WCTR 2013 RIO

# SELECTED PROCEEDINGS

## OPERATIONS RESEARCH IN HUMANITARIAN LOGISTICS DECISIONS

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**This is an abridged version of the paper presented at the conference. The full version is being submitted elsewhere. Details on the full paper can be obtained from the author.**

ISBN: 978-85-285-0232-9

13th World Conference on Transport Research

www.wctr2013rio.com

15-18 JULY 2013

Rio de Janeiro, Brazil

unicast

# OPERATIONS RESEARCH IN HUMANITARIAN LOGISTICS DECISIONS

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## ABSTRACT

The decision-making process on humanitarian logistics deals with variables related to the flow and quality of supplies, since the receipt of emergency relief items, its classification, stock, separation and delivery. Consequently, this decision-making process is crucial for seeking the best results in the allocation of scarce resources for storage and transportation in humanitarian operations, while preventing the flow of unnecessary products, which leads to losses and costs that may have consequences in the effectiveness of the operation. In this context, humanitarian logistics become a suitable topic for research in the fields of operations management and of operations research (OM/OR). Therefore, this paper surveys the existing literature in disaster relief operations; discuss relevant issues and topics that can be studied by OM/OR; and provide an overview of the existing models that can be applied in such context.

*Keywords: natural disasters, humanitarian logistics; optimization; operations research; operations management; decision-making.*

## INTRODUCTION

Natural events can be characterized as natural disasters when they occur in populated areas, causing the destruction of local infrastructure and population leading to a state of deprivation and suffering. In the last three decades, the occurrence of natural disasters has increased significantly.

Immediately after the occurrence of disasters, humanitarian operations are initiated with the intent to provide rapid assistance to victims in different ways, such as salvaging those who are wounded and/or stranded, collecting and disposing corpses, resource allocation, provision of food aid, shelter and medical care, and restoring access to remote locations. In humanitarian actions, delays in delivery or relief can cost lives. Therefore, efficiency in logistics is a key success factor, because it ensures the smooth flow of goods and services in a complex supply chain.

Logistics plays a key role in disaster response operations; it serves as a link between disaster preparedness and response, between procurement and distribution, and between headquarters and the field, and is crucial to the effectiveness and responsiveness to major humanitarian programs such as health, food, shelter, water and sanitation (Thomas, 2003).

Decisions on humanitarian logistics are usually taken in urgency, based on the experience of the practitioners involved in the disaster response. According to Beamon and Balcik (2005), the decision-making process during a disaster response may differ from conventional decision-making, since important attributes of the problem are uncertain and needs change rapidly, besides there is little time and information may not be available for making a decision. Considering this context, we identified in the literature existing mathematical models, based on Operations Management (OM) and Operations Research (OR) techniques that can be applied to solve logistics challenges in disaster relief operations and thus helping the decision-making process. We believe that these models can be adapted to support logistics procedures to be applied in response operations for natural disasters in Brazil.

This paper analyzes logistics models that can be applied to help humanitarian logistics decisions regarding activities such as procurement, storage and handling, and transportation and distribution in natural disaster relief operations. In the second section of the article, the literature review is presented and the researched papers were classified according to the stage of the logistics process. The operations research techniques applied to solve humanitarian logistics problems are also discussed in section 2. Afterwards, the mathematical models are classified according to their application regarding the moment of the disaster occurrence and the decision variables adopted in the objective functions. In the following section, some suggestions that would facilitate the application of mathematical models in real operations are presented, particularly in Brazilian conditions. Finally, the last section presents the conclusions and suggestions for futures researches.

# OPERATIONS RESEARCH AND OPERATIONS MANAGEMENT MODELS IN HUMANITARIAN LOGISTICS

The scope of the paper consists in analyzing the existing Operations Research and Operations Management models found in the humanitarian logistics literature that can be applied to help the decision-making process regarding the following activities in disaster relief operations: procurement; storage and handling; and transport and distribution.

1. Procurement: consider the activities relating to supply chain preparation, planning and evaluation, supply chain optimization and pre-positioning of products (allocation problem).

2. Storage and handling: operational issues regarding to storage and movement of materials and inventory planning - supply network design, determination of inventory levels, facilities location (location problem) and personnel allocation.

3. Transport and distribution: associated with the delivery of the product to the end user or a point to redispatch - routing of deliveries and distribution flow coordination.

In the bibliographical research, a limited amount of work related to applications of operations research (OR) for relief operations and disaster management was found on the recent literature (Beamon and Balcik, 2005; Altay and Green III , 2006). Perez *et al.* (2010) reinforce this small amount of studies published, showing that the field is still incipient with opportunities of research.

Only forty-four articles related to humanitarian logistics process modeling, or associated to its theoretical basis were found and twenty-five were organized and classified in accordance to the scope of this study, as their contents address the activities defined for the object of the study, offering specific optimization models for application in operating conditions of emergency relief responses (urgency, lack of resources, limited availability of data, variable demand). Table I presents the researched articles classified according to the scope of the study and to the logistics activity it focus. Articles that address more than one logistics activity are marked with asterisks.

Table I - Classification of articles studied in accordance with the logistics scope of the study

| Logistics Process Stages | Logistical Activities | Authors |
|---|---|---|
| **Procurement** | **Supply Chain Optimization** | Nagurney *et al.* (2012) |
| | | Nagurney *et al.* (2010) |
| | | Salmeron and Apte (2010) |
| | | Clark and Culkin (2007) |
| | **Inventory Pre-positioning** | Rawls and Turnquist (2009) |
| | | Mete and Zabinsky (2009) |
| | | Yushimito and Ukkusuri (2007) |
| **Storage and Handling** | **Supply Chain Project** | Beamon and Balcik (2005) |
| | | Barbarosoglu and Arda (2004) |
| | **Inventory Planning** | Wyk *et al.* (2011) |
| | | Emmett and Lodree (2011) |
| | | Ozbay and Ozguven (2007) |
| | | Balcik and Beamon (2008)* |
| | | Beamon and Kotleba (2006) |
| | **Facilities Location** | Jaller and Holguín-Veras (2011) |
| | | Balcik and Beamon (2008)* |
| | | Günnec and Salman (2007) |
| | | Yi and Özdamar (2007)** |
| | | Huang *et al.* (2012) |
| | **Staff Allocation** | Falasca *ei al.* (2009) |
| **Transport and Distribution** | **Deliveries Routing** | Lin *et al.* (2011) |
| | | Lin *et al.* (2010) |
| | | Perez *et al.* (2010) |
| | | Lin *et al.* (2009) |
| | | Campbell *et al.* (2008) |
| | | Yi and Özdamar (2007)** |
| | **Distribution Flow Coordination** | Özdamar *et al.* (2004) |

## Procurement

Regarding the logistics process of procurement, the existing mathematical models focus on decisions related to supply chain optimization and inventory pre-positioning. The OR/OM techniques applied in these models are discussed as follows.

### *Supply Chain Optimization*

Most supply chain optimization problems, developed in the context of humanitarian logistics apply Linear Programming (LP) techniques. Nagurney *et al*. (2012), applying Linear Programming techniques, developed a multiproduct supply chain network design model, solved as a variational inequality problem (adjusted for computational purposes), so that the total cost in the humanitarian operation is minimized and the demands are satisfied as nearly as possible. To solve the variational inequality formulation, the Euler method and Lagrange multipliers are used.

Salmeron and Apte (2010) proposed a stochastic optimization model to guide strategic resource allocation for cyclic disasters in geographical areas. It is a Prepositioning multi-objective Optimization Model, solved in two stages, applying both mixed-integer programming and simulation techniques.

Clark and Culkin (2007) develop a mathematical transshipment multi-commodity and multi-objective supplychain network model, using LP with an objective function that minimizes transportation and inventory costs, weighted according to the component cost reduction priority. The Cplex 9.1 solver was used.

### *Inventory Pre-positioning*

For facility location, Rawls and Turnquist (2009) proposed a two-stage stochastic mixed integer program (SMIP) model, which can be formulated as an optimization problem to decisions regarding stocking levels for emergency supplies and distribution. The proposed model uses the L-shaped method to reduce the number of second-stage problems, and also a Lagrangian Relaxation. For the same purpose, Mete and Zabinsky (2009) also proposed a stochastic optimization approach with a two-stage stochastic programming model, with a mixed-integer programming (MIP) model, that is a reduce capacitated vehicle routing problem (CVRP) in the second stage, solved with Cplex solver. Nonetheless, Yushimito and Ukkusuri (2007) used a combination of the most reliable path and an Integer Programming to model the pre-positioning of supplies for disasters as a facility location problem that accounts for the vehicle routing to minimize both the fixed costs and the routing costs.

## Storage and Handling

Regarding the logistics process of storage and handling in the context of humanitarian operations, the existing mathematical models focus on decisions related to supply chain project, inventory planning, facilities location and staff allocation. The OR/OM techniques applied in these models are discussed as follows.

### *Supply Chain Project*

Beamon and Balcik (2005) modeled a facility location problem for small-scale emergencies, through the minimization of the sum of the expected response times of items over all scenarios, with the objective of finding the best distribution network configuration for the relief chain (the number, location and the capacity of the DCs)

Looking for planhing the transportation of vital first-aid commodities to disaster-affected areas during emergency response, Barbarosoglu and Arda (2004) propose a two-stage stochastic programming model. As Beamon and Balcik's (2005) model, this one also was solved using GAMS/OSL and SLPIOR solver.

### *Inventory Planning*

Wyk *et al*. (2011) proposed a stochastic inventory model to help anticipate the types and quantities of aid supplies to be kept in a pre-positioned facility, minimizing the overall cost of inventory kept; using LINGO version 8.0 for the solution.

The study of Emmett and Lodree (2011) focused in the local retailer's inventory management problem that emerges upon recognition of a possible pre-storm demand surge; evaluating the reactive and proactive strategies over inventory level for a fast-moving item. They use the minimax decision criterion (the decision rule that optimizes the worst case scenario that does not require any probabilistic information) for the classic economic order quantity (EOQ) model.

Ozbay and Ozguven's (2007) paper is concerned with the development of a model which can determine the safety stock that will prevent disruptions at a minimal cost. They mathematically formulate the humanitarian inventory management problem as a version of Hungarian Inventory Control Model (convex nonlinear programming problem); and then propose a solution to this time-dependent stochastic model using pLEPs algorithm (p-level efficient points - pLEPs), after converted the continuous distribution functions into discrete distributions.

Beamon and Kotleba (2006) treated the development of an inventory management policy to improve the effectiveness and efficiency of emergency relief during long-term humanitarian responses, through a multi-supplier inventory model, as an extension of the standard (Q, r) inventory policy that allows for two different lot sizes and two different reorder levels. They developed a mathematical model that optimised the reorder quantity and reorder level based on reordering, holding and back-order costs.

Balcik and Beamon (2008) proposed a maximal-covering type model that determines the number and locations of the distribution centres in the relief network and the amount of relief supplies to be stocked at each distribution centre, developping an inventory strategy for stocking different types of supplies. The results were obtained using GAMS/Cplex solver.

### *Facilities Location*

Jaller and Holguín-Veras (2011) provide an indication of the optimal number of points of distribution (PODs) and their serving capacity required to support efficient humanitarian logistics, with a nonlinear integer programming model that minimizes the total facility location and server cost while minimizing human suffering taking into consideration the social cost associated with the walking effort to the facilities and the social deprivation cost due to congestion at the facilities.The solution is the result of a tradeoff analisys between the number of PODs and the number of servers, through simulation.

The approach of Günnec and Salman (2007) for facilities location was through a two-stage multi-criteria stochastic programming model, with an objective function to minimize the deviations from five goals classified in four priority levels. However, there is no numerical aplication in their paper that allowing the solution evaluation.

Yi and Özdamar (2007) proposed an integrated location-routing model which aims in maximizing response service level by enabling fast relief access to affected areas and locating temporary emergency units in appropriate sites. The proposed two-stage procedure is compared with the vehicle routing problem (VRP) based single-stage model of the problem and its effectiveness is shown on a number of test instances.

### *Staff Allocation*

Falasca *et al*. (2009) discuss a series of principles from the field of volunteer management and develops a multi criteria optimization model, presented as a bi-criteria integer programming model (minimizing task shortages and minimizes the number of undesired assignments). They used a traditional method for solving bicriteria problems: the efficient frontier method (i.e. a trade-off curve between the two conflicting objectives).

Huang *et al*. (2012) formulate a model to determine the storage locations and their capacities at minimum total construction cost. The solution uses an approximation algorithm introducing LP-rounding technique, firstly, by LP-relaxation of SLLD (storage location and level determination problem), that can be solved efficiently since it is a linear programming.

## Transport and Distribution

Regarding transport and distribution process in the context of humanitarian operations, the existing mathematical models focus on decisions related to distribution routing and coordination. The OR/OM techniques applied in these models are discussed as follows.

### *Deliveries Routing*

Lin *et al*. (2009; 2010) propose a new logistics model for the emergency supply of critical items in the aftermath of a disaster. The model is multi-items, multi-vehicles, multi-periods, soft time windows, and a split delivery strategy, and is formulated as a multi-objective integer programming model. They developed a heuristic approach, named the Decomposition and Assignment heuristic (DAH), to overcome the computational challenge of enumerating all possible tours. In Lin *et al*. (2011), the authors demonstrates how to apply their model (Lin et al., 2009) to a case study.

Perez *et al*. (2010) present formulations for vehicle routing in which the optimal solution is the strategy minimizing the total costs incurred in responding to the emergency, as determined by both operational and social considerations.

Campbell *et al*. (2008) intended take the first steps in developing new methodologies for the classic cost-minimizing routing problems properly reflect the priorities relevant in disaster relief. We focus speciffically on two alternative objective functions for the TSP (traveling salesman problem) and VRP (vehicle routing problem): one that minimizes the maximum arrival time (minmax) and one that minimizes the average arrival time (minavg). To demonstrate the potential impact of using these new objective functions, we bound the worst case performance of optimal TSP solutions with respect to these new variants and extend these bounds to include multiple vehicles and vehicle capacity. Similarly, we examine the potential increase in routing costs that result from using these alternate objectives.

### *Distribution Flow Coordination*

Özdamar *et al*. (2004) propose a mathematical model that describes a setting that is considerably different than the conventional vehicle routing problem. The problem is a hybrid that integrates the multi-commodity network flow problem and the vehicle routing problem. The model is readily decomposed into two multi-commodity network flow problems, the first one being linear (for conventional commodities) and the second integer (for vehicle flows). The objective aims at minimising the sum of unsatisfied demand of all commodities throughout the planning horizon. The solution approach, these submodels are coupled with relaxed arc capacity constraints using Lagrangean relaxation. The algorithm is also compared to a greedy heuristic designed specifically for this problem.

## Application regarding the moment of the disaster ocurrence

Some of the models proposed by the researched literature can be applied in the prevention of a disaster and in its preparedness, while others are directed to the response operation to natural disasters. Table II shows the papers that deal with the pre-disaster, the post-disaster or both (these, mostly working with two stages models, seeking to improve the results of the response stage).

Table II - Classification of articles studied in accordance with the moment of the disaster

| | | | Moment of the disaster | |
|---|---|---|---|---|
| | | | pre-disaster | response |
| Procurement | Supply Chain Optimization | Nagurney *et al.* (2012) | x | x |
| | | Nagurney *et al.* (2010) | x | |
| | | Salmeron and Apte (2010) | x | x |
| | | Clark and Culkin (2007) | x | |
| | Inventory Pre-positioning | Rawls and Turnquist (2009) | x | x |
| | | Mete and Zabinsky (2009) | x | x |
| | | Yushimito and Ukkusuri (2007) | x | |
| Storage and Handling | Supply Chain Project | Beamon and Balcik (2005) | x | |
| | | Barbarosoglu and Arda (2004) | x | x |
| | Inventory Planning | Wyk *et al.* (2011) | x | |
| | | Emmett and Lodree (2011) | x | |
| | | Ozbay and Ozguven (2007) | x | x |
| | | Balcik and Beamon (2008)* | x | x |
| | | Beamon and Kotleba (2006) | x | x |
| | Facilities Location | Jaller and Holguín-Veras (2011) | | x |
| | | Balcik and Beamon (2008)* | x | x |
| | | Günnec and Salman (2007) | x | x |
| | | Huang *et al.* (2012) | | x |
| | | Yi and Özdamar (2007)** | | x |
| | Staff Allocation | Falasca *et al.* (2009) | x | |
| Transport and Distribution | Deliveries Routing | Lin *et al.* (2011) | | x |
| | | Lin *et al.* (2010) | | x |
| | | Perez *et al.* (2010) | | x |
| | | Lin *et al.* (2009) | | x |
| | | Campbell *et al.* (2008) | | x |
| | | Yi and Özdamar (2007)** | | x |
| | Distribution Flow Coordination | Özdamar *et al.* (2004) | | x |

For Long and Wood (1995) and McGuire (2001), mathematical models are not helpful in the immediate response phase of a humanitarian operation due to the unique characteristic of each disaster, which makes it difficult to plan during the early stages of the humanitarian response. Therefore, these authors defend that, in the beginning of a relief operation, decision makers should be able to "improvise and create a supply chain that can provide everyone, instead of contemplating the best solutions and cost efficient". Nonetheless, Van Wassenhove (2006) and PAHO (2000) share the idea that such improvisation is an error that must be eliminated. According to the Pan American Health Organization (PAHO, 2000), most of the disasters and the resulting demands for help are usually predictable and, therefore, studying recent humanitarian assistance programs and modelling their operation can result in more accurate predictions, allowing regions at risk to prepare themselves and relief agencies to plan their efforts (Woods *et al*., 1995). For instance, Balcik and Beamon (2008) developed a model for optimizing the pre-positioning of the stocks of pre-package kits in a pre-disaster approach. Such solution increases the ability of relief organizations to mobilize resources and deliver relief supplies quickly, although it can be financially prohibitive and only a few humanitarian organizations (such as the World Vision International) can support the operating expenses of international distribution centers to store and distribute relief supplies of pre-packaged modules, which can be shipped immediately anywhere in the world (Beamon and Kotleba, 2006).

Despite such problems involved in the application of solutions in advance of natural events, they provide conditions to reduce the effort in response operations. The preparation strategies are not restricted to the pre-positioning of stocks, and may also include: the design of the supply chain (Beamon and Balcik, 2005; Barbarosoglu and Arda, 2004), inventory planning (Wyk *et al*., 2011; Emmett and Lodree, 2011; Ozbay and Ozguven, 2007; Balcik and Beamon, 2008 and Beamon and Kotleba, 2006) and localization of facilities, considering the existing infrastructure or not (Holguín-Veras and Jaller, 2011; Balcik and Beamon, 2008; Günnec and Salman, 2007; Yi and Özdamar, 2007). On the other hand, solutions that are applied in the response phase of the operation, generally, aim to reduce the waiting time for relief and to improve an equitable distribution of the usually scarce resources. Nonetheless, the use of solutions that integrate the two initial stages of a natural disaster (pre and post) can bring benefits to the whole process, by the availability of goods and resources previously arranged in defined locations. However, the dependence to data (most of the time not available and difficult to obtain) quality may incur in erros that directly affect the result of the operation.

# DECISION VARIABLES

Regardless of the moment of the humanitarian operation, its main goal is to minimize suffering. In such circumstances, logistics operating costs become a secondary concern, and thus a component in the mathematical model that represents the victims suffering that has to be minimized (Perez *et al,* 2010). According to Perez et al. (2010), the valuation of human suffering has been studied by economists with important practical applications, such as cases where the human suffering value is a key factor in the decision-making criteria for rationing organ transplantation; or for the development of approaches in health policy; or for the financial assessment of an individual's life in the life insurance industry. Nonetheless, this is a subjective goal and quantifying it is not a simple process (Nagurney *et al.,* 2012). Therefore, authors apply in their models proxy measures as decision variables in other to somehow prioritize their concerns with the affected victims and reduce their suffering.

For instance, Nagurney *et al*. (2012), Salmeron and Apte (2010) and Beamon and Kotleba (2006) structure the objective function of their models to minimize the unmet demand through funds restrictions to ensure a minimum frequency of deliveries. Mete and Zabinsky (2009), Balcik and Beamon (2008) and Yushimito and Ukkusuri (2007) propose models that search for a fair distribution of resources through restrictions which require to meet the demand of at least a minimum number of affected areas, while other models simply limit the time between successive deliveries. Clark and Culkin (2007) use approximated costs in their objective functions as penalties for any deprivation suffered by victims due to the resulted resource allocation. Other models adopt the use of factors (weights) that act as guidelines for deliveries priorities, but the reliability of the solutions found depends on modellers' subjective considerations.

The main solutions adopted by the researched papers as decision variables in their objective functions can be categorized as: (i) Demand - aimed at reducing unmet needs; (ii) Attendance - associated with maximizing the level of service and equity in aid distribution; (iii) Minimizing response and travel times - for the full cycle of care and the delivery of the activity; (iv) Minimizing operational costs; and (v) Maximizing Volunteers' motivation - indirect measurement with respect to the proper allocation of staff to the activities of humanitarian logistics in the search for greater operational effectiveness. Table III presents the researched models according to this categorization.

Table III – Classification of articles according to the decision variables of their objective function

| | | | Decision variables of the models | | | | |
|---|---|---|---|---|---|---|---|
| | | | demand | service level | response time | total cost | staff management |
| Procurement | Supply Chain Optimization | Nagurney *et al.* (2012) | × | | | × | |
| | | Nagurney *et al.* (2010) | × | | | × | |
| | | Salmeron and Apte (2010) | × | | | | |
| | | Clark and Culkin (2007) | × | × | × | × | |
| | Inventory Pre-positioning | Rawls and Turnquist (2009) | | | | × | |
| | | Mete and Zabinsky (2009) | | × | × | × | |
| | | Yushimito and Ukkusuri (2007) | | × | | | |
| Storage and Handling | Supply Chain Project | Beamon and Balcik (2005) | | | × | | |
| | | Barbarosoglu and Arda (2004) | | | | × | |
| | Inventory Planning | Wyk *et al.* (2011) | | | | × | |
| | | Emmett and Lodree (2011) | | | | × | |
| | | Ozbay and Ozguven (2007) | | | | × | |
| | | Balcik and Beamon (2008)* | | × | × | | |
| | | Beamon and Kotleba (2006) | × | × | | | |
| | Facilities Location | Jaller and Holguin-Veras (2011) | | × | | × | |
| | | Balcik and Beamon (2008)* | | × | × | | |
| | | Günnec and Salman (2007) | × | | × | × | |
| | | Huang *et al.* (2012) | | × | | × | |
| | | Yi and Özdamar (2007)** | × | | × | | |
| | Staff Allocation | Falasca *et al.* (2009) | | | | × | × |
| Transport and Distribution | Deliveries Routing | Lin *et al.* (2011) | × | × | × | | |
| | | Lin *et al.* (2010) | × | × | × | | |
| | | Perez *et al.* (2010) | | × | | × | |
| | | Lin *et al.* (2009) | × | × | × | | |
| | | Campbell *et al.* (2008) | | | × | | |
| | | Yi and Özdamar (2007)** | × | | × | | |
| | Distribution Flow Coordination | Özdamar *et al.* (2004) | × | | × | | |

# SUGGESTIONS FOR THE APPLICATION OF MODELS IN REAL OPERATIONAL CONDITIONS

The experience of practitioners precludes the application of mathematical OM/OR models in the decision-making for logistics processes in response to natural disasters. Practitioners generally complain that mathematical models have so many limitations that they do not represent the reality of such a complex process as a humanitarian operation for relief after a natural disaster, due to the unpredictable nature of the scenario, quick response time, demand variability, and the availability of information and resources - material and financial (Beamon and Balcik, 2005). Besides, practitioners reinforce that mathematical models tend to be very complex and require time and computer resources not available after the strike of a disaster.

Nonetheless, in this study, our findings indicate the application of OR/OM models on the context of humanitarian logistics can be of great support to the development of procedures for management decisions in response to natural disasters. However, when developing a mathematical model for humanitarian logistics, certain aspects should be considered to facilitate its application on the field, on real operational conditions. For that reason, the following aspects of the models were analyzed and suggestions were made to improve the functionality of the proposed models, regarding:

- Operational costs
- Humanitarian relief parameters
- Support of humanitarian organizations
- Implementation of mathematical solutions

## Considerations regarding operational costs

In some of the models studied, the total operating cost is considered a decision variable, as part of the objective function, in others it appeared as a constraint. However, in real operations, costs must be considered in two different conditions by decision makers. In the first, the objective is the minimum cost as looking for operational efficiency, to enable an estimate of the amount required for funding (private or government). In the second condition, the value of the budget must be known or estimated, and the estimation quality will directly affect the quality of the relief operation regarding attendance to the demand of the victims. The choice of the model should be associated with this understanding, or its formulation should allow flexibility as the real condition is known.

In all solutions studied, costs are key factors in formulating and application. Except for the work of Wyk *et al*. (2011), the papers do not show clearly a routine and the data source to calculate the different cost components.

For models focused in disaster response, the determination of the costs for transport, handling and storage, among others, becomes very difficult, so there is the need for a systematic costs calculation, simply and quickly due to this situation (post-disaster). The use of models aimed to the pre-disaster phase allows more time for the calculation of relevant costs, although using more estimates than facts. In any situation, not just the time required for costs calculation is important, but also the quality, both being key factors for the feasibility of any mathematical solution.

### Considerations regarding humanitarian relief parameters

Due to the characteristics of the objectives of humanitarian activities, the objective function of proposed models should involve decision variables associated with welfare. In addition to the time and the service level, which are the most obvious factors that affects welfare, penalties in costs associated with the sacrifice of victims and losses based on the level of care provided have also been used.

Regarding the sacrifice of lives, financial parameters associated with losses were presented by Perez *et al*. (2010), Holguín-Veras and Jaller (2011) and Wyk *et al*. (2011), including data from the Department of Transport in South Africa. However, they are still attempts to find an optimal formulation.

The collection of information for demand forecasting, including items and quantities to be supplied to the victims, are important factors that affect the service level of a relief operation. In these circumstances, the models that use weights on the cost components to drive the decision about resource allocation (Clark and Culkin, 2007) may be the most appropriate; considering the need of an experienced team, responsible for the action coordination and for the decision making process.

### Considerations regarding the support of humanitarian organizations

The works of Balcik and Beamon (2008), Wyk *et al*. (2011), Mete and Zabinsky (2009), Beamon and Kotleba (2006) and Özdamar *et al*. (2004), that have the support organizations or participate in programs focused on developing solutions for the optimization of logistics activities in the humanitarian context, have the advantage of supporting for obtaining resources and data, and for application under field conditions.

There are ongoing projects and organizations such as IFRC, PAHO, PARVAC and SADC (among the aforementioned articles) that have studies, experiments, operational guidelines and techniques directed to humanitarian aid environment, in addition to the practical experience of participation in humanitarian operations. The relationship with these organizations can be helpful in speeding up the process of developing more appropriate solution, due to the gain in knowledge arising from a possible synergy (theory and practice in the field).

### Considerations regarding the implementation of mathematical solutions

The presentation of the steps to implement the solution proposed by mathematical models is an important item to be considered for the application of such models in real operations because it enables to evaluate the degree of complexity, and the need for funds and resources required for its use in field conditions of humanitarian responses. Nonetheless, the articles presented do not describe how to implement the solutions proposed, which is a point that makes the choice of which model to apply more difficult, as it demands the identification of the requirements and the application for further assessment of the conditions at the scenario of the disaster response. Thus, reproducing the results shown may be compromised due to difference in the implantation procedure of any model chosen. Besides, it complicates the possibility of exchanging experiences and possible improvements in the standardization of procedures.

## AN OVERVIEW OF THE BRAZILIAN CONDITIONS

In Brazil, such as happens in most of the world, the decisions taken in response to natural disasters are based on the experience of practitioners. Mathematical OM/OR models are hardly ever applied in practice due to the complexity of both the situation and of the model itself and its application. Nevertheless, as presented on the previous section, the application of OR/OM models on the context of humanitarian logistics can be of great support to the development of procedures for management decisions in response to natural disasters in Brazil as well. However, despite the aspects previously discussed, when developing a mathematical model for humanitarian logistics for the Brazilian condition, other specific factors need to be considered.

In order to analyze the possibility of the application of mathematical solutions and to improve humanitarian responses to natural disasters in Brazil, four important points regarding the Brazilian context in terms of humanitarian logistics must be considered:

1. Scarcity of data in details for mathematical modelling that can be validated in typical conditions of disasters in Brazil.

2. According to Van Wassenhove and Martinez (2010): "The key to restructure the logistics network is a better design". Nonetheless, there are no works in Brazil oriented to networking projects, which analyze the responses to the disasters (such as floods and landslides) that succeed periodically in the country.

3. Experience and knowledge in humanitarian responses to natural disasters in the country is scattered among the Civil Defense, the Armed Forces and, personally, by the volunteers who participated in the actions.

4. Some Brazilian regions have characteristics of cyclical occurrence of natural disasters but, every year, events occur without the proper improvement in the response action.

Based on these conditions, a model with a focus on pre-disaster stage may be selected for use in a scenario developed based on the characteristics of natural disasters and affected regions in Brazil. The model should be developed in the context of a procedure for structuring the supply network to support field decision-making, determining the location and the roles to be played in humanitarian action, taking advantage of the existing infrastructure.

In the Brazilian situation, the use of mathematical models for optimization of results should be part of a set of actions that give the country an initial increase in responsiveness: logistics planning, coordination structure, definition of roles and responsibilities; people training; communication, data and information structures; and developing a culture of "learning and continuous improvement" after every occurrence of a natural disaster.

The country has academic potential able to produce together with governments, the Civil Defence and the Armed Forces (the main actors in the humanitarian response actions) solutions to the issues previously mentioned. It is important to stress the relevance of the support of these organizations (as well as other actors involved in the response operation, such as NGOs) when developing solutions for the optimization of logistics activities in the humanitarian context. Their support is essential for obtaining data, as well as for application under field conditions, besides the potential gain in knowledge due to the synergy between theory and practice in the field. Thus, the vision of an integrated humanitarian supply chain enable more effective results, leading to the reduction of waste and operational costs, with consequent increase in the service level offered to the victims (where applying OR will be essential).

# CONCLUSIONS

There is a tendency to use mental models, based on the experience and intuition of practitioners, in the complex decision-making processes (Forrester, 1971). This reality also occurs in response operations to natural disasters. However, in this context, a mental model to envision the entire operation becomes too complex, besides the fact that human intuition and experience are affected by irrational factors, such as emotions and time pressure. Moreover, delays in this decision-making process tend to affect the efficiency of the humanitarian operation to meet the needs of victims. Therefore, the development of mathematical models on the context of humanitarian logistics can be of great support for the decision-making process in response to natural disasters.

The study of articles with the proposals for application of mathematical models to improve the logistics results in disaster response shows that there remains a gap between what is modelled and what actually occurs in the environment of the disasters. There are important progresses with the inclusion of humanitarian aspects as decision variables in the formulation of the models. However, studies seem scattered, with little synergy between developments, seeking to present alternatives, but not complementary and, with some exceptions, with little adherence to field conditions, which is one of the main points that may motivate operations managers to use mathematical models proposed. It is possible to link many of those works because they deal with logistics stages (including humanitarian context), but only through a backbone procedure in which they can be applied.

For future works, it is important to persist in developing models that consider the specific characteristics of the problems in the humanitarian supply chain, leveraging the advances achieved in other studies, and deepening the analysis of disasters occurred, to identify issues where research can effectively provide objective improvements.

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