A Multi-product Stochastic Programming Model for Supplier Selection in a Humanitarian Relief Chain

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Abstract. This paper focuses on the supplier selection in a humanitarian relief chain. Considering the negative impact that natural disasters have in society and their environment, the procurement costs could be a challenging issue for humanitarian organizations (HO). Post-disaster procurement and pre-positioning inventory usually carry large costs due to the haste of the situation in the first or the extensive administration in the latter. This work analyzes supplier selection tools proposed in the literature and focuses primarily on the final decision stage where an organization optimizes the purchase of items from a supplier base.

We propose a scenario-based two-stage stochastic programming model for a statutory agency; it considers a limited budget and the procurement from a higher-level source like the federal government. We also consider framework agreements (FA's) where the buyer commits to purchase some reserved capacity from suppliers during a given period of time (also called horizon) so that better prices could be negotiated and help the organization lower their procurement costs.

The proposed model delivers an optimal solution for a statutory agency and helps in the decision-making process as to what candidate suppliers are desirable to establish a framework agreement with. The solution shows important information as to what percentage of demand is covered from the selected suppliers.

Limited funding in HO's is a very important factor for decision-making. The model incorporates a budget constraint and delivers information about the amount of relief items to procure form a different source other than the supplier base.

Keywords: Humanitarian logistics · Supplier selection · Stochastic programming

1 Introduction

Natural disaster like hurricanes, earthquakes, volcano eruptions, and others, represent great logistical challenges because of their unpredictability. Every time a catastrophic event occurs in a community, it leaves behind dozens of victims, damaged infrastructure, a polluted environment, and disruptions in services like water and electricity. Humanitarian organizations (among many other actors) make great efforts to coordinate the

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procurement of relief items; they recruit volunteers, perform search and rescue activities; they purchase machinery, or any item needed by the first responders, and many other plans are executed. If the procurement of these items is done after the disaster, humanitarian organizations may find scarce or overpriced products that make the procurement costs very high. Considering that many of these organizations do not sell products or make profits, it could be very difficult to fund the procurement of such items; indeed, they expect to receive donations from the community or have a budget allocated by the local government.

It is known that when a disaster or an emergency occurs, there are many people involved willing to help such as mass media, local and international governments, volunteers, Non-governmental organizations (NGO) and a long list of donors who form the humanitarian supply chain. However, the great number of people involved could make the logistics very complex and difficult. On top of that, the time plays an important role in humanitarian logistics since the victims need immediate assistance and cannot wait long for help. It becomes a matter of life and death.

One of the strategies that has been addressed regarding the post-disaster procurement is the pre-positioned inventory. Some organizations have the capability of storing large quantities of items as prevention when a disaster arises, nevertheless, as it may be expected, this strategy carries out large administrative and inventory costs. As explained before, some (or many) humanitarian organizations have limited funds and many do not have a warehouse to store items, tools and machinery, or the resources to hire personnel to administrate it. This is relevant due to the importance of considering the available budget of an organization.

In 2001, the International Federation of Red Cross and Red Crescent Society (IFRC) adopted Framework agreements as part of their strategy to procure humanitarian relief items. These agreements seek to reduce costs and delivery lead times when a disaster occurs. In a Framework Agreement, the supplier reserves an agreed capacity for the buyer who commits to purchase the number of items established in a given period of time (also called ‘horizon’). The agreements are usually placed for standard items or high-volume items. This strategy turns out to be beneficial for both, suppliers and humanitarian organizations. On the one hand, the humanitarian organization, secures the supply of such items given and sudden-onset disaster; prior to settling the agreement, the organization is able to negotiate pricing according to the volume of purchase. On the other hand, the supplier is able to sell volume and could negotiate penalty fees in case of a breach between the reserved capacity and the actual purchase.

One important aspect of establishing contracts is the price negotiation that comes with it. Many suppliers offer price discounts depending of the volume of the purchase. This is beneficial for humanitarian organizations given their limited funds and the large volumes that are required for some items.

Some HO’s that are directly linked to their local governments are given, by law, the responsibility to plan out strategies in order to assist during and after a disaster. These statutory agencies may receive annual funds that could be use in case of emergencies and the resource ought to be used wisely if the organization wants to fulfill the unpredicted demand.

We have to emphasize that at this point that the decision about what supplier the organization must procure from, already considers a set of suppliers approved to supply the products that are going to be needed in terms of quality, supplier coverage, price and quantity. This implicates that the organizations ought to run a previous assessment and advise the suppliers that were approved by the agency, nevertheless, the final decision will be made after the optimization presented in this work.

We address the supplier selection decision of a statutory agency with a limited budget but with the possibility of being assisted by the federal government; we propose a two-stage stochastic programming model given the nature of disasters and emergencies. The organization is willing to establish framework agreements with approved suppliers that are able to supply different relief items. Given the uncertainty of the demand, we build scenarios based on historical data from a specific region and denote the scenario formulation. The organization will commit to purchase the reserved capacity established in the agreement. However, we do not consider penalty costs given the fact that in the regional context of our case study, the government cannot be penalized by a civilian or a company for the breach of contract.

In Sect. 2 we address supplier selection tools and in Sect. 3 we do a general review of humanitarian logistics. In Sect. 4 a literature review is shown. Section 5 explains the methodology followed for this work. Section 6 explains the experimentation and the case instance. In Sect. 7 we comment on the results of the instance, and in Sect. 8 we make conclusions to this work.

2 Supplier Selection

Procurement refers to the different activities such as transportation, purchasing, tracking and traceability of the merchandise; supplier development and supplier selection. Procurement could translate in a great competitive advantage for an organization depending on the criteria chosen to carry out the supplier selection. This selection must be aligned to the objectives and strategies of the company as their performance also depends on their commercial partners [1].

The globalization has expanded the supply worldwide. Suppliers are located farther away making supply chains more complex and delivery lead times longer [2]. Thus, it is important to develop strategies that simplify the procurement of products through the appropriate selection of commercial partners that help ensure on-time deliveries and product availability [3].

Nevertheless, supplier selection is normally a complex activity given the qualitative criteria involved. Some authors have proposed multi-criteria tools as a first stage on the selection and optimization tools in a later stage.

The use of quantitative approaches has been broadly studied by different authors. [2] and [1] present state-of-the-art supplier selection tools that have been addressed. Throughout the purchasing process, they identify the pre-qualification methods that are useful to shorten the supplier base, and the final decision methods that help optimize the final purchase of items from an approved base of reliable suppliers.

Pre-qualification methods include and are not limited to:

- Categorical methods.
- Fuzzy set theory.
- Data envelopment analysis.
- Case-based reasoning.
- Analytical hierarchy process.

Final decision methods include and are not limited to:

- Linear and non-linear mathematical programming.
- Mixed integer programming.
- Meta-programming.
- Multi-objective programming.

In a competitive environment where multiple suppliers offer similar quality and performance, decisions are likely to be made based on pricing. In some cases, these decisions are based on quality or lead time, depending on the nature of the company.

Procurement from different sources occurs when a single supplier cannot meet the demand, thus, the buyer must allocate the demand to multiple suppliers.

Organizations also have to make decisions as to how many candidates will be part of their selected pool of suppliers. Allocating full demand to a single supplier could carry important risks of interruption of flow throughout the chain if any unpredicted event arises. On the other hand, having multiple sources may increase administration costs and establishing strong relationships becomes hard to manage. It is important for organizations to maintain a robust yet adequately small supplier base so that costs are kept low and performance remains high.

3 Humanitarian Logistics

Humanitarian logistics is defined as the process of planning, implementing and controlling the cost-efficient and effective flow and storing of goods and materials, and the related information, from the point of origin to the point of consumption to ease the suffering of vulnerable people [4, 5].

A disaster is an event that has great negative impact in the society and its environment. It could be natural-made such as hurricanes, earthquakes and volcanic eruptions; or man-made like air crashes, nuclear accidents or wars. Natural disasters, in particular, represent great logistical challenges due to the on-sudden event and the uncertainty that it holds.

In the last decades, through the opening of mass media, people all over the world has been aware of the catastrophic consequences of natural disasters on large and small populations, and the great economic impacts that they carry.

[4] identifies four stages in the humanitarian chains, two before and two after the disaster.

In the mitigation stage, the community runs risk assessments on infrastructure and roads, and if necessary, construction of systems to reduce the damage of a disaster like the anti-tsunami systems that Japan put in place.

In the preparedness stage, the community carries out activities such as the recruitment of volunteers, education of the society in regards of emergencies, acquisition of vehicles and emergency tools; storing of relief items and the development of emergency plans to be executed in case of a crisis.

After the disasters, the response stage is immediately triggered. Some of the activities in this stage include, search and rescue of people, data collection regarding the disaster zone, establishment of shelters, and transportation of humanitarian relief items.

Lastly, the rehabilitation stage begins usually weeks after de disaster and the activities performed in this stage target the re-establishment of normality within the community.

Many organizations use to procure the relief items after the disaster, also called post-disaster procurement. Nevertheless, due to the high demand of relief items, prices are usually expensive or and products are scarce. If the HO is able to procure these items, the delivery lead times are usually long which is not aligned to the objective of the humanitarian logistics. Some authors have proposed to keep a pre-positioned inventory [3, 6, 7], this is, to store relief items in the preparedness stage so that the humanitarian organization is able to start shipping to the affected zones immediately after a disaster strike. This, of course, would be ideal if humanitarian organizations had enough funds, staff, space and budget to keep a large warehouse operating. Unfortunately, this is not the case for most of HO's. Keeping pre-positioned inventory means high storing costs, complex administration and risk of obsolescence, since many of the relief items may be perishable. [6] have proposed the use of framework agreements. By settling an agreement or contract with commercial partners, the integration of the humanitarian chain becomes stronger, since terms such as pricing, quality, packaging and lead time are established before the actual purchase.

Humanitarian relief items are usually believed to be first-aid items like bottled water, food, or medicines. Nevertheless, items such as peak axes, shovels, gloves and other materials use to carry out the actual rescue activities during the response stage can also be considered as relief items. Depending on their objectives and internal administration, HO's may procure first-aid items or tools necessary for perform such activities.

3.1 Differences Between Commercial Logistics and Humanitarian Logistics

Commercial logistics have been broadly studied. The main objective is to maximize the profit of products, services and information moved along the supply chain. Although, humanitarian logistics move, not only products, but also people, the main objective is to ease the suffering of vulnerable people.

Whereas in commercial chain, we speak about a relatively stable demand, humanitarian logistics stands before a very irregular and unexpected demand; the time, place or quantity remain unknown but until the disaster has ocurred. Some authors have developed scenario-based stochastic programming models to normalize demand. This is, they collect information from past events to somehow determine patterns, means, and statistics to structure possible scenarios [6, 8].

Another great difference is the people that are involved. Common parties in commercial chains are suppliers and/or service providers, distributors, warehouses, third-party logistics, customs, and others; an interdependency along the chain exists and all parties seek to maximize their benefits and be effective and cost-efficient. In humanitarian logistics we observe parties like donors, HO's, churches, governments, volunteers, warehouses, suppliers, transportation providers, among others, seeking to bring help all at the same time (many of these with their own agendas and interests); some of these parties even take advantage of the mass media to advertise their products as a marketing strategy. At the same time, even the local citizens, toss away unnecessary items that they no longer need.

Commercial logistics have a broad performance validation based on international standards of the supply chain. A clear example of this is the six-sigma methodology, the SCORE model, and others. In the humanitarian fields, a performance indicator is usually the response time, fill rate, percentage of demand satisfied and the expectations of donors [9]. See Table 1.

Table 1. Differences between commercial logistics and humanitarian logistics.

	Commercial logistics	Humanitarian logistics
Objective	Maximize profit	Save lives and ease suffering
Demand	Generally stable	Irregular
Human resources	Professional careers	High rotation of volunteers
Resource flow	Commercial products	People, food, shelter, etc.
Stakeholder	Shareholders, customers	Donors, governments, NGO's, etc.
Inventory control	Safety stocks in place	Difficult to control
Performance validation	Standard to the supply chain	Response time, % of demand covered

4 Literature Review

Supplier selection has a large list of scientific and academic papers. For this literature review, we used: "supplier selection", "supplier evaluation", and "humanitarian logistics". In the most recent papers from the last five years from the National Consortium for Scientific and Technological Information Resources (CONRICYT) data base, we find the ones from [3] and [10] who develop a two-stage stochastic programming model to analyze the pre-positioned inventory at the supplier's expense. [11] propose a stochastic programming model to resolve the optimal stock quantity reducing costs of transportation, penalty and inventory; similarly, [12] integrate carrier and supplier selection for developing contractual agreements, they use a scenario-based two-stage stochastic programming model for the establishment of joint decision-making and help minimize the fixed contract costs, commodity and vehicle reservation costs, commodity purchasing costs, vehicle rental costs, transportation costs, and others. The work of [13] proposes a bi-objective mixed possibilistic, two-stage stochastic programming model to strengthen the decision-making process considering risks of disruptions in the chain as well as the suppliers profiles based on the action plans in case of a major disruption. [14] propose a multi-stage programming model to minimize the expected costs of having an agreement in place and procuring relief items from the suppliers. They consider commitment quantities of the relief agency, reserve capacity of suppliers, and discount rates. [6] considers framework agreements with suppliers establishing a fixed agreement fee and reserved capacity. [8] also propose a two-stage stochastic programming model based in scenarios and then compare it with a chance-constrained programming (CCP) model that assumes a probability distribution and restricts the probability of not covering the demand. Despite the work of [15] and [16] is not in humanitarian logistics, they use the analytics hierarchy process (AHP) and the technique for order of preference by similarity to ideal solution (TOPSIS) respectively, to later combine it with Mixed Integer Programming (MIP) by inserting the data obtained from the previous methods in order to optimize it. [17] develop a supply partner framework for continuous-aid procurement using fuzzy AHP and fuzzy TOPSIS to rank different supplier alternatives. They identify 6 attributes and 24 sub-criteria that consider relevant for the multi-criteria decision-making problem.

[18] use a multi-criteria decision-making tool, TOPSIS, to help on the supplier selection problem for the blood-bag industry and take into consideration attributes such as product quality, delivery performance, financial status, purchasing costs, personnel and facilities.

We have identified that literature in humanitarian logistics is not as extensive as in commercial chains, nevertheless, we have found important works on the field. Stochastic programming is the tool found in most works for supplier selection.

We see that only the work of [16] considered a budget despite it is an important factor for many HO given the limited funds. We believe that it's important to address budget constraints in the humanitarian field for the final decision methods that have been previously addressed by other authors (Table 2).

Table 2. Literature review.

	Humanitarian Logistics	Supplier Selection	Item procurement	Budget	Pre-positioned inventory	Solution	Tool
[10]	x	x	x		x	Optimal	Stochastic programming
[3]	x	x	x		x	Optimal	Stochastic programming
[11]	x	x	x		x	Optimal	Stochastic programming
[13]	x	x	x		x	Optimal	Stochastic programming
[6]	x	x	x			Optimal	Stochastic programming
[8]		x	x			Optimal	Stochastic programming/CCP
[15]		x	x			Approximate	AHP/MIP

(*continued*)

Table 2. (*continued*)

	Humanitarian Logistics	Supplier Selection	Item procurement	Budget	Pre-positioned inventory	Solution	Tool
[16]		x	x	x		Optimal	Fuzzy TOPSIS/MIP
[12]	x	x	x			Optimal	Stochastic programming
[14]	x	x	x		x	Optimal	Stochastic programming
[17]	x	x				Approximate	Fuzzy AHP and fuzzy TOPSIS
[18]		x	x			Approximate	TOPSIS

5 Methodology

Given the literature review, we have followed the methodology proposed in [19] for the formulation of mathematical models:

1. Formulate the problem.
2. Observe the system.
3. Formulate a mathematical problem for the problem.
4. Verify the model.
5. Select a suitable alternative.

5.1 Problem Description

A statutory agency seeks to make decisions as to what suppliers must they purchase from when a sudden-onset disaster occurs. The organization receives an annual budget from the federal government that is available for emergencies only. For 2020 the budget was $21 million pesos. The organization procures first need items and machinery through the Procurement Office. These purchases are made in different ways; however, it is known that tender processes can be done and that the organization can establish framework agreements with suppliers.

A list of suppliers already approved by the organization exists, however, there are many suppliers that are candidates to use. Only the suppliers in the list can be selected in case of an emergency. The suppliers may have different characteristics and offer different deals. The reserved capacity, the unit price and the coverage may differ from one another.

Another important information is that in case of a high-impact disaster that exceeds the capacity of the organization to help the population, the organization can procure the items needs from the federal government. The procurement of this items is not monetary which means that the organizations has specific quantities to request to the federation.

The suppliers offer discounts depending on the volume of the purchase. The price will also depend on the shipping destination and the requested lead time. The suppliers may offer different pricing schedule for each region depending on their coverage. We assume that these prices will always be better or lower enough to buying the items in the spot market (post-disaster procurement).

The organization has to define the minimum and maximum number of suppliers to be selected. It is important to pinpoint that the more suppliers available for selection, the higher the costs of procuring. On the other hand, if the organization was to pick only one supplier, there is a high risk of falling short on demand coverage if a medium or high-impact disaster occurs.

5.2 Regional Context

For the case study we take the Mexican state of Nuevo Leon. It holds a population of 5.13 million habitants and 80% inhabit the metropolitan area. Historically, the state has been impacted every year for severe storms and hurricanes. Between 2000 and 2015, eleven storms were categorized as natural disaster. In more recent years, the storm “Fernand” in 2019 and “Hanna” in 2020 were also categorized as natural disasters.

Storms that form in the Atlantic Ocean are common to pass through the Gulf of Mexico and hit the Mexican coasts every year. Studies ran by several government institutions determine that Nuevo Leon is likely to be struck by Tropical Storms, and Hurricanes categories II and III in the scale of Saffir-Simpson. See Table 3.

Table 3. Saffir-Simpson hurricane wind scale.

Category	Winds	Damages
I	119–153 km/h	Minimum damage
II	154–177 km/h	Moderate damage
III	178–208 km/h	Important damage
IV	209–251 km/h	Severe damage
V	Above 252 km/h	Catastrophic damage

The State capital, Monterrey, is the third largest city in Mexico and given the fact that it holds eighty percent of the population, storms cause great damages to the population and the infrastructure of the city and its metropolitan area. Annually, the state accumulates 650 mm with rains that are mostly seen in the summer.

5.3 Model Formulation

We use the following notation for the supplier selection problem:

Sets	
I:	Set of candidate suppliers
K:	Set of items
L:	Set of delivery lead time intervals
M:	Set of quantity intervals offered by supplier i for item k
R:	Set of demand regions
S:	Set of scenarios
Parameters	
p_s:	Probability of scenario s
η_{min}:	Minimum number of suppliers to select
η_{max}:	Maximum number of suppliers to select
d_{kr}^{s}:	Demand of product k for region in scenario s
z_{kl}^{s}:	Portion of demand to be satisfied in interval l for product k in scenario s
v_{ik}^{max}:	Maximum capacity reserved for item k from supplier i
f_i :	Fixed agreement costs supplier i
α_{iklmr}^{s}:	Lower breakpoint associated with quantity interval m offered by supplier i, for item k, serving region r, within the lead time interval l in scenario s
β_{iklmr}^{s}:	Upper breakpoint associated with quantity interval m offered by supplier I, for item k, serving region r, within the lead time interval l in scenario s
u_{iklmr}:	Unit price offered by supplier i for delivering purchased item k at quantity interval m, to serve region r, within the lead time interval l, in scenario s
ω_{kr}:	Unit price offered by the external source at quantity interval m, to serve region r, within the lead time interval l, in scenario s
Ψ:	Budget allocated by the agency for the procurement of k
Variables	
Q_{iklmr}^{s}:	Amount purchased of item k from supplier i at quantity interval m, to serve region r, within the lead time interval l, in scenario s
E_{kr}^{s}:	Amount purchased of item k from the external source at quantity interval m, to serve region r, within the lead time interval l, in scenario s
$Y_i =$	1, if the supplier i is selected for the agreement; 0, otherwise
$X_{iklmr}^{s} =$	1, if the agreement with supplier i is executed by purchasing item k at quantity interval m, to serve region r, within the lead time interval l in scenario s

The problem is formulated as follows:

$$\min \sum_{i \in I} \sum_{k \in K} f_i Y_i$$

$$+\sum_{s\in S} p_s\left[\sum_{i\in I}\sum_{k\in K}\sum_{l\in L}\sum_{m\in M}\sum_{r\in R} u_{iklmr}Q^s_{kilmr} + \sum_{k\in K}\sum_{r\in R}\omega_{iklmr}E^s_{kr}\right] \tag{1}$$

Subject to:

$$\sum_{i\in I}\sum_{k\in K} Y_{ik} \geq \eta_{min} \qquad \forall i \in I \tag{2}$$

$$\sum_{i\in I}\sum_{k\in K} Y_{ik} \leq \eta_{máx} \qquad \forall i \in I \tag{3}$$

$$\sum_{i\forall I}\sum_{l\forall L}\sum_{m\in M} Q^s_{iklmr} + E^s_{kr} \geq d^s_{kr} \qquad \forall k \in K,\ r \in R,\ s \in S \tag{4}$$

$$\sum_{i\in I}\sum_{l\in L}\sum_{m\in M}\sum_{r\in R} Q^s_{iklmr} \geq d^s_{kr}10\% \qquad \forall k \in K,\ s \in S \tag{5}$$

$$\sum_{l\in L}\sum_{m\in M} Q^s_{kilmr} \leq v^{máx}_{ik} Y_{ik} \qquad \forall i \in I, k \in K,\ r \in R,\ s \in S \tag{6}$$

$$\sum_{i\in I}\sum_{m\in M} Q^s_{iklmr} \geq z^s_{kl} d^s_{kr} \qquad \forall i \in I, k \in K,\ l \in L,\ r \in R,\ s \in S \tag{7}$$

$$Q^s_{kilmr} \geq X^s_{kilmr}\alpha_{iklmr} \qquad \forall i \in I, k \in K, l \in L, m \in M, r \in R, s \in S \tag{8}$$

$$Q^s_{kilmr} \geq X^s_{kilmr}\beta_{iklmr} \qquad \forall i \in I, k \in K, l \in L, m \in M, r \in R, s \in S \tag{9}$$

$$\sum_{m\in M} X^s_{kilmr} \leq Y_i \qquad \forall i \in I, k \in K, l \in L, r \in R, s \in S \tag{10}$$

$$\sum_{i\in I}\sum_{k\in K}\sum_{l\in L}\sum_{m\in M}\sum_{r\in R} u_{iklmr}Q^s_{iklmr} + \sum_{i\in I} f_i Y_i \leq \Psi \tag{11}$$

$$Q^s_{iklmr} \in \mathbb{Z}^+_0 \qquad \forall i \in I, k \in K, l \in L, m \in M, r \in R, s \in S \tag{12}$$

$$E^s_{kr} \in \mathbb{Z}^+_0 \qquad \forall k \in K, r \in R, s \in S \tag{13}$$

$$X^s_{iklmr} \in \{1, 0\} \qquad \forall i \in I, k \in K, l \in L, m \in M, r \in R, s \in S \tag{14}$$

$$Y_i \in \{1, 0\} \qquad \forall i \in I \tag{15}$$

Where the objective function (1) seeks to reduce procurement and agreement costs. In a first stage, it makes the decision as to what suppliers are selected; in stage two, it reduces the procurement costs associated to those suppliers and the procurement from a higher-level source (federal government). Constraint (2) and (3) are the minimum and maximum number of candidate suppliers to use. (4) ensures that the demand is covered by sourcing from the selected suppliers and from the higher-level source. (5) ensures that at least 10% of the demand is covered by the suppliers for each item. (6) ensures that the reserved capacity is not exceeded. (7) indicates the level of service, which indicates the portion of the demand to be satisfied in a determined delivery lead time interval. (8) and (9) ensure that the items are procured within the lead time and quantity intervals. (10) ensures that the items are only procured from the selected suppliers. (11) is the budget constraint. (12) and (13) are the integer variables, and (14) and (15) are binary variables.

6 Experimentation

6.1 Scenario Formulation

The parameter p_s of the mathematical model represents the probability of occurrence of a determined scenario. To formulate the scenarios, we have looked into the possible development of a disaster in the region. Particularly, this region is hit by tropical storms, and hurricanes categories II and III, which are considered to be low, medium and high impact phenomena respectively. These commonly land by the coast of the Gulf of Mexico and make their path to the state of Nuevo Leon.

The State evaluates the risk in the territory and divide it in 5 regions: north, south, west, citrus, and metro. Specifically, the citrus and west regions are considered to be always hit by these phenomena due to their geographical position and given the track of hydrometeorological disasters.

By making possible combinations of regions affected, we identify six possible combinations shown in Table 4.

Table 4. Combination of affected regions.

Combination	Fixed regions	Region
1	Citrus – West	North
2		South
3		Metro
4		Metro – North
5		Metro – South
6		Metro – North – South

We discard the combination where regions are impacted except the metro region (Citrus–West–North–South) as we believe it is very unlikely that a storm affects both, the north and the south regions but not the metro that is located between these two.

6.2 Probability of Occurrence

For each disaster impact we would consider each of the six combinations given before, which makes a total of 18 possible scenarios. The sum of the probability of occurrence must be equal to 1, this is $\sum_{s \in S} p_s = 1$. For that, we estimate it as follows:

1. A random number is generated for each scenario, $\overline{p}_s$. Depending on the disaster impact a random number with normal distribution is generated, U[80,100], U[20,40], and U[0,20] for tropical storms, hurricane category II and hurricane category III, respectively.
2. Each number $\overline{p}_s$ is divided by the sum of all random numbers. $p_s = \overline{p}_s / \sum_{s \in S} \overline{p}_s$.

The tree of scenarios can be observed in Fig. 1 where the 18 scenarios are shown and their probability of occurrence which was estimated using the steps described above. We observe that the probability of occurrence in scenarios where the regions are affected by tropical storms have a higher probability than those scenarios where hurricanes category III strike.

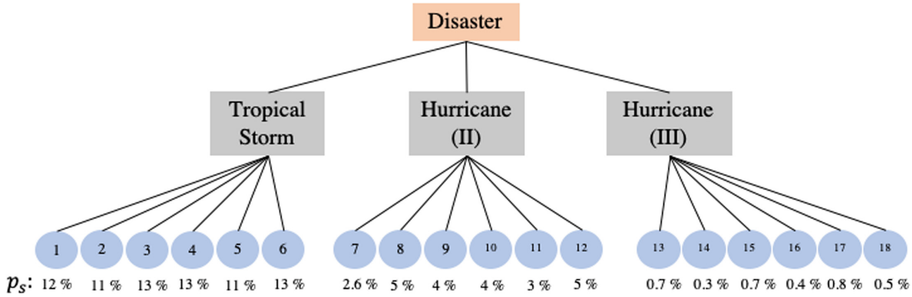

Fig. 1. Tree of scenarios – probability of occurrence

6.3 Demand Scenarios

For each disaster impact we generate a possible demand which represents the number of people affected by the storm. The demand will be low, medium and high for tropical storms, hurricanes category II and hurricanes category III respectively. The unit of measure for items k will be calculated based on the result of this demand. We followed the steps below to calculate demand:

1. We generate a random number with uniform distribution for each region that is affected in a determined scenario with exemption of those that are not.
2. We multiply the demand by the percentage of population concentrated in that region. North, west, south and citrus hold 5%, and the metro region holds 80% of the population.
3. We obtain the total demand per scenario.

The minimum and maximum of victims in point 1 is to be determined based on historical data for the region of case study. According to the history of Nuevo León, we generate numbers as follows: 100 – 5,000 victims in case of tropical storms; 5,000 – 15,000 in case of hurricane category II; and 15,000 – 50,000 in case of hurricane category III. The total victims per scenario is shown in Table 5.

Table 5. Number of victims per scenario.

Scenario#	Impact	Probability	Total victims
1	Low	12.48%	501
2	Low	12.75%	183
3	Low	11.83%	3,556
4	Low	12.22%	2,812
5	Low	12.75%	2,300
6	Low	10.78%	994
7	Medium	2.63%	1,993
8	Medium	3.15%	1,318
9	Medium	5.12%	12,974
10	Medium	5.12%	7,578
11	Medium	3.55%	10,275
12	Medium	3.55%	6,555
13	High	0.26%	4,727
14	High	0.13%	4,683
15	High	1.31%	33,427
16	High	0.26%	37,239
17	High	1.18%	20,218
18	High	0.92%	38,782

6.4 Case Instance

For the experimentation, we considered two items: bottled water and blankets.

Water is vital for humans. For the demand generation of bottled water, we estimated a 2 L consumption per person per seven days. This means that each victim will require 14 L of water. The standard presentation of bottled water is a 24 pack of bottles of 500 ml, or packs with 12 L.

Blankets are required by victims that had to be reallocated to a community shelter. For the case instance, we considered that only 30% of the victims require shelter, thus, they will need a blanket. No further specifications for blankets were considered.

The demand of each items is presented in Table 6, where the demand for water was calculated multiplying the total victims in each scenario by 14, and by 0.30 for blankets.

We also consider a supplier base of 10 candidates, 5 for each item and a fixed cost for singing an agreement with any of the candidates. The cost is $1,000.

Table 6. Demand scenarios per item.

Scenario#	Scaled Prob.	Bottled water					Blankets				
		West	Citrus	North	South	Metro	West	Citrus	North	South	Metro
1	12.48%	275	46	264	0	0	71	12	68	0	0
2	12.75%	17	85	0	112	0	4	22	0	29	0
3	11.83%	127	108	0	0	3914	33	28	0	0	1007
4	12.22%	281	257	187	0	2555	72	66	48	0	657
5	12.75%	35	153	0	157	2337	9	39	0	40	601
6	10.78%	117	243	121	153	525	30	62	31	39	135
7	2.63%	822	728	776	0	0	211	187	200	0	0
8	3.15%	337	772	0	429	0	87	198	0	110	0
9	5.12%	408	855	0	0	13874	105	220	0	0	3568
10	5.12%	480	468	781	0	7112	123	120	201	0	1829
11	3.55%	318	386	0	621	10662	82	99	0	160	2742
12	3.55%	617	406	808	506	5310	159	104	208	130	1365
13	0.26%	2849	175	891	0	0	733	456	229	0	0
14	0.13%	2067	196	0	1460	0	532	498	0	375	0
15	1.31%	2746	1187	0	0	35064	706	305	0	0	9017
16	0.26%	1117	1302	2519	0	38507	287	335	648	0	9902
17	1.18%	1313	2783	0	1084	18408	338	716	0	279	4734
18	0.92%	1701	1500	2733	2402	36910	437	386	703	618	9491

The minimum purchase of each item is 100 units. Nevertheless, suppliers offer a 5% discount in purchases over 1,000 units of bottled water, or 500 blankets. Prices, and quantity and lead time intervals are shown in Table 7.

As per the costs of procuring from the federal government ($\omega_{kr}E^{s}_{kr}$) we establish a price large enough to not be selected as a first choice but until the reserved capacity or the budget is used up.

It is also assumed that the agency established the first lead time interval to be from 5–7 days, and the second lead time to be 8–10 days; and wishes a to supply at least 30% of the demand within the first lead time interval. This means that the selected candidate suppliers must deliver the item(s) within 5 to 7 days. Lastly, the agency holds an annual budget of 21 million pesos for 2020. We assume that the agency wishes to allocate 1.5 million to the procurement of these two items. According to the formulated mathematical model, the associated costs to the procurement of bottled water and blanked must not exceed the assigned budget.

This model was run using the General Algebraic Modeling System (GAMS) using the solver CPLEX. An equipment with processor AMD A6–3620 APU 2.20 GHz and 6 GB RAM was used.

Table 7. Prices offered by suppliers.

	Supplier	Price < 100 units	Price within 2nd quantity interval	Price within 2nd delivery lead time interval
Bottled water	1	$ 81.00	$ 76.95	$ 73.10
	2	$ 90.00	$ 85.50	$ 81.23
	3	$ 93.00	$ 88.35	$ 83.93
	4	$ 80.00	$ 75.00	$ 72.20
	5	$ 83.00	$ 78.85	$ 74.91
Blankets	6	$ 133.00	$ 126.35	$ 120.03
	7	$ 129.00	$ 122.55	$ 116.42
	8	$ 120.00	$ 144.00	$ 108.30
	9	$ 135.00	$ 128.25	$ 121.84
	10	$ 122.00	$ 115.90	$ 110.11

7 Results

The instance was solved in 0.171 min for 14,591 variables and the results are presented in Table 8.

Table 8. Results.

	Results
Selected suppliers	3
Suppliers of bottled water	2
Suppliers of blankets	1
Procurement costs (thousands)	$ 1,496.95
Fixed costs (thousands)	$ 3.00
Total costs (thousands)	$ 1,499.95
Demand satisfied by selected suppliers	56%
Demand satisfied by the federal government	44%

Observation 1. From the 10-supplier base, only 3 candidates were selected, two suppliers of water bottled and 1 of supplier of blankets. Given the prices listed on Table 6, the results show to be aligned as the selected candidates were the ones with the lower price offer.

Observation 2. The budget is used up at 100% without surpassing it. This indicates that the budget constraint has been honored in the execution. With this solution we can cover up 100% of the demand in scenarios from 1 to 14; and up until 56% in for the rest. The uncovered demand must be covered by the federal government.

Observation 3. It is observed that the relief items to procure in the first lead time interval is 60% for bottled water and 76% for blankets which indicate that the service level of 30% at the first lead time interval was honored.

Observation 4. We observe a small surplus of 0.48%. This is due to the minimum purchases established by the suppliers that had to be procured even when the demand was lower than the minimum, mostly in the scenarios under tropical storms.

7.1 Budget Analysis

Observation 5. We adjusted the budget parameter to see the performance and the behavior of our model. If the parameter Ψ is set under 1.5 million pesos, the stochastic model will be infeasible, as it is not possible to meet the demand of at least 10% indicated in constraint 5. Nevertheless, by increasing the budget, the agency is able to select even more suppliers and satisfy the demand. By reaching up to 4.75 million pesos in budget, the agency is able to satisfy the demand with the allocated resource without going through the process of sourcing from the federal government. See Table 9.

Table 9. Budget allocation analysis.

Budget ($)	Suppliers selected	Request aid from federal government?
Less than 1.5 million	Infeasible	Yes
1.5 million	3	Yes
2 million	4	Yes
2.5 million	5	Yes
2.75 million	5	Yes
3 million	6	Yes
4 million	7	Yes
4.75 million	7	No

As mentioned above, monetary resources are very important for HO's. This brief analysis could be of help to a statutory agency in the decision-making process as to how much budget must be allocated for certain relief items or tooling. At the same time, it helps the agency to understand the range of minimum and maximum budget allocation; on the one hand it is important to cover at least 10% of the demand generated for bottled water and blankets, nevertheless, it would not be possible by allocating Less than 1.5 million pesos. On the other hand, the agency could make a decision as to how much more resources allocate to these relief items; by allocating the maximum budget, 4.75 million, the state government would not be in need to request aid from the federal government and would meet the demand from their own resources, saving time and of course, lives, since it may take more waiting time to transport federal resources to the disaster zone.

7.2 Deterministic Solutions

The GAMS code of the presented model was built in such fashion that it also provides deterministic solutions for each scenario taking the random demand as a known parameter. In this way, we are able to compare the solution provided by the stochastic model versus eighteen solutions of the deterministic version of the model. We can observe the results in Tables 9, 10 and 11.

Table 10. Deterministic solutions I.

		Deterministic model (tropical storm)					
	Stochastic model	S1	S2	S3	S4	S5	S6
Candidate suppliers selected	3	3	2	2	2	2	2
Bottled water	2	2	1	1	1	1	1
Blankets	1	1	1	1	1	1	1
Procurement costs (thousands)	$1,496.95	$87.12	$60.96	$441.77	$357.17	$309.85	$156.92
Fixed costs (thousands)	$3.00	$3.00	$2.00	$2.00	$2.00	$2.00	$2.00
Total (thousands)	$1,499.95	$90.12	$62.96	$443.77	$359.17	$311.85	$158.92
Budget used	100%	6%	4%	30%	24%	21%	11%

Table 11. Deterministic solutions II.

		Deterministic model (hurricane category II)					
	Stochastic model	S7	S8	S9	S10	S11	S12
Candidate suppliers selected	3	2	2	3	2	3	2
Bottled water	2	1	1	2	1	2	1
Blankets	1	1	1	1	1	1	1
Procurement costs (thousands)	$1,496.95	$257.84	$172.00	$149.70	$914.41	$1,233.70	$799.20
Fixed costs (thousands)	$3.00	$2.00	$2.00	$3.00	$2.00	$3.00	$2.00
Total (thousands)	$1,499.95	$259.84	$174.00	$152.70	$916.41	$1,236.70	$801.20
Budget used	100%	17%	12%	10%	61%	82%	53%

Observation 6. We observe that the organization can satisfy the demand with 1.5 million pesos in 80% of the scenarios. This is important for decision-making as to how much budget to allocate and what suppliers are the best candidates (Table 12).

Table 12. Deterministic solutions III.

		Deterministic model (hurricane category III)					
	Stochastic model	S13	S14	S15	S16	S17	S18
Candidate suppliers selected	3	2	2	3	3	3	3
Bottled water	2	1	1	2	2	2	2
Blankets	1	1	1	1	1	1	1
Procurement costs (thousands)	$1,496.95	$577.25	$568.94	$1,496.67	$1,496.99	$1,496.97	$1,496.95
Fixed costs (thousands)	$3.00	$2.00	$2.00	$3.00	$3.00	$3.00	$3.00
Total (thousands)	$1,499.95	$579.25	$570.94	$1,499.67	$1,499.99	$1,499.97	$1,499.95
Budget used	100%	39%	38%	100%	100%	100%	100%

After the observations previously made, we determine that the model delivers a logical solution. It is important to keep in mind that the procurement costs are those of $u_{iklmr}Q^s_{iklmr}$, and that the costs of E^s_{kr}, are auxiliary costs for the mathematical compilation purpose. Binary variables X^s_{iklmr} and Y_i are also coherent to the solution delivered for Q^s_{iklmr}, this is, the contracts and the suppliers that are selected correspond to the suppliers to procure the items from.

8 Conclusions

Humanitarian logistics are of special attention for many societies. Its main importance relies on the ease of suffering caused by natural (or man-made) disasters that have happened and will, probably, continue to happen.

Logistics per se, is a detailed plan which in humanitarian logistics takes place in the preparedness stage. HO's and the actors involved in humanitarian chains are able to improve their performance significantly through the planning and development of strategies that will be implemented in any of the stages of humanitarian logistics.

Given the important differences between commercial and humanitarian chains it's important to bring different approaches to help communities be better prepared for a humanitarian crisis.

This work seeks to help integrate the humanitarian chain by strengthening the relationships between suppliers and HO's by establishing framework agreements.

This research provides a quantitative approach for decision-making in humanitarian logistics. Results indicate that it is possible to minimize the costs associated to the procurement of humanitarian relief items by using stochastic programming as a supplier selections tool. Despite the use of mathematical programming in other papers, the main contribution of this work is based on the budget constraint given the limited funds of many humanitarian organizations and the possibility of estimating the procurement amounts of a higher-level source like the federal government in our case study. The model is able to provide information useful for the decision-making process within a humanitarian organization regarding budget allocation. The proposed model shows an optimal solution given the type of scenarios and its distribution of probability delivering a 100% of demand satisfied in fourteen scenarios and up to 58% of demand satisfied in scenarios where the it spikes considerably as a consequence of an important natural phenomenon.

The proposed model is not limited to the type of items nor to the type of disasters so we believed this could be adapted to different HO's that hold a limited budget.

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