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A decision support system for robust humanitarian facility location

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ABSTRACT

Each year, more than 400 natural disasters hit the world. To be more responsive, humanitarians organize stocks of relief items. It is an issue to know the quantity of items to be stored and where they should be positioned. Many authors have tried to address this issue both in industrial and humanitarian environments. However, humanitarian supply chains today do not perform correctly, particularly as regards resilience and efficiency. This is mainly due to the fact that when a disaster occurs, some hazards can strongly impact the network by destroying some resources or collapsing infrastructure. The expected performance of the relief response is consequently strongly decreased. The problem statement of our research work consists in proposing a decision-making support model in artificial intelligence dedicated to the humanitarian world and capable of designing a coherent network that is still able to adequately manage the response to a disaster despite failures or inadequacies of infrastructure and potential resources. This contribution is defined through a Stochastic Multi-Scenarios Program as a core and a set of extensions. A real-life application case based on the design of a humanitarian supply chain in Peru is developed in order to highlight the benefits and limits of the proposition.

1. Introduction

Today, humanitarian professionals face new challenges in the context of their activities. Donors in particular impose more and more drastic guarantees on the proper use of funds made available in case of crisis. Although very common in the business world, this requirement is very new in this sector, almost in contradiction with the doctrines and fundamentals of the humanitarian world. Another challenge clearly lies in the ability of humanitarian organizations to integrate several performance dimensions in their reasoning. The approach of simply responding quickly to an emergency situation is no longer satisfactory. The performance of the humanitarian response to crisis should be measured not only according to its speed of execution, but also according to its ability to minimize costs, to allow high flexibility, to limit its environmental footprint or to maximize its (media) visibility.

These contextual elements raise the issue of developing artificial intelligence (AI) tools, especially decision-support systems that the key actors can use for evaluating and defining operational solutions to be implemented. In the face of this observation, many researchers, in the past 15 years, have widely carried out studies and proposed tools and methods in this field. Authors such as Natarajarathinam et al. (2009), and Peres et al. (2012) have studied this phenomenon and observed that a big majority of the published works (more than 50% of articles) are based on analytical models, and in particular on mathematical programming models. However, in practice today, very few humanitarian organizations (not to say none) use tools stemming from AI as decision-making support tools. This point demonstrates the big gap that yet today separates academics and practitioners in the field of humanitarian activities, more especially humanitarian logistics. In attempt to bridge this gap, authors such as Kovács and Spens (2007) and Peres et al. (2012) identified very concrete research themes and particularly made the following suggestions:

- Given that humanitarian workers evolve in very uncertain environments, scientists should consider these uncertainties in a much more systematic way, within the framework of their research works.
- Researchers should try to come up with answers to the new efficiency requirements facing humanitarian organizations, and should not just confine themselves to the improvement of responsiveness.

Nevertheless, it would be difficult to take these two suggestions into account in only one research work given that the scope and spectrum of issues in a supply chain are very vast. Therefore, we

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have decided in this paper to focus only on the configuration and dimensioning of a humanitarian supply chain (HSC). Though location and sizing problems can be considered to have attained maturity from a scientific standpoint, their implementation in the humanitarian context encounters two major difficulties:

– the difficulty of having access to the data necessary for the elaboration and the validation of their models;
– the difficulty of assessing the severity of the disrupted situation once the disaster has been established to be true.

This paper aims to address these difficulties by studying the design of a HSC associated with recurring disasters, for example, cyclones in the Caribbean, earthquakes along the ring of fire, and floods in South-East Asia. These small-and-medium-scale crises constitute a very big percentage of emergency interventions by humanitarian organizations. For these particular crises, it is possible to build realistic scenarios based on past events as demonstrated by Charles (2010) or Comes et al. (2015). Other researchers such as Kovács and Spens (2007) and Peres et al. (2012) simply consider that for small- and medium-size disasters, future occurrences will generally be similar to those that had occurred in the past. In practice, the analysis of data from past disasters provides valuable information that enables to understand disaster trends (localization, intensity, typology and seasonality, etc.).

In these cases, the goal is to know where to pre-locate materials and how much in order to maximize responsiveness and effectiveness on the one hand, and minimize costs on the other hand. Moreover, this problematic has to take into account the main difficulties inherent to the humanitarian world, particularly demand uncertainty and non-availability of infrastructure. In other words, this paper addresses the following research question:

How should HSCs be designed such as to guarantee good performance levels in terms of efficiency (minimum costs) and resilience (the capability to deliver come what may)?

To address this question, we developed a research project that comprises two complementary parts. The first part is a robust HSC design model for a single scenario. Stemming from a classical location/allocation problem, the originality of this model lies not only in its ability to take into account the potential degradation of resources and infrastructure following the occurrence of a disaster (the resilience dimension), but also in its attempt to optimize the ratio between the committed costs and the obtained result (the efficiency dimension). Presented in the form of an Integer Linear Program, this part proposes an operation that guarantees greater robustness by allowing the smoothing of possible shortages. The second part, which is an extension of the first part, allows to consider a set of probability scenarios. This multi-scenarios approach is essential in view of the very uncertain character of humanitarian disasters. In practice, this takes the form of a Stochastic Multi Scenarios Program (SMSP).

These two parts would be too long to be presented in one single paper. In this paper, we have therefore chosen to present only the second part, which we consider to be a major contribution. The model that we developed was tested by applying it to a real life case of recurrent disaster in Peru. The paper starts with a literature review related to the design of supply chains, as well as existing approaches to solving location problems in both traditional and humanitarian supply chains. Then, it continues by defining an AI model that supports decision-making for designing robust HSCs. Finally, it develops a numerical application based on a sizing problem of the HSC in Peru. This numerical application enables to highlight the benefits and limits of our proposal.

2. Literature review and scientific problem

2.1. Determinist, stochastic or robust models

In our study, we try to develop a model to support decision-making for facility location, based on artificial intelligence (AI). One characteristic that is common to all mathematical modeling used in AI is representing a part of the reality and using variables and parameters to achieve the end results. This representation enables to make decisions, to implement them or to understand the implications of the decisions on the studied reality. The mathematical programming models used in this case represent the reality through the combination of variables and parameters in form of constraints and/or objective functions. Generally, the constraints must be respected and the objective function allows making the difference between a given solution and another solution that is potentially better.

A model is said to be determinist when all the data are supposedly known without uncertainty, while in a stochastic model certain first-order variables are represented by probability distributions. Consequently, in the results of the latter, the model is capable of taking randomness or uncertainty into account. Anjorin (2010) asserts that stochastic optimization problems are typically dynamic. The algorithms used in solving these problems are classified as NP-hard (Dyer and Stougie, 2006).

For Bertsimas and Thieley (2006), stochastic programming stood out as a powerful tool for modeling when a random probability description is available. However, in numerous real-life applications, the decision-maker does not possess this information. Therefore, robust models need to be developed. The idea is to design the model such that the effective scenario would have the least possible influence on the proposed solutions. Robustness is defined by Klibi et al. (2010) as a measure of useful flexibility maintained by a decision that leaves some allowance for future choices. She came up with this based on an optimization of the solution starting from pre-established scenarios but favored none of them such that the performance of the solution would be good whatever the scenario (Baud-Lavigne, 2012).

In a nutshell, we note that stochastic programming assumes that the probability function of random parameters is known, while in the case of robust models the random parameters and the probability functions are not necessarily known. For robust approaches, the uncertain parameters can be given by a set of discrete scenarios or a continuum. The purpose of this type of method is to obtain an optimal solution, which is insensitive to almost all the values of the uncertain parameters. Though we conducted our research on both deterministic and stochastic/robust models, we will in this paper present only the results of the latter since they constitute our major contribution to this stream of research.

2.2. Location problems

The determination of geographical locations of diverse units is referred to as a location problem. In all location problems, the main goal is to locate a limited number of units in order to provide the best services to the geographical area in question. The first location problem applicable to the industrial sector was formulated by Weber (1929). The industrial application consists in locating a warehouse such as to minimize the costs of products circulating between the warehouse and a set of customers (the cost of transportation being proportional to distance, as well as to the transported volume or weight). In the extant literature, there are diverse categories of problems that are extensions of the simple location problem. In the past 15 years, a certain number

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