# Pre-positioning relief supplies in Brazil using stochastic optimization and multi-criteria decision analysis

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## Abstract
This paper proposes a methodology to define locations for pre-positioning disaster relief supplies through a two-stage stochastic optimization model with multi-criteria decision analysis. An application in Brazil illustrates the effectiveness of the proposed approach. Results show that consideration of qualitative and quantitative criteria improves decisions in humanitarian operations.

**Keywords**: Humanitarian logistics, Facility location, Stochastic optimization, Multi-criteria decision analysis

### Introduction

The subject disaster was highlighted in the scientific community and media due to the increase in the number of people affected by natural disasters (floods, hurricanes, earthquakes, tsunamis); man-made disasters (conflicts, terrorist attacks and wars); and the increase of economic damage which has demanded greater efforts by states and humanitarian organizations (Guha-Sapir *et al.*, 2011). These events and their consequences illustrate how challenging the response to extreme events is (Holguín-Veras *et al.* 2007).

Agile and effective mobilization of resources is essential to help people in disaster vulnerability. The shortage of materials or inefficient management of resources could jeopardize the emergency response, resulting in an increase in the suffering of the victims (Holguín-Veras *et al.*, 2013).

Several studies under a global perspective have been developed to improve this response, demonstrating the importance of logistics in humanitarian operations (Beamon and Kotleba, 2006; Thomas, 2004; Van Wassenhove, 2006); however, the reality of these logistics operations is not well understood (Holguín-Veras *et al.*, 2014).

Regardless of natural or anthropogenic causes, scientific articles in high impact journals show change in the pattern of rainfall, causing dry regions to register less rainfall, becoming even more arid and areas prone to flooding increase their rainfall rates (Marvel; Bonfils, 2013). Also shown are the greater occurrence of climatic extremes and consequent increase in the number of natural disasters in Brazil (Sampaio, 2014), as well as the increased frequency of storms in southeastern Brazil, as a result of global warming (Marengo; Valverde; Obregon, 2013) (Pinto Jr.; Pinto; Ferro, 2013).

Relief supplies are basic elements for affected people to have access to food and hygiene products in the first moments after the disaster. Agility and readiness in the distribution of these items are necessary, especially in the first 72 hours after the event (Salmerón and Apte, 2010) so that rescue teams can begin the recovery activities, and the victims can thus stabilize their lives. Materials are also required for relief teams (response) to act immediately after the event (Fiedrich; Gehbauer; Rickers, 2000),

We propose a methodology to support the decision on where to locate relief supplies facilities. This work is a continuation of the paper presented at POMS 2014 (Brito Jr. et al, 2014) that defines locations for pre-positioning disaster relief supplies through a two-stage stochastic model with coverage constraints based on distribution costs, penalties for unattended demand, disruptions in highways, and media influence. The stochastic model minimized the operational costs and presented the optimal and suboptimal solutions; however, decisions in humanitarian operations have multiple criteria and small differences in the costs of the solutions may not be significant by considering other criteria. An analysis of these solutions through Multi-criteria Decision Analysis (MCDA) is then performed. An application in Brazil illustrates the effectiveness of the proposed approach.

## Literature review

The MCDA methodology aims to assist analysts, facilitators and decision-makers in situations in which there is a need to identify priorities, when there are several criteria, which typically occur when conflicting interests coexist (Gomes; Araya; Carignano, 2004 ).

Belton and Stewart (2002) defined MCDA considering three dimensions:

- Formal Approach;
- Presence of several criteria;
- Decisions are taken by individuals or groups.

These dimensions, similar to studies on natural resource management (Mendoza; Martins, 2006), are the reasons why the MCDA can be a model applied to humanitarian decisions as it addresses several aspect, such as:

- Structured and rational approach able to integrate key elements of humanitarian management;
- Existence of several criteria regarding humanitarian issues;
- Considers multiple stakeholders and interest groups, each with his/her own views, objectives and requirements.

Montibeller and Franco (2007) state that the location of permanent installations in a supply chain is a strategic decision. . Taking this type of decision, multiple objectives, often conflicting, have to be considered; the interconnection of strategic policies; the long-term consequences, resulting from the implementation of decisions; and the engagement of stakeholders are in these discussions.

Farahani; SteadieSeifi and Asgari (2010) developed a review article which analyzed the application of multi-criteria methods in location problems by providing an analysis of such problems into three categories, including biobjective problems, multiobjective and multi-attribute utility theory and methods for their solution. They provided an overview on several criteria used, defined, classified the types and methods for solving problems in accordance with the approach adopted in the decision problem. One of their conclusions recommends the use of stochastic models in location problems. They search the main criteria used in locating facilities under one point of view of practical applications:

- In the single criteria localization problem, the criteria have typically been cost or coverage. This approach was criticized because in location, due to the nature of these problems, at least one more criteria should be considered that can be in conflict with the first.
- In multi-objective problems, in addition to the cost, one also observes the use of general criteria, such as coverage; service level; environmental hazards; and profit, in addition to criteria specific to the problem assessed, for example, social and political risks.
- In multi-attribute problems, the number of criteria presented in the literature are high and include costs (land, transportation, installation, maintenance); revenue; environmental hazards; pollution; competition; accessibility; nearby highways, ports, airports and terminals; policies and regulatory issues; labor; business environment; possibility of expansion and distances.

Cheng; Chan and Huang (2003) integrated MCDA and Inexact Mixed Integer Linear Programming (IMILP) in a study to locate a landfill in Regina (Canada), because they need to consider qualitative, quantitative, tangible, intangible and often contradictory criteria. First, they performed the linear programming model in order to minimize the total cost and optimize the waste flow. In a later step, they took into account the total cost and other criteria to determine the best alternative location.

Yoshizaki and Montibeller (2009) state that intangible factors can change a network configuration resulting from a mathematical model. In location decision making, traditional network models take into account quantitative factors and aim to minimize the total cost or maximize profitability or coverage. Non quantitative criteria, such as, for example, man power qualification; geographical characteristics and road network are also important in location decisions. The authors suggest the use of MCDA to take these criteria into consideration.

Vitoriano *et al.* (2011) in a study of distribution of relief supplies postulate that in humanitarian operations logistics, cost minimization is not the focus during the response phase and parameters such as response time, distribution equity, priority item reliability and safety of the route are more relevant. They involved an interaction with decision-makers in driving problem.

We evaluated 45 articles from peer-reviewed journals with the application of multi-criteria methodology in location (humanitarian or not). Out of these articles, 16 concern the logistics of humanitarian operations or management of disasters and emergencies. In 14 of them, it was possible to identify the application in one or more phases of a disaster. Aggregating the criteria used in these articles, according to the disaster phase (application in more than one phase or overlap in applications, some phases were grouped), it can be observed that, according to the disaster phase, the criteria used change, but the criteria relating to geographic attributes and physical location, as well as the distance and the characteristics of the distribution, are widely deployed. The cost criteria, albeit to a lesser extent, appears in three of the four phases. This criteria identification can be observed in Table 1:

*Table 1 – Location criteria according to the disaster phase.*

| Disaster phase | Grouped criteria adopted for selecting the place | Number of times |
|---|---|---|
| Prevention/Mitigation (7 papers) | Geographical and Physical | 15 |
| | Demographic | 8 |
| | Distance and distribution | 6 |
| | Socioeconomic | 3 |
| | Meteorological | 2 |
| | Land use | 2 |
| | Environmental | 1 |
| | Cost | 1 |
| | Human Resources | 1 |
| Preparation (3 papers) | Distance and distribution | 6 |
| | Geographical and Physical | 2 |
| | Environmental | 1 |
| | Cost | 1 |
| | Human Resources | 1 |
| | Safety | 1 |
| | Socioeconomic | 1 |
| Preparation / Response (3 papers) | Distance and distribution | 11 |
| | Cost | 1 |
| | Socioeconomic | 1 |
| Response / Recovery (1 papers) | Socioeconomic | 2 |
| | Environmental | 1 |
| | Demographic | 1 |
| Total (14 papers) | Distance and distribution | 23 |
| | Geographical and Physical | 18 |
| | Demographic | 9 |
| | Socioeconomic | 7 |
| | Environmental | 3 |
| | Cost | 3 |
| | Meteorological | 2 |
| | Human Resources | 2 |
| | Land use | 2 |
| | Safety | 1 |

Obs: Some criteria are considered more than 14 times due to aggregation.

## The MCDA model

The stochastic model results showed the optimal and suboptimal solutions for the cost criteria for a 5-year period. All the solutions contain the city of São Paulo (SP), where there is already a depot and another city. Table 2 shows these solutions.

*Table 2: Optimal and suboptimal stochastic solutions*

| Solutions | Cost (BRL$) |
|---|---|
| SP and Tremembé | 247.841,00 |
| SP and Taubaté | 247.843,00 |
| SP and Caçapava | 248.239,00 |
| SP and São José dos Campos | 248.760,00 |
| SP, Taubaté and Tremembé | 298.600,00 |

The location of humanitarian facilities involves many decision makers: civil defense; military; service providers; NGOs; suppliers; and public organizations (Besiou; Stapleton; Van Wassenhove, 2011), which may have different priorities and strategic objectives. Due to this diversity of participants and objectives, the use of a multi-criteria method is applicable to this study. The approach adopted is the MAVT proposed by Keeney (1992) and reviewed by Franco and Montibeller (2011) and VFT (Value Focused Thinking), which breaks down the fundamental objectives, using a facilitator in the process.

The process of implementing MCDA interventions in this work follows the Franco and Montibeller (2011) framework. In phase 1, the situation is exposed and the facilitator assists in defining the problem, designing the decision-making process and, together with the team of managers, defines the stakeholders. Once this phase is completed, the second phase starts, which consists in structuring a tree value, setting the attributes and identifying the decision alternatives.

A preliminary meeting with the managers team decision, two meetings with all stakeholders, two meetings for final evaluation and a meeting for re-evaluation, also with the leadership team were performed (6 meetings, totaling approximately 10 hours)

### *Problem definition*

The problem was defined with the managing team prior to the beginning of the stochastic modeling process. In every meeting with the decision team, this definition was verified and re-validated, and can be described as:

"Where to locate a warehouse for relief supply materials in the Paraíba Valley (Brazil, State of São Paulo) ?"

In the preliminary meeting and in the two meetings with the managing team and the stakeholders, the following strategic objectives were defined and validated:

- Optimizing the management and distribution of relief supplies in case of disasters in the region.
- Minimizing victims suffering.

### *Stakeholders*

During a MCDA intervention, attention to stakeholders is desired to assess and to improve political viability of decision implementation and it is important to convince and to satisfy those involved, or affected by the decision (Franco and Montibeller, 2011). In our work, the stakeholders definition was performed according to the methodologies established by Bryson (2004) and related to the non-business and public sector. The technique used is the power-interest grid shown in Figure 1.

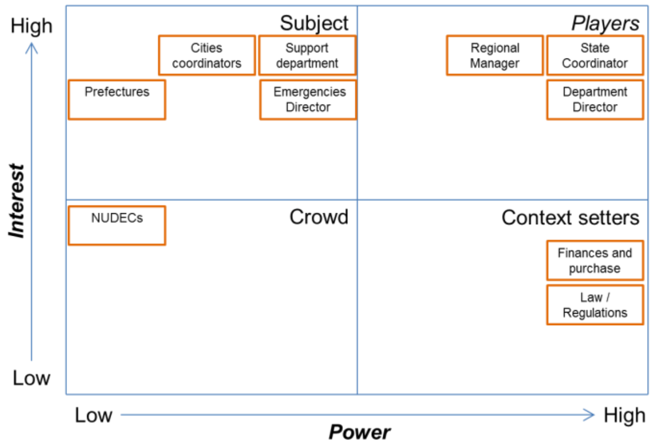


*Figure 1: Power Interest Grid*

*Value tree*

The value tree was performed using a top down approach, according to Franco and Montibeller (2011), and aligned with the VFT, in order to decompose the primary goal into objectives and sub-objectives.

Initially, using the brainstorming technique, the objectives to be met when installing a new relief supply depot were discussed and mapped, as well as the values considered by stakeholders. After the mapping, common features among the objectives were detected. These characteristics enabled the definition of sub-criteria and grouping the objectives for elaborating the tree value.

The attributes were defined as follows:

- Cost: considering that the deposit is established during the disaster preparation phase to be used during the response phase, this is set for the preparation stage of a disaster, as it needs to meet a general budget which includes installing the deposit. During the response phase, this objective changes, because minimizing human suffering (Holguín-Veras *et al.*, 2013) is a priority activity in relation to costs .
- Management: divided into two sub-objectives:
  - ✓ Proximity to Civil Defense Regional Director: During a disaster response operation, the Civil Defense Regional Director manages the relief supply distribution and the closer the depot is to the coordination, the better the operational readiness.
  - ✓ Human Resources: this objective takes into account labor mobilization during the response operations to a disaster. A characteristic of the São Paulo State Civil Defense is that response operations are initiated with the help of the military, especially the military police and firemen.
- Infrastructure: divided into the following three objectives.
  - ✓ Safety: this objective was considered from two aspects called "Social" and "Natural Hazards". The social aspect refers to the site vulnerability to deviations or theft of materials; Natural hazards refer to the susceptibility to the occurrence of natural disasters and, consequently, unfeasible operations.

✓ Hygiene and storage environment (salubrity): the aim is to meet the storage conditions, especially food, and operational ease of storage, such as temperature, prevention of deterioration and handling.
✓ Accessibility: this objective refers to the quality of routes to the depot; pavement conditions; lighting in the surroundings; signaling, in addition to the consideration of alternative routes that allow access in case of disruptions.

Based on these goals, their connections and grouping, the value tree was established for the problem and evaluation of stakeholders as illustrated in Figure 2.

The definition of the weights of each attribute was established on the basis of the methodology called swing-weights. Initially, the criteria costs, management and infrastructure were assessed by stakeholders and, subsequently, the evaluation was conducted for each of the sub-criteria.

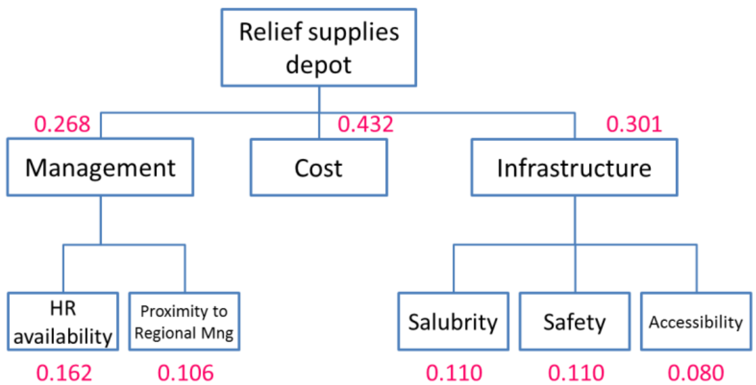


*Figure 2: Value tree*

For each criteria and sub-criteria, value functions were established according to the MCDA methodology.

*Identifying and evaluating decision alternatives*

Stakeholders evaluated the performance of the alternatives in each of the attributes and the value of the function, the score in the corresponding criteria was obtained. Table 3 presents the evaluation results. The V.I.S.A. software allowed the stakeholders an immediate visualization of their judgments.

The stochastic linear programming model provides the performance of local candidates in relation to costs and coverage and showed that the best solution is two places, and that the city of São Paulo is present in all the solutions, due to the current operation and facilities already available, and consequently fixed costs for allocation of relief supplies are only marginal. In summary, the stochastic solution alternatives to be evaluated were:

- São Paulo and Caçapava.
- São Paulo and Taubaté.
- São Paulo and Tremembe.
- Although some solutions are not part of the stochastic model solution, they were maintained in the multi-criteria model only as a comparative reference and sensitivity analysis. These solutions are:
  ✓ São Paulo and São Jose dos Campos.
  ✓ São Paulo, Taubaté and Tremembé (3 sites).

*Table 3 - Results of the stakeholders' evaluation of alternatives.*

| Solution: SP depot + | Proximity to Regional Director | Human Resources | Cost (BRL$) | Accessibility | Salubrity | Safety |
|---|---|---|---|---|---|---|
| **Caçapava** | 20 | 75 | 248,239.00 | 75 | 43 | 75 |
| **Taubaté** | 0 | 100 | 247,843.00 | 100 | 79 | 75 |
| **Tremembé** | 15 | 50 | 247,841.00 | 50 | 57 | 50 |
| **São José dos Campos** | 44 | 100 | 248,760.00 | 100 | 79 | 100 |
| **Taubaté + Tremembé (3 sites)** | 0 | 100 | 298,600.00 | 75 | 68 | 75 |

*Global performance*

The results, after the application of the multi-criteria model is represented in Figure 3 and shows the evaluation in each criteria and the final solution using the cities of São Paulo and Taubaté to be the best location for the relief supply depot.

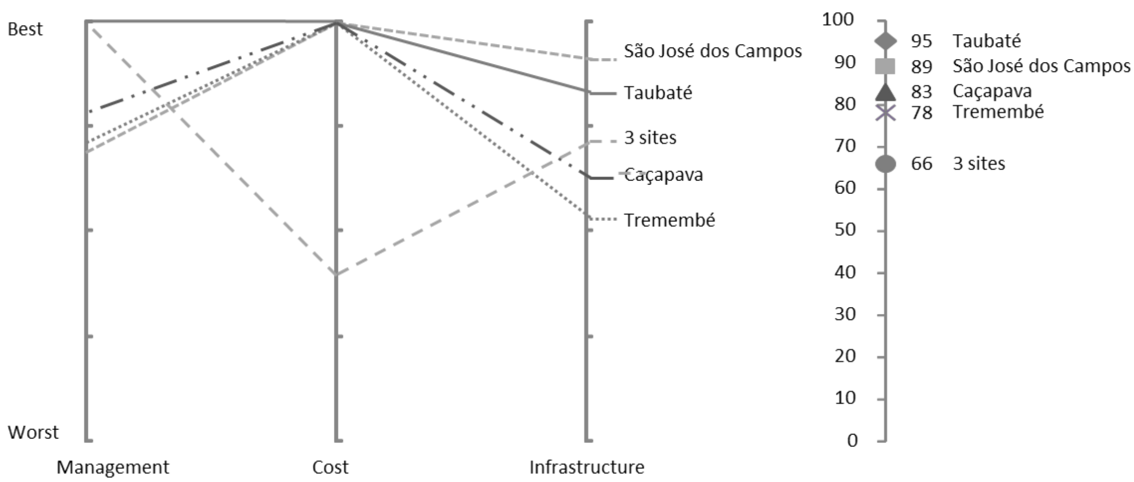


*Figure 3: Criteria solutions and global performance*

After evaluating all the alternatives, the overall results were exposed to stakeholders for review. The evaluation methodology presented by De Boer and Wegern (2003), indicated for evaluating selection processes of suppliers was adapted to the facilities localization process. The results were considered satisfactory, as well as the applicability to other regions in the State.

*Sensitivity analysis*

The sensitivity analysis was taken for the cost attribute in case of change in the scaling constants and the value function, to evaluate whether or not to discriminate solutions and also the distance from the Civil Defense Regional Director. The purpose is to check if changes in analyses carried out during the processes and model evaluation may modify the results. Only the distance from the Civil Defense Regional Director can change the results

Figure 5 shows the sensitivity analysis for distance from the Civil Defense Regional Director.

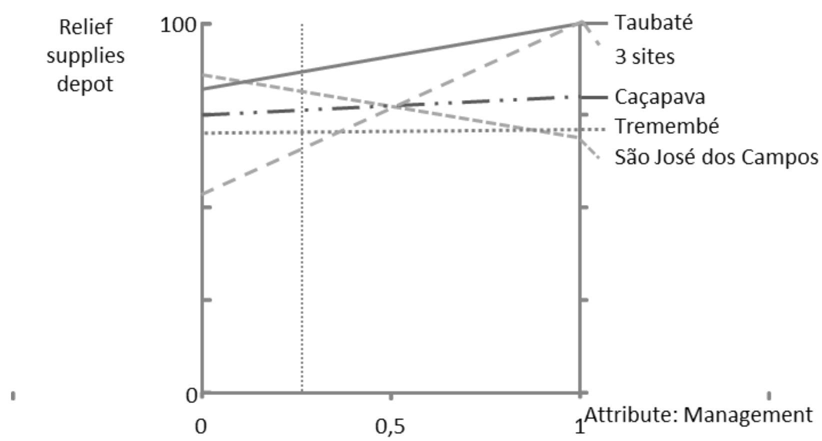


*Figure 5: sensitivity analysis for distance from the Civil Defense Regional Director*

The model is observed to be sensitive to the attribute distance from the Civil Defense Regional Director, which is currently located in the city of Taubaté. In case of changes, the result can be also changed.

*Results*

The results of multi-criteria modeling and sensitivity analysis showed that characteristics concerning larger cities, located at road junctions, have dominance in the solutions. This occurs due to the management tools and infrastructure in these locations, especially larger units of the Military Police, which provide availability of human resources, in addition to better road accessibility. These locations provide better robustness to the solution, because in addition to characteristics of optimality, they count on Management and Infrastructure attributes, which ensure the operation under different scenarios. Sensitivity analyses showed that the result can be modified by changes in management attribute (distance from Civil Defense Regional Director).

## Conclusions

The humanitarian location problem characteristics with intangible and subjective criteria using only the costs criteria is not robust enough to support decision making. The use of multiple criteria proposes a rational and systematic methodology for decision and an easily and practical implementation. After the stochastic modeling, the multi-criteria model was applied to the location problem, using the MCDA (MAVT). The process was structured by developing value trees to define the attributes. Subsequently, in interaction with stakeholders, the value functions and weights were obtained for each of the attributes to then evaluate candidate locations, adding performances and obtaining the overall result. Sensitivity analysis for changes in the attributes was performed. The results showed sensitivity to the attribute "Civil Defense Regional Director." A comparison between the results of the stochastic model with the multi-criteria model shows change in location from Sao Paulo and Tremembe solutions to Sao Paulo and Taubaté. This change caused a displacement of 14 km in the solution.

## Acknowledgments

The authors would like to thank CAPES (BEX 7168/13-6) Ministry of Education of Brazil, Brasília, and the Vanzolini Foundation, São Paulo, Brazil.

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