, decisions and management. Robinson considers that one of the reasons for the discipline to remain invisible or visible but not well understood, is because it has been practiced under different names. Besides *Operations Research*, other almost synonymous terms have been used such as *Management Science, Decision Technology, Decision Support, Policy Science, Systems Analysis* (with relative applications to administration and decisions), *Management Technology* and *Management Analytics.* ***Business Analytics*** is another recent name that integrates descriptive and prescriptive analytic methodologies.

An important feature of Operations Research is maintaining a **global perspective** on the projects, analyzing the particular problems in the context in which they occur. In both the classical and the most modern definitions of Operations Research the **system concept** is fundamental. Let us see some examples that will illustrate this.

Many companies calculate the unit production cost at a machine shop or a production line, taking into account all of the costs of the resources used. The lower the unit production cost the greater the efficiency. This procedure is valid only for production processes that consist of a single phase and where there is no trouble in selling the product. When the company has complex production processes with several products (e.g. tile companies) and each line produces different parts - often in small batches-, which are used as inputs in subsequent phases of the production process, this acts as an incentive for the machines to be producing all the time. If the next production line in the manufacturing process does not require these intermediate stocks immediately, the company will need to store them temporarily, incurring a cost for these intermediate stocks that are not attributed to the line that generated them. Therefore, the production line seems to be efficient, while the company has to deal with excessive costs caused by these intermediate stocks.

As we have seen in the previous example, the operation efficiency of a particular division of a company can impair the overall performance in terms of objectives and goals. The efficiency measures how well resources in a given activity are used. Thus we can speak of ***technical efficiency***, which does not need to be the same as ***economic efficiency***, which maximizes the difference between revenues and costs. However, a company is interested in achieving its objectives, which we can evaluate via its ***effectiveness***. That the several parts of a system operate efficiently does not necessarily mean that the whole system is effective in achieving its objectives. This is not to say that efficiency is contrary to effectiveness. **Real efficiency is measured in terms of the overall objectives of the company**. Efficiency and effectiveness are complementary concepts. In short, we can say that *effectiveness* deals with *"doing the right thing"* and *efficiency* with *"doing things right"* (Daellenbach and McNickle, 2012).

Here is another example to illustrate the concept of system in Operations Research. In a company with five departments (raw materials procurement, production, marketing, finance and personnel) marketing proposes an increase in the duration of the guarantee of one of its products to better compete. What forms the system? What forms the environment?

The marketing department consists of distribution, sales and customer services. The company assumes that extending the guarantee period will increase sales. However, they also increase guarantee costs due to added customer services. Therefore, the system to be studied could be reduced to sales and customer services (System 1), with all other operations of the company, customers and competitors which form the environment. The aim of System 1 is to find out the guarantee period that maximizes the difference between benefits from sales and guarantee costs.

System 1 considers product quality as a part of the environment, but product quality will affect both sales and warranty costs. For this reason, System 1 could be expanded to include production (System 2). The objective of this system is to determine the optimal combination of product quality and the guarantee period to maximize profits. However, product quality is also affected by the quality of the raw materials used, which are part of the system 2 environment. Thus System 2 could be expanded further to include the procurement of raw materials and form System 3. System 3 could also be extended to include other company's products, if sales of these products are affected by changes in the guarantee period of the first product, leading to System 4.

In Figure 1.1 we can see how each system is included in a larger one. With this example we want to illustrate the fact that the Operations Research always tries to solve the conflicts of interest within the company, so that the best result for the company in terms of its objectives is achieved. This does not mean that the study should always explicitly consider all aspects, but that the objectives sought after have to be consistent with those of the company.

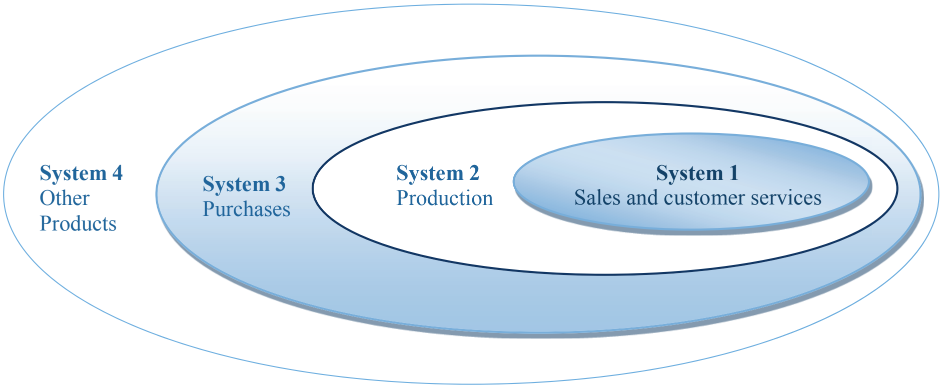

Figure 1.1. Example to ilustrate the system concept. Source: Daellenbach et al. 1987.

1.3. APLICATIONS

After World War II the British as well as the American army maintained active Operations Research teams. As a result, nowadays there is a large number of people called "military operations researchers" that apply the Operations Research approach to national defense problems. Operations Research is also widely used in other types of organization and in the business world. In fact, almost all large and many medium sized enterprises worldwide have established Operations Research teams.

Among the industries that apply Operations Research are those dealing with aviation and missiles, computer science, electric power generation, electronics, food, metallurgy, mining, paper, petroleum, transportation, as well as financial institutions, government agencies and hospitals. The companies which were finalists of the Franz Edelman INFORMS (***Institute for Operations Research and the Management Science***) prize provide excellent examples of real applications of Operations Research (http://www.informs.org).

Among the finalists in 2012 were Hewlett-Packard (HP), Intel and **TNT Express**. The latter won the award for its "Global Optimization", which uses advanced methods to optimize the transport network of the company. This program solves problems in warehouse location, optimal routes for trucks, fleet management and personnel scheduling.

In 2011 *Midwest Independent Transmission System Operator (Midwest ISO)*, a non-profit organization that **manages the electricity market** in 13 U.S. states (North Central region) and one in Canada (Manitoba), won the *award*. It has operational control of more than 1,500 energy production plants and 55,000 miles of power lines. It notifies the plants, every 5 minutes, of the amount of energy required to meet the current demand. It uses a linear programming model to calculate production levels and establish the market price of electricity. The model size is up to 3 million continuous variables and 4 million constraints. The solution to the model provides plant production levels and energy prices (shadow prices or opportunity costs). It also uses an integer programming model to determine when a plant should be producing or not. The individual companies retain physical control of the plants and transmission lines. *Midwest ISO* manages the real-time power to bid and buy on demand, manages the market and maximizes the benefit of the company which sells the cheapest electricity. In short, using techniques discussed in this book, in this example the price at which electricity is bought and sold is determined and, what is more important, the electricity is available when and where it is needed and provided safely.

In **2009 HP** and the **Marriot hotel chain** were notable entries with two Operations Research tools to manage the product portfolio and with a price optimizer respectively. Also in 2009 Zara was among the finalists for applying Operations Research to improve its distribution process. **Cocacola Enterprises**, the world's largest bottler and distributor of Coke products (Coke, Fanta, Sprite, Minute Maid, etc) was also recognized in 2007 for its application to schedule the daily routes of 10,000 trucks.

We will discuss the application of Zara in a little more detail. Zara´s supply chain consists of two main warehouses located in Spain, which regularly receive shipments of finished garments from suppliers and replenish all Zara stores twice a week. The key is to determine the exact number of each size (up to 8 different sizes) and each item (up to 3,000 at a time) to be included in each shipment to each store (there are over 1,500). Until 2005 Zara used a procedure that required a large number of employees to determine shipments to each store. The company developed a decision making process based on Operations Research methods, including methods of forecasting and a very large mixed **integer programming** model. The implementation of this new process presented many technical difficulties. One of them was to include the uncertainty of estimates and inventory policies of the stores, and the integration of a complex mathematical model with many large databases. They also had to have the software and hardware infrastructure necessary to solve optimization of thousands of problems in a couple of hours each day. Additionally, it presented challenges related to human resources, because the Zara corporate culture highly values intuition and personal judgment in decision-making. The development of this new process, supported by Operations Research techniques, was completed in all stores and articles and it has been used since 2007.

In general, **linear programming** and **integer programming** have been successfully used in solving problems related to the allocation of the means of production, material mixing, distribution, transportation, investment selection and planning of agriculture, among others. A very important application of linear programming in the field of economics is Data Envelopment Analysis (DEA), developed by Charnes, Cooper and Rhodes (1978). DEA is a linear programming based technique that allows us to empirically measure the productive efficiency of decision units such as groups of companies in the same sector, financial institutions, hospitals, educational institutions, etc. and identify the companies that are on the *efficient frontier* of production. The efficiency is measured by the weighted sum of the outputs on the inputs. The weighting structure is calculated using linear programming. Furthermore, the concepts of linear programming guide and facilitate the analysis and interpretation of the results of the DEA models. At present this is still a very active field of work, both in the application and in the research being conducted.

Nonlinear programming is also used in certain problems of resource allocation, selection of efficient portfolios, new product design, production problems, mixtures in chemical processes, etc. **Multiobjective programming** and **goal programming** also have many applications such as natural resource management (Weintraub et al., 2007), scheduling of advertising media, land use management, location of utilities and planning of resources in hospitals to name just a few. Other Operations Research techniques such as inventory theory, game theory and simulation have been used in a variety of contexts.

Operations Research shares with Artificial Intelligence the objective of providing methods and procedures for solving problems and making decisions. Artificial Intelligence is inferential and has expert knowledge and heuristic methods. Operations Research is mainly based on mathematical algorithms. A careful integration of these two approaches has a bright future ahead for the performance and acceptance of the systems. **Decision Support Systems** for decision making integrate Operations Research and Artificial Intelligence techniques in information systems that are very useful in the decision making process. This integration can make Operations Research techniques more accessible to decision makers and the models can also use Artificial Intelligence techniques. We should also highlight heuristic search techniques such as genetic algorithms, tabu search and simulated annealing.

Operations Research models are common in **finance**, often grouped under the name of **financial engineering**. Similarly **marketing engineering** usually means Operations Research applied to marketing. In this field it is applied to strategic decisions (planning, portfolio, etc.) and at the tactical level (product design, advertising, etc.). They also play an important role in the analysis of electronic markets. Other opportunities will come from electronic trade and investment, from online banking to online insurance.

With regard to supply chain management, the digital economy provides opportunities to use Operations Research in resource planning in companies. Given the information that is available online, advanced planning and production scheduling, will improve coordination and cooperation between suppliers and customers. The growth of mobile computing and communication will increase the aid that applications give to decision-making in transport trucks. Thus there are companies that optimize loading and truck routes using web applications to obtain data and distribute solutions. The Internet also facilitates the expansion of supply management towards integrating product design, sales and customers.

Finally, we must emphasize the strengths of **Operations Research** in the digital economy era: it exploits the vast amount of data available, which is of ever increasing complexity due to its analytical nature and uncertainty, modeling **increases our understanding of business processes and virtual experiments can be made without risk to business and thus provides decision making technology** for the automation of recurring decisions in real time, such as for web applications. In short, the Operations Research of the future is Operations Research in real time. Customers often ask when their order will be delivered. Providers base their response on their inventory and the scheduled production in progress. However, they should now be able to respond after performing a scheduling algorithm including the potential order. To achieve the required performance in real time sometimes we need to resort to heuristic algorithms such as those discussed in the last chapter of the book.

1.4. METHODOLOGY OF OPERATIONS RESEARCH

Daellenbach and McNickle (2012) clearly establish three major phases in the methodology of Operational Research which are: problem formulation, modelling and implementation, which in turn break down into the sub-phases indicated in Figure 1.2.

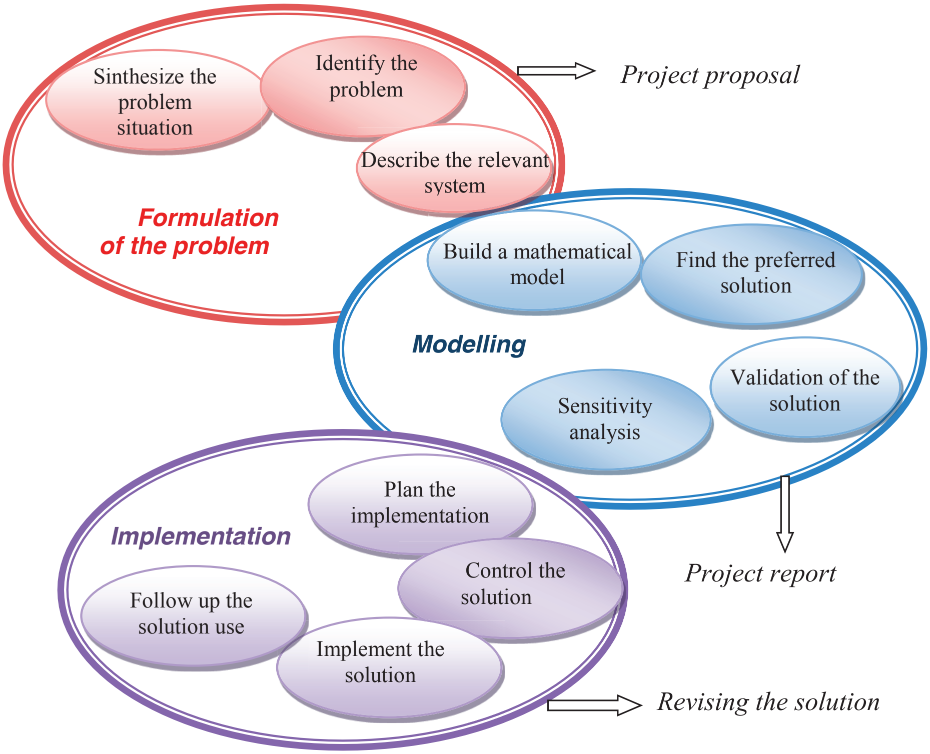

Figure 1.2. Methodology of Operation Research. Source: Daellenbach and McNickle (2012)

1.4.1. FORMULATION OF THE PROBLEM

In the first place, we should make a **synthesis of the situation**, for example through **graphics or charts** which will help us during the problem definition phase, after which we should identify the structure, the transformation processes, the components and the inputs and outputs of the relevant system. For a problem to exist there must be an individual or group of individuals, called **decision-makers**, who are not satisfied with the current situation or who have unsatisfied necessities, such as reaching some goals or objectives. They also know when the goals or objectives have been satisfactorily reached and they have control over the aspects of the situation that affect the extent to which the goals or objectives are achieved. The four elements of a problem are:

- The decision-maker/s.
- The decision-maker´s **objectives**.
- The **measurement** of efficiency in order to be able to assess the extent to which **objectives** are achieved.
- The **action alternatives** or **decision variables** to reach the objectives.

The second step of the formulation of the problem is its identification and consists of defining these four elements. The third step consists of defining the relevant system for the problem that we have identified in the previous step, including its environment. The decision-maker has an esential role in the problem formulation phase.

In practice, the determination of these four components might not be so easy to obtain by simply asking the decision-maker. Sometimes the decision-maker only has a vague intuition that things could go better. We should explore and clarify the situation through several people involved in the situation. Sometimes, it may happen that the person who makes the decisions does not have access to the information needed to make an effective decision and the one that has the information does not have enough authority to make decisions. In these cases, the first thing to do is to change the structure of the organization, re-assigning the roles in the decision making. In most real applications, problem formulation is not achieved in these three steps, rather the initial formulation is detailed with successive reformulations, as the problem is better understood. In fact, it continues until the project concludes. However, it is in this phase where the success or failure of many projects occur.

Once we know the problem and the relevant system well enough, we can decide whether Operations Research may provide a solution to the problem. Therefore we should ask ourselves the following questions:

Can the problem be expressed in quantitative terms?

Are the required data available or can they be obtained at a reasonable cost?

Does the cost of the analysis justify the possible benefits that will be obtained from the implementation of the results? To what extent can the decision-maker expectations be fulfilled?

If we answer these questions affirmatively, then the formulation phase concludes with a proposal that will be the document which the decision-maker will use to decide to continue with the project or not. Therefore, the proposal is a key element. We should not promise more than we know that we can obtain with the available resources. Since Operations Research has much in common with the scientific research, it should be guided by the **ethics** of the scientific method.

The following anecdote from Ackoff illustrates both the difficulty of formulating the problem in real cases, and the fact that we can not always solve an unsatisfactory situation by making models. It is as important to know what models are useful and when we can improve decision making, as it is to know how to recognize when they are not the right tool. The administration of a large office building received complaints for years about excessive staff time spent waiting for the elevators in the main lobby. Several teams of Operations Research analyzed this problem of excessive waiting time. Different solutions were proposed: to use some elevators for lower floors and others for higher floors only. However, it was concluded that a significant reduction would be possible only by installing new elevators with a high associated cost. A member of the last team to study the problem asked why staff complained and after appropiate inquiries it turned out to be because of boredom. The Operations Research team then proposed installing mirrors. Some workers used them to make a final check of themselves or to check out other staff without being too obvious. When this solution was implemented the complaints disappeared (Ackoff, 1987). Nowadays, screens with information of interest to the staff can achieve the same effect as the mirrors did then.

Operations Research, in many cases, does not intend to find the optimal solution, but to find some degree of improvement over the previous situation. One of the founding fathers of the discipline colloquially explained it as follows: "Operations Research is the art of providing bad solutions to problems that otherwise would have worse solutions."

1.4.2. MODELLING

This phase distinguishes Operations Research from other methods of solving problems. According to Daellenbach and McNickle (2012), Operations Research is often seen as a number of techniques and mathematical tools, which do not favour the discipline at all to the detriment of its potential. The modelling phase begins by expressing the system related to the problem in quantitative terms. A mathematical model expresses in quantitative terms the relationships between especially important components of the system that have been defined in the formulation phase. These relationships can sometimes be represented in a spreadsheet and for some others it is necessary to formulate the relationships in terms of mathematical expressions, such as equations, inequalities or functions. The term model is used in a broad sense, since it can take the form of a chart as well as of mathematical expressions.

We call the action alternatives or controllable aspects of the problem **decision variables**. The term **action alternatives** is used when the number is discrete and usually small. The measurement of the behaviour or effectiveness is the aspect that measures the extent to which the objectives of the company are reached. If this measure of effectiveness can be expressed as a function of the variables, we call it the **objective function.** Our goal is to find the values of the decision variables that maximize or minimize the objective function. The **parameters or coefficients** represent the uncontrollable aspects of the problem. And the **constraints** are the mathematical expressions that limit the range of values of the decision variables. From the early 50’s, a number of mathematical models have been developed with their own resolution procedure, such as linear programming