Towards a method for qualitative and quantitative assessment of humanitarian disaster demand forecast

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Abstract
Humanitarian Supply Chains have received a lot of attention over the last fifteen years, and can now be considered a new research area. But a gap exists between the research work proposals and their application on the field. One of the main issues is that the demand, in case of humanitarian disaster, is particularly hard to assess because of the high level of uncertainty. Consequently, too many academic propositions are still purely theoretical. Gathering knowledge about future demand is thus of prime importance to be able to propose models, which are easy and relevant to implement for a real problem. This paper tackles this problematic by proposing a 2 steps methodology that be able to forecast roughly the future needs in terms of humanitarian relief operations. This contribution is based on simple regression and above all, on vulnerability ratio calculation. A numerical example based on the case of Peruvian earthquakes is finally presented.

Keywords: Humanitarian, Vulnerability, Demand Forecast.

Introduction
Almost every year, losses due to natural disasters are increasing. For instance, economic damages from natural disasters in 2010 (US$ 123.9 billion) increased by 160.4% compared to 2009, and were above the annual average damages for the period 2000-2009 (US$ 98.9 billion) (em-dat, statistical review, 2011). In the meantime, over the last decade, the funding of humanitarian operations has been multiplied by thirteen (reliefweb.int).

All these facts have pushed humanitarian organizations to become more result-oriented. They need to prove to donors that the funds they get are used in the most efficient way. But because of what is at stake, that is to say human lives, they also need to ensure that, whatever the circumstances, those who need their help are rescued quickly and effectively.

Consequently, Humanitarian Supply Chains (HSC) have received a lot of attention over the last fifteen years, and can now be considered a new research area. The number of scientific and applicative publications has considerably increased over this period and particularly over the last five years. Reviews in humanitarian logistics and disaster operations management have allowed bringing out trends and future research directions dedicated to this area (Altay and Green; 2006; Van Wassenhove, 2006; Natarajarathinam et al., 2009; Charles et al., 2010; Peres et al., 2012). These authors show that the HSC research projects are mainly based on the development of analytical models followed by case studies and theory. As for research methodologies, mathematical programming is the most frequently utilized method. But we must notice that few or no humanitarian organizations go as far as using optimization-based decision-support systems. This demonstrates that a real gap exists between the research work proposals and their application on the field. To bridge this gap, authors such as (Van Wassenhove, 2006; Kovacs and Spens, 2007; Charles, 2010; Peres et al, 2012) have proposed some trails among which:

- Humanitarians naturally evolve in a very hazardous environment and the academic works must consider more systematically the uncertainties they face with. For instance, a great majority of the research works is deterministic and just few of them propose stochastic approaches.
- A consequence of the previous points is that the research works should be more realistic by considering real problem and real data gathering past and future trends (Van Wassenhove, 2006; Charles, 2010). Due to the youth of this academic area, researchers are finding it difficult to get accurate, and above all, reliable data to support their steps towards improvement.
- The future research works should consider the new requirement on efficiency for humanitarian organizations. Productivity and efficiency studies are challenging issues that have gained importance to humanitarian operations because of the donor’s pressure on humanitarian organizations to deliver aid to beneficiaries in a cost-effective way (Peres et al., 2012).

One of the main issues is so that the demand, in case of humanitarian disaster, is particularly hard to understand and to assess because of the high level of uncertainty. Consequently, too many academic propositions are still purely theoretical. Gathering knowledge about future demand is thus of prime importance to be able to propose models, which are easy and relevant to implement for a real problem.

The paper tackles this issue by proposing an original humanitarian demand forecast approach able to assess qualitatively and quantitatively the humanitarian demand. The final objective of this research work is to allow quantitative models to fit better with reality.

Background and research statement

A thorough logistics network analysis should consider complex transportation cost structures, warehouse sizes, environment constraints, inventory turnover ratios, inventory costs, objective service levels and many other data and parameters. As discussed before, these issues are quite difficult to gather in humanitarian world. But due to the youth of this academic area, researchers are finding it difficult to get accurate, and above all, reliable data to support their steps towards improvement. This is particularly true with the demand forecast. It is difficult, if not impossible, to foresee the location of disasters to come. And even after a crisis occurs, the environment changes so quickly that most of the time information is either not available or not reliable. Despite all, humanitarians could benefit a lot from the use of optimisation-based decision-support systems to design a highly capable HSC.

The objective of our research work consists thereby in proposing a HSC design method able to integer all the lacks previously presented. Concretely, we want to develop a HSC characterized by the following properties:

- “Leagile”: The proposed HSC should be efficient (minimization of the costs) but also agile in that sense that the deliveries must be responsive, effective and flexible.
- “Robust”: The HSC proposed should perform independently of the disaster that will occur.
- “True to life”: The proposed HSC should correspond to real data in order to become really applicable on the field.

These properties are essential to bring a real added value to practitioners and to be sure that the propositions will be implemented (confidence).

In the case of humanitarian organisations, this uncertainty is reaching a climax. "Natural disaster risk assessment is a typical issue with imprecision, uncertainty and partial truth. The two basic forms of uncertainty related to natural disaster risk assessment are randomness caused by inherent stochastic variability and fuzziness due to macroscopic grad and incomplete knowledge sample" (Huang and Shi, 2002). The usual methods to deal with uncertainty are to use a stochastic or a robust optimization model. Both need at least some knowledge about future demand. Indeed, stochastic optimization uses probabilities of occurrence and robust optimization uses various alternatives, from the most optimists to the worst-case scenarios. Stochastic optimization models optimize the random outcome on average. According to (Shapiro et al., 2009), “this is justified when the Law of Large Numbers can be invoked and we are interested in the long-term performance, irrespective of the fluctuations of specific outcome realizations”. In our case, the impact of those "fluctuations" is on human lives and can be devastating. As for robust location problems, according to (Snyder, 2006), they have proven difficult to solve for realistic instances. If a great majority of the published research works is deterministic, more and more humanitarian researchers propose now stochastic models in order to better consider uncertainty on demand.

Nevertheless, these models are limited because they do not consider the fact that disaster relief operations often have to be carried out in an disrupted environment with destabilized infrastructures (Cassidy, 2003; Long and Wood, 1995) ranging from a lack of electricity supplies to limited transport infrastructure. Furthermore, since most natural disasters are unpredictable, the demand for goods in these disasters is also unpredictable (Cassidy, 2003; Murray, 2005). We think that a HSC design model should include these both dimensions of uncertainty to be accurate and relevant for practitioners.

Researchers are no doubt aware that the main criteria of the success of optimization based approaches consists in producing a complete and representative mathematical model of the studied system. But considered an art by many and weird science by some, mathematical modelling is not as simple as it seems. This is particularly true in the humanitarian context, as in all new research areas, where researchers have difficulty identifying the right data, parameters and decision variables to be able to develop accurate and relevant analytical models. Our project tackles this problem by organizing the research work in the following steps:

- The first step will consist in defining the different scenarios of demand that the future HSC design should consider. The demand scenarios will be defined through two dimensions, which are:
    - The quantity of products that the response should deliver (function of the impacted population, the nature of the disaster, the geographical localization, etc.)
    - The criticality level that is based on three criteria: (i) probability of occurrence of the disaster, (ii) seriousness of the disaster, (iii) vulnerability of the area where the disaster can occur.
- The second step will define a particular set of parameters associated to each scenario. Thus we will be able to consider the impact of environment's uncertainty. For instance, let's consider a scenario based on an earthquake in an area where three routes are available to go from A to B:
    - If the criticality of the scenario is particularly low then the three routes will be available to run the HSC optimization.
    - If the criticality of the scenario is particularly high then only one route will stay available to run the HSC optimization.
- The third step will consist in modeling and implementing the facility location problem. The model will thus include:
    - Uncertainty of demand through classical stochastic approach on demand.
    - Uncertainty of environment through variable parameters function of the criticality of each scenario.
- The fourth step will implement the proposal on a real case study, which is the Peruvian earthquakes preparedness.

This paper focuses on the first step of this global approach.

Proposition and findings

According to the current thinking, disaster trends are changing. If we refer to (IFRC, 2007; IPCC, 2007; Charles, 2010; em-dat, 2011) disasters should be more numerous but of smaller scale in the future. Added to this is urbanization, which further alters the impacts of disasters. Studies of the potential impacts of climate change also predict developments in the types of disaster recorded, their locations, and their intensities.

Considering those facts, we made the assumption that two complementary problems must be solved in order to estimate the future "demand" in a humanitarian context (see. Figure 1):

- Step 1: Forecast of "triggered event" that should allow assessing the scenarios of future events (earthquakes, floods, etc.) corresponding to a set {date, disaster typology};
- Step 2: Forecast of "criticality" that should allow assessing the potential severity of the disaster on the impacted area.

Our proposition suggests to combine these elements to assess the future needs (scenarios of demand) in terms of {quantity of product, date, geographical zone}.

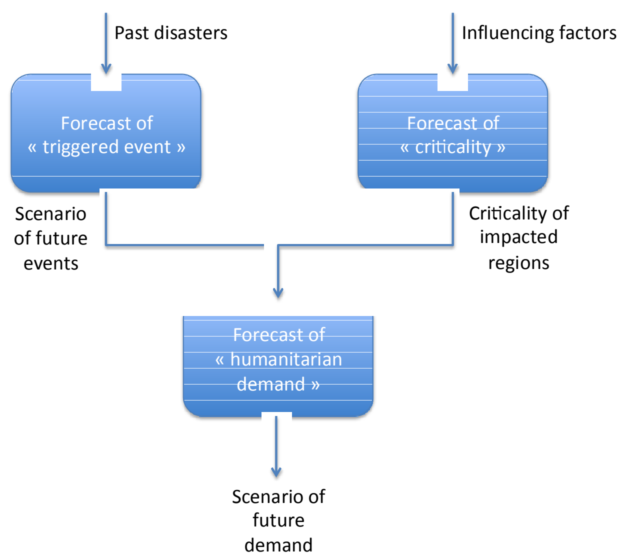

Figure 1 – Disaster Demand Forecast Methodology

In practice, the step 1 has consisted in analyzing data from past disasters in order to provide valuable information regarding trends of disasters (localization, intensity, typology, seasonality, etc.). This part of the work was based mainly on the results of (Charles, 2010). Actually, she proposed a deep analysis of the ten years past disasters. This study shows that:

- Parts of the world exhibiting similar disaster types are geographically close (see. Figure 2): African countries are more subject to epidemics, whereas in Asia there is a greater risk of being affected by earthquakes of floods; Australia, New Zealand, the Caribbean and North America are most affected by storms…
- A trend toward more frequent medium-size disasters affecting between 10,000 and 1,000,000 people is clearly visible;

- A real and increased seasonality of disasters exists (see. Figure 3).

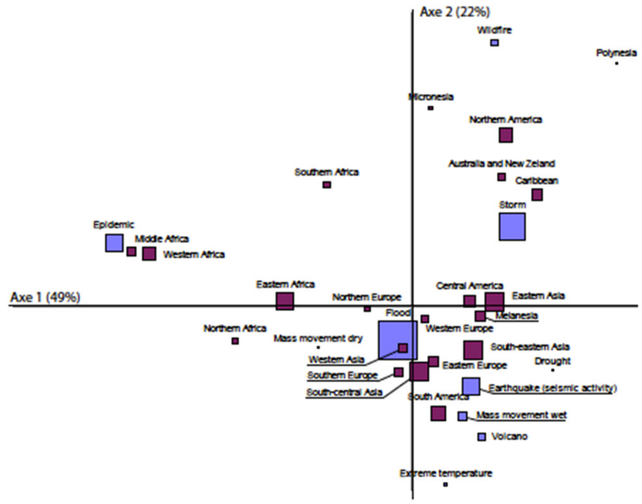

Figure 2 – Factorial Analysis of the past disasters (period 1998 – 2008) – from (Charles, 2010)

All these results provide information regarding the nature of the products that should be stored at the various locations and at a given period: Medical treatments created in response to epidemics, for example, could be maintained in Africa when safety, financial corruption and climatic conditions allow. But, these results show also that the forecast of “triggered event” is not so hazardous. Future humanitarian demand, though highly uncertain, can be predicted. Thus, a parallel with more traditional demand forecasting can be done. Demand forecasting involves techniques including both informal methods and quantitative methods, such as the use of historical data to estimate the future needs by extrapolation (regression, exponential smoothing, etc.). Considering the previous discussions, the use of such quantitative techniques should be relevant. We have so proposed to use a simple regression analysis allowing to extrapolate the historical data and to consider the trends discussed before (see. Figure 3). This technique permits to forecast quantitatively the future frequency of disasters. These potential “triggered events” should be defined through the following set {Impacted Area; Typology of Disaster; Date; Quantity of Items needed}. If the three main components of this set can be considered as quite robust, the necessary quantity of items seems much more random. Actually, the same triggered-event occurred in two different contexts might produce different consequences...

The step 2 of our approach handles this limit by establishing the “criticality” of the potential disaster. The notion of “criticality” referred to the failure mode, effects and criticality analysis (FMECA). This method includes a criticality analysis, which is used to chart the probability of failure modes against the severity of their consequences. The result highlights failure modes with relatively high probability and severity of consequences, allowing remedial effort to be directed where it will produce the greatest value. If our step 1 allows us obtaining an idea of the probability of failure (estimation of disaster occurrence), the severity of the potential disaster was not yet estimated. In practice, our step 2 has consisted in designing a vulnerability framework able to support the calculation of an expected gravity level for a given situation (disaster in a specific area). Practically, we have analyzed the available literature regarding factors that are considered likely to become highly influential on demand (and particularly on the consequences of future disasters). These factors include social and economic vulnerabilities, urbanization rates and climate change.

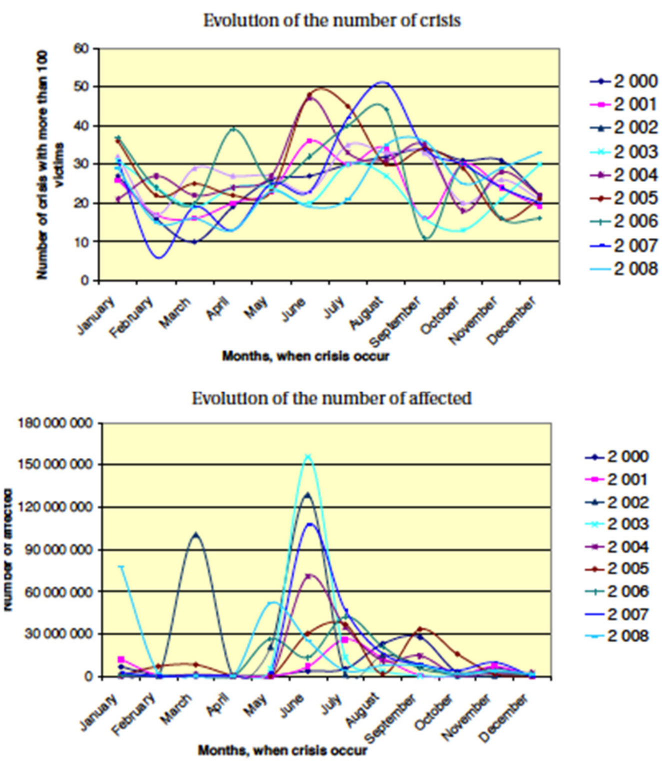

Figure 3 – Seasonality of the past disasters (period 2000 – 2008) – from (Charles, 2010)

Considering research works on vulnerability in humanitarian context (such as (UNDP, 2004; Charles, 2010)), four criteria could be retained to define the vulnerability of an area to a potential disaster (see. Figure 4):

- The Density Ratio that defines the number of people potentially impacted by the disaster. This ratio should be defined by a number of inhabitants per square kilometer.
- The Human Development Index (HDI) established by UN Nations that proposes an assessment of country achievements in different areas of human development. The value of this index is valued between 0 (low human development) and 1 (high human development);
- The Accessibility Ratio that expresses the quantity and the coverage of infrastructure available in a given area. This ratio can be valued in kilometers of road per 1000 inhabitants;
- The Telecommunication Ratio that indicates the coverage of telecommunication means in a given area. The most representative units are probably the number of mobile phones per 1000 inhabitants.

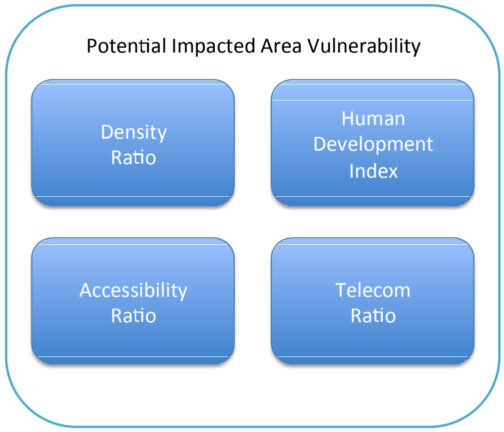

Figure 4 – Vulnerability Framework

Our proposition consists finally in comparing values associated to a potential impacted area with a set of reference values extracted from a previous disaster. These values of reference correspond to a known representative past disaster for which the consequences (victims) and the vulnerability (density, HDI, accessibility, telecommunication) are known. Based on these values and on our vulnerability framework, we can estimate, for a potential impacted area (called scenario), an expected gravity level as following:

$$G_s = G_{ref} \times V_s \quad \text{with} \quad V_s = \sum_i \left(\alpha_i \times \frac{X_i}{R_i}\right)$$

In which:

- G_s is the Expected Gravity Level (number of victims) associated to the studied scenario s (i.e. potential impacted area) ;
- G_{ref} is the Gravity Level (number of victims) of the previous reference disaster ref;
- V_s is the estimated vulnerability ratio associated to the studied scenario s;
- i is the indice of the vulnerability criteria {Density; HDI; Accessibility; Telecom};
- α_i is the weight given to each criteria ($\sum_i \alpha_i = 1$);
- X_i is the value of each criteria associated to the scenario s;
- R_i is the value of each criteria associated to the reference disaster ref.

Finally, the step 1 produces the following set of data {Impacted Area; Date; Type of Disaster; Intensity of Disaster} while the step 2 roughly gives some estimations about the needs {Quantity of products}.

Application case

In this section, we present a brief numerical application case in order to illustrate the contributions of our proposal. This instantiation is a very small part of an ongoing project that consists in designing an efficient and reactive Humanitarian Supply Chain for the response to earthquakes in Peru.

In this paper we show how Peruvian decision-makers can estimate the potential impacts of future earthquakes in their country.

Regarding step 1 of our methodology, it is possible to extrapolate historical data on Peruvian earthquakes to estimate future disasters that can occur. This forecast can allow assessing roughly intensity, localization and period of occurrence. Due to the lack of space, we do not develop this part of the method in this paper. The reader can refer to (Badal et al., 2005) or (Charles, 2010) for examples of application.

The step 2 tries to assess the potential needs through an estimation of victims that should be impacted by the forecasted disaster function of the localization and its vulnerability. From this estimation, it should be possible to dimension warehouses with resources suited to enable rapid response to this kind of disaster, such as tents and shelter kits.

Our numerical application is based on the Pisco's earthquake of 2007. This disaster of a 7.9 magnitude on Richter scale made 596 deaths. The question is how many victims this kind of event would be done if the epicenter was in Lima or in Cusco?

By applying the methodology we proposed in previous section, we obtained the results presented in the following table. We can see that the vulnerability ratio is more important in the two cases than during the Pisco's earthquake. The density ratio is particularly sensitive and explains a great part of this difference. But we can see that the Cusco vulnerability seems damaged by the three other ratios while it is not the case for the Lima disaster. Finally, the Lima case would present a number of victims (and so a quantity of needs) forty times upper than in a Pisco disaster…

Table 1 – Numerical Application

DISASTER GRAVITY CALCULATION		Lima		Cusco		Value of Reference
	Coef.	Value	%	Value	%	Pisco 2007
Density Ratio (inhab/km2)	0,4	3126	9473%	680	2061%	33
Human Development Index (%)	0,3	75	96%	65	111%	72
Accessibility Ratio (km of paved road/1000 inhab)	0,2	30	67%	14	143%	20
Telecom Ratio (mobile/1000 inhab)	0,1	1200	67%	537	149%	800
Estimated Vulnerability Ratio (Vs)			38,379		9,009	
Expected Gravity Level (deaths) (Gs)			22874		5370	596

Conclusion

Our methodology has consisted in establishing a forecast mechanism able to estimate roughly the future humanitarian relief needs. This approach is based on extrapolation (through simple regression) of past disasters in order to forecast future disaster occurrence on one hand, and on estimation of associated expected gravity level on the other hand (based on principle of FMECA). This proposition allows assessing the needs in terms of {Date; Localization; Type of Product; Quantity}.

Although our proposal constitutes a significant first step towards solving the problem of demand forecast in humanitarian context, our contribution engenders several limitations that we propose to study in our future research works. The main further research consists in assessing the quality of the forecast to confirm that the produced results are representative of to the reality. To do this, we are carrying out experiments over several past disasters (particularly in the case of pas Peruvian earthquakes) in order to validate our model. Other perspective concerns the sensitivity analysis of the criticality estimation. This analysis should include several developments to adjust: (i) the weights between the different vulnerability coefficients, (ii) the relationship between the Vulnerability Ratio, the Expected Gravity Level and the estimated demand.

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