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A dynamic model for disaster response considering prioritized demand points

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ABSTRACT

This paper addresses the problem of distributing relief supplies after the occurrence of a disaster. We develop a dynamic model to serve demand, while prioritizing the response, according to the level of urgency of demand points. Our model is thought to be applied during a planning horizon and it considers dynamic demand, capacity constraints and priorities. To evaluate the applicability of our model, we use a real case study of a flood occurred in Colombia. We also test the computational solvability of our model and we propose and test different solution methodologies for solving larger instances of our problem.

1. Introduction

The world is frequently affected by natural disasters that typically produce shocking consequences for humanity [1]. According to [2] only between 2000 and 2009 there were 4.484 natural disasters that caused 2.2 billion affected people, 840.000 casualties and at least US $ 891 billion in economic damage. Given the high frequency at which disasters occur and their significant impact, it is of great importance to develop effective strategies to reduce the risk and impact of disasters.

One of the strategies that are commonly applied upon the occurrence of a disaster is the deployment of resources in order to distribute relief items to the affected population. An important consideration is that it is likely that among these affected population there are different levels of urgency for the allocation of relief items. For instance, there might be some people who have been in deprivation of certain basic items for a given time, whose priority for relief items would be higher than for those who have been in deprivation for a shorter time. In this paper we present an optimization model for planning the distribution of relief items in a planning horizon taking into consideration priority levels of the affected population.

Our problem setting was inspired in a flooding situation that occurred in Colombia in 2010–2011, which affected several towns in a northern region of the country. In this region, poverty indexes are considerably high, thus most of the population were not in position of easily overcoming their basic needs. This highlights the relevance of conducting relief operations as effectively as possible. Affected towns were located close to two retailer centers from where it was possible to deliver relief items to cover the initial needs of the population. Since such retailer centers could cover only a part of the total initial demand, the remaining portion would be served from a farther distribution center located in a major city. Due to the topology of the network, there were some affected points that became geographically isolated. These isolated points required the use of multi-modal transportation with the use of transfer points. Additionally, in situations such as the one hereby described, it is common that local government earmarks a certain amount of financial resources to attend the disaster. Therefore, we consider an available budget for the humanitarian operations. We are interested in developing a model that could optimize the allocation and distribution from the available distribution centers to the demand points in a problem settings with characteristics that are similar to those corresponding to the flooding situation in Colombia.

As mentioned before, we model different levels of urgency or priorities among demand points. Such urgency can be defined by taking into account the following considerations: (i) accessibility of

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demand points, (ii) time that people at demand points have been waiting for relief items, and (iii) importance or urgency of each type of relief items. Such urgency or priority of demand points is assumed to be dynamic.

Also, it is important to remark that our model combines a strategic perspective with an operational one, since we allocate demand to distribution centers by taking into account their capacities, while considering vehicles capacities (in terms of volume and weight) and schedules to define the flow of vehicles and units from each origin to each destiny. Moreover, since we consider stock and vehicle capacities, as well as budget constraints, our model applies to certain settings in which we must undertake distribution actions during several time periods, since it is not possible to serve the whole demand at once. Therefore, we define a dynamic model that plans the distribution of relief items not only during a single time period, but over a planning horizon, along which we consider dynamic parameters. For instance, we consider dynamic demand values. In this respect, we have that demand values can change over time due to diverse reasons, such as inaccuracy of initial information or the occurrence of exogenous and endogenous events that might increase or decrease demand at some points. In fact, according to [3] some of the unrealistic assumptions in humanitarian operations include to consider that demand values and other parameters are accurately known at the beginning of the operation and that they have a static behavior. Also, our model can be applied under a rolling horizon setting, since we can continue updating our decisions as more information becomes available.

Additionally, we model dynamic values of demand urgency. Therefore, we must decide which locations to attend first, where different locations have different urgency or priorities. The answer is not always to attend first those populations with higher priorities. In this case, we need to consider that other locations with relatively low-priority now, might become a worse problem in the future if they are left unattended for some time. In summary, the main questions that we would like to address is how to schedule a distribution plan where capacity and monetary limitations do not allow serving demand at once, under a dynamic setting and prioritized demand locations, where the objective is to minimize human suffering?

In order to realize the importance of considering dynamic parameters consider that during the flooding situation in Colombia in 2010–2011, we could observe multiple migration movements of people from a certain *DP* to another, in search for safer conditions. Also, there were constant updates regarding the amount of affected people, as well as new emergency events that caused increments in the priority service in certain demand points, among others features that should be considered in the humanitarian logistic models.

The distinguishing features of our paper are: (I) the development and formulation of a novel objective function such as a proxy measurement of minimizing the human suffering in a natural disaster, (II) the application of our approach to a real case study based on a natural disaster occurred in Colombia, in 2010, and (III) the development of a series of solution methodologies for solving instances of our problems with important policy implications and (IV) the combination of a strategic and operational perspective into a dynamic model with limited capacities and the possibility of activities in several time periods.

The remaining of this paper is organized as follows: Section 2 contains our literature review. Section 3 describes our problem setting. Section 4 shows our model formulation. Section 5 discusses a case study based on a real flood setting that took place in Colombia in 2010. Section 6 focuses on solving large instances of our problem. Finally in Section 7 we present our conclusions and further research directions.

2. Literature review

Traditionally, there are four main stages identified in Disaster Management: mitigation, preparedness, response, and recovery [4]. Our research can be classified within the response stage, since it involves activities that are performed immediately before, during and right after a disaster occurs to serve the affected community [4]. In the available literature, there are numerous research papers that have focused on the response stage of a natural disaster ([3] and [5]). The papers that are most related to our work are those that address the problem of delivering relief items after the occurrence of a disaster. Therefore, for our literature review we have only considered papers that focus on the problem of delivering relief goods in a certain planning horizon. Among these, recent publications have mainly addressed the following topics (among others):

1. the problems of identifying the most appropriate types of objective functions for humanitarian logistics formulations;
2. the problems of location and inventory routing for the distribution of critical supplies with dynamic and stochastic demands;
3. deprivation costs and times; and
4. urgency or priority of demands.

In our model we address every of the items above.

Regarding the identification of the most appropriate objective functions, we have that, unlike private logistics, in humanitarian logistics researchers pursue social goals instead of financial ones. Therefore, recent research in humanitarian logistics provide diverse types of non-cost-related functions, such as fairness or equity, and proxy measures of minimization of human suffering, among others. In Table 1 and in Table 2 we have classified the papers in our literature review according to the type of objective being pursued. Notice that the criteria of multi-objective models included in Table 2 mostly coincide with the single objectives included in Table 1.

Even though maximizing fairness, minimizing response time or minimizing unmet demand (or equivalently, maximizing met demand) are appealing objectives, they do not guarantee the minimization of human suffering since they leave aside deprivation times and different urgency or priorities of demand.

Therefore, the objective pursued in our approach relates more to that consigned in the fourth row of Table 1. Nevertheless, the definition of our objective function also includes a term that accounts for unmet demand. In fact, our objective function is defined based on the proportion of unmet demand at each demand point, weighted by a priority score. Additionally, it indirectly relates to minimization of response time, since the priority score is a function of the time that affected people waits until receiving relief goods.

From the papers in our review, the ones that are most closely related to our work are [20] and [21]. In Ref. [20] the authors develop a dynamic model that, like ours, considers the relative urgency of demand in their objective function. Such urgency is said to be based on the type of commodity, the characteristics of the demand point and the response time. However, the authors do not describe how to compute the numerical value of such urgency, whereas we provide a possible priority function based on deprivation costs for computing the priority scores in our model. Also, in their objective function the authors use the whole value of unmet demand instead of the corresponding proportion. Additionally, the problem setting in Ref. [20] does not account for a limited budget for the humanitarian operations.

With regard to [21], the authors minimize the social costs,