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Metaheuristics for Logistics

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Metaheuristics for Logistics

Introduction

General Eisenhower stated that: "*You will not find it difficult to prove that battles, campaigns, and even wars have been won or lost primarily because of logistics*". The military genius introduced the term "logistics" as the activity that allows supplying troops, temporally and spatially in order to maintain all of their operational abilities.

Logistics has progressively imposed itself in the industrial world ever since its revolution during the 19th Century, and nowadays it constitutes a means of pressure essential for the competitiveness of companies.

How can we exploit the full potential of logistics?

By bringing its flow under control and by structuring its logistic activity, which are the concerns of Supply Chain Management (SCM), several tools have been developed in various fields (manufacturing, inventory, supply and information management, etc.).

These tools can be of different kinds. They may be organizational (Lean Manufacturing, Kanban, Just-in-Time, etc.) or related to data management and use (Enterprise Resource Planning, Advanced Planning and Scheduling, Electronic Data Interchange, etc.). The scope of this work is limited to the latter category and, more specifically, to the field of decision-making tools and to the specialty they belong to, i.e. Operations Research (OR).

Robert Faure, one of the pioneers of Operations Research in France, qualified his discipline as "*the set of rational methods and techniques for the analysis and the synthesis of organizational phenomena that can be used to make better decisions*". The advent of informatics, which has revolutionized our way of thinking and allowed Operations Research to take shape, has enabled us to approach logistics from a quantitative point of view.

Logistics-related problems have been pointed out, modeled and studied. However, some of them originated in the earliest stages of logistics. They were already stimulating the minds of talented scientists in the form of numerous conundrums and other mathematical challenges that they proposed to the world.

It is all the more to these pioneers' credit that some of these problems have not been solved yet. Could it be that they are resistant to mathematics itself? Contemporary mathematicians have grouped them into two broad categories that are summarized as follows: "easy" problems and "hard" problems.

I am used to telling my students that the last person they should trust is their Operations Research professor. The words "easy" and "hard", when uttered by a professor, are quite far from their original meaning. Thus, a problem deemed easy may turn out to be tricky to solve for someone with no insider knowledge (the two-machine flow-shop scheduling problem). Likewise, a "hard" problem may seem simple at first sight (the knapsack problem). You will soon know the two problems I have given as examples inside out!

In simple terms, "easy" problems include the set of combinatorial optimization[1] problems for which we know an effective solving algorithm. This clearly shows that the number of necessary calculations is a polynomial function of the size of the problem. These problems belong to the P class of problems, which are called polynomial. On the contrary, we say that a problem is "hard" when the only algorithms we know for its solution are verified in exponential time. These problems belong to the NP class and will be called non-polynomial.

The greater part of the scientific community thinks that if we have no effective method for the solution of an NP-class problem, it is simply because there is no solution! This question, stemming from the complexity theory, is known as the "P versus NP" problem. To date, it remains unsolved and is

1 A combinatorial optimization problem consists of looking for the best solution among a very large, if finite, set of solutions. A more formal definition is offered in Chapter 4. All the logical problems found in this book belong to this category of problems.

classified by the Clay Mathematics Institute as one of the seven Millennium Prize Problems. A US $1,000,000 prize will be awarded to whoever solves it.

As it happens in mathematics, whenever a problem is too complex to be solved, approximate methods are applied. Metaheuristics, which constitutes a family of generic procedures, belongs to this category. They have proved their ability to solve complex optimization problems for several years.

Throughout this book I will aim to show these procedures, to see definitively how they can be applied to logistic problems, and to understand the solutions they can provide for the quantitative optimization of the mechanism of a supply chain.

For that reason, this book is made up of 3 parts and 12 chapters.

The first part is called "*Basic Notions*". It enables us to lay some foundations whether in relation to logistic problems or concerning optimization procedures. It includes Chapters 1 to 4.

– Chapter 1 presents us with a certain number of logistic problems in the form of exercises drawn from everyday life, which offer a first playful approach to the field. Some detailed answers, together with comments, are provided in the last chapter of this book.

– Chapter 2 draws up a methodical inventory of logistic problems, emphasizing their variety and the richness of the solutions they provide to a great number of logistic sectors. Each of these problems is presented formally in the form of a linear program. This kind of mathematical modeling, despite seeming possibly rigid, can nonetheless contain information useful for the concept of metaheuristics.

– Chapter 3 constitutes an introduction to metaheuristics. The scope of the application of these methods and the general concepts are presented. Some metaheuristic procedures are then explained in detail, while emphasis is put on their historical background, on the concepts that make them differ or bring them together, on their advantages and on their drawbacks.

– Chapter 4 constitutes a first concrete example of the application of metaheuristics. A detailed and progressive implementation, provided with comments, is proposed for an important category of optimization problems, i.e. permutation problems. This first piece of work on metaheuristics will allow us to develop a range of tools adaptable to many logistic problems and be able to give us acceptable results.

The second part is called "*Advanced notions*", as surprising as this might seem. This part aims to propose a certain number of more sophisticated tools, which will enable us to better the performance of metaheuristics. It includes Chapters 5, 6 and 7.

– The whole of Chapter 5 is dedicated to the emblematic traveling salesman problem. As for this permutation problem, metaheuristics can increase their effectiveness if they incorporate more elaborate procedures. Some of these mechanisms, such as variable neighborhood search or ejection chains, will be split into their components through the prism of the important relevant literature.

– Chapter 6 will sum up some research we have carried out in order to adapt the mechanisms mentioned in the previous chapter to the permutation flow-shop scheduling problem. This problem is also, as its name points out, a permutation problem.

– Chapter 7 aims to extend our reflection to other logistic problems that do not deal with permutation. Two general kinds of approaches are compared: the indirect approach, which consists of adapting the problem to metaheuristics and the direct approach, which consists of adapting metaheuristics to the problem.

The last part is called "*Evolutions and Current Trends*". The significance of logistic problems progressively dwindles before the current needs of the supply chain. This section is designed to define these needs and to determine the solutions that metaheuristics can provide when confronted with these new challenges. It includes Chapters 8 to 12.

– Chapter 8 introduces the concept of supply chain management. Logistic problems on their own can no longer provide satisfactory solutions to the new issues concerning the supply chain. We define the notions of horizontal and vertical synchronization in order to define the interactions between all these problems with more precision.

– Chapter 9 is also dedicated to solution methods. Faced with the study of increasingly complex systems, solving techniques have to join forces. The notion of hybridization of the optimization methods and the concept of interaction between an optimization procedure and a performance evaluation technique are studied.

– Chapter 10 describes an analysis we have carried out on flexible production systems. This study enables us to show the solutions that can be provided by an approach that combines several procedures in the study of a complex system.

– Chapter 11 describes two complex problems, set up by combining two logistic problems, which occur more and more often in the literature on the subject. These problems can clearly show the significant role they play in relation to decision-making in a supply chain. In addition to the problems, we will also describe some solving techniques present in the literature.

– Chapter 12 provides detailed solutions to the problems presented in Chapter 2.

Contents

PART 1

Basic Notions

1

Introductory Problems

Logistic problems are all around us. We only need to observe a little and to have some imagination to find them. In this chapter we propose three problems that perfectly illustrate the potential touch of madness of an operations researcher. These examples enable us to approach the issues that may crop up in the industrial world gradually, which will be described more formally in the following chapters. They are drawn from exam papers assigned to undergraduate students that have taken classes in a subject called "optimization problems and procedures". They are kept in their original form on purpose. The questions asked will be answered over the course of this book. A detailed answer key for the exercises, including comments, is supplied in the last chapter of this book. Beginners in combinatorial optimization can play the following little game: could you recognize the correlation between each practical problem and its theoretical equivalent?

1.1. The "swing states" problem

In the United States of America, during the presidential elections, there are certain states called "swing states", which are liable to swing from the Democratic Party towards the Republican or vice versa. It is these states that both parties pay most attention to, especially when the results day is drawing near. Table 1.1 shows the list of these states and the figures of their Electoral College.

The advisers of one of two candidates (you are free to choose either side) ask you to help them make the most of their last week of campaigning. You