A Systemic Process Model for Procurement Decisions in Humanitarian Logistics

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ABSTRACT

The relief organizations work in volatile environments involving a variety of actors with different skills and knowledge. The service of emergency for victims of natural disasters requires a rapid decision-making. The objective of the approach presented in this paper is to develop a Systemic Process Model (SPM) for procurement decisions in humanitarian logistics. The SPM aims to support procurement tasks of humanitarian organizations during the response phase in disaster relief. The approach provides a decision support tool using an appropriate quantitative model reflecting the specific area of humanitarian logistics processes.

Keywords

Humanitarian logistics, quantitative model, k-means, network flow problem, process models

INTRODUCTION

Emergency situations are highly unpredictable. Hence, the success of an operation depends on good logistical planning. The speed of response in an emergency is essential and depends on the logistics performance to receive, transport and deliver the supplies to the affected area (Van Wassenhove and Tomasini, 2009). In humanitarian logistics the time benefit is more important than economic benefits. The development of models and tools that can reduce the time for decision-making in order to limit the impact of natural disasters is a key issue in today's global world. Only a few quantitative approaches have been proposed regarding the procurement for humanitarian relief operations. We highlight the work of Trestrail et al. (2009), who describe a mixed-integer program (MIP) decision support tool. Alternatively, Falasca and Zobel (2011) have developed procurement decision models for humanitarian relief. They use a two-stage stochastic optimization model to provide guidance in relief operations in order to minimize expected demand shortages, as well as total procurement costs. Both works target specific situations, a general guideline for the usage of quantitative methods in disaster relief operations does not exist yet. In order to assist in this gap of research in the area of humanitarian logistics, we propose a Systemic Process Model (SPM) for humanitarian logistics. The SPM aims to support procurement tasks of humanitarian organizations. The proposed planning approaches can be configured in the preparation phase in advance of possible disasters, allowing humanitarian organizations to adapt to different crisis scenarios. This approach provides a decision support tool which uses appropriate quantitative models reflecting the specific area of humanitarian logistics processes. It is enabled by the integration of the reference task model for humanitarian logistics (RTM) presented by Blecken (2010). In order to relate the type and frequency of disasters, the quantitative model contains methods for clustering historical data and uses the k-means algorithm as a tool for pattern analysis. For the purpose of balancing the allocation of supplies the network flow problem was adapted for the quantitative model also contains the variables time, demand, capacity and the set of adequate suppliers. In order to understand and model all relevant logistics processes, the RTM needs to be analyzed and integrated within the SPM. The paper starts with a presentation of the proposed quantitative model SPM focusing on the applied k-means and network flow problem approaches. Based on these results a potential integration of the RTM into the SPM will be discussed. In the final section the broader research agenda will be discussed and a short outlook will be outlined.

In order to achieve the goal described above, a quantitative research approach will be used where, according to Cauchick (2010), this line of research the preoccupation is ensuring that there is adhesion between observations and actions in reality and the reality of the developed model. Empirical research seeks to create models that fit well to the causal relationships existing within the real problem (Coughlan and Coghlan, 2002).With the intention to understand how the method can facilitate decision support for different individuals as well as to draw general conclusions and discuss the limitations and opportunities for decision support during emergency events, the intention is to use discrete simulation. It will be attempted to align the functioning of the system in order to evaluate the proposed SPM in the management processes along a humanitarian supply chain. A methodology for arranging the activities will be defined with the main goal to reduce the time of decision-making in humanitarian operations. In this paper, two large phases will be specified and discussed. The first phase consists of the definition of the quantitative model, SPM whereas the second phase comprises the integration of the RTM into the SPM.

FIRST PHASE: SYSTEMIC PROCESS MODEL

Studies conducted by humanitarian organizations, reflect the need to improve the effectiveness of disaster response by ensuring greater predictability, accountability and partnership (Jahre and Jensen, 2010). These studies refer to the cluster approach in order to serve more beneficiaries. To check the frequency of various types of disaster in a given region can help standardizing a method to prepare for such catastrophes and to improve the decision-making in humanitarian logistics. For each cluster, the experience and knowledge can be shared. This could be the basis for the integrated planning and preparation of the logistics processes for the relief operation. In the disaster relief operations many variables need to be considered. Generally, the time variable is one the major aim to focus on. Flexible and fast decision support enables a reduced response time to meet the affected region and, consequently, result in a greater number of rescued victims. Thus, several activities aimed at managing the humanitarian supply chain, advance the decision-making process. The purpose of procurement is to ensure that the humanitarian organization has the needed material resources to meet operational requirements and operational support (Blecken, 2010). In a recent literature review only few works have been found, which use clustering methods for historical data for Humanitarian Logistics operations in natural disasters (Chu et al, 2012; Chang et al.,2010; Wan, 2012; Acosta,2011; Jahre and Jensen, 2010; Dalal, Mohapatra and Mitra, 2007), they use specific methods of grouping, for example k-means, fuzzy c-means and hierarchical clustering. These were utilized seeking to develop an analysis and categorization of the data of different events related to natural disasters. It is worth referring to the work by Jahre and Navangul (2011) where the main objective was to suggest ways to predict demand for goods and services for relief operations in Humanitarian Logistics. With the use of historical data related to humanitarian assistance information it is possible to understand and predict future demand. Referring to optimization models, we highlight the work done by Haghani and Oh (1996), who developed a multi-commodity, multi-modal network flow problem with time windows in the context of disaster relief operations. According to the authors, these models can be incorporated into a decision support system to support emergency response managers in planning for disaster relief operations. In the proposed model, a large number of extensions could be implemented in order to meet the specific needs of a given organization.

The SPM is carried out in two stages:

(a) Identification of the type of disasters by region. At this stage, an analysis of historical data is used to form clusters of disaster by region. For the standard analysis the clusters approach is being used. The clustering technique is descriptive and its purpose is to identify from a particular, given database a finite set of clusters. These are based on the similarity of the attributes of each available sample. This approach is strongly linked to automatic knowledge generated through data mining. It can be used both as an independent task in the mining process and to express the intrinsic characteristics of data as a pre-processing step (Kogan, Nicholas and Teboulle, 2006).The process of clustering is executed in the following sequence: 1st - Selection of resources, where the characteristics for the implementation of the groupings are defined and codes for each type of information are determined; 2nd - The algorithm, which will determine the form of grouping of all the data, is selected and the k-means algorithm used; 3rd - Validation of the results through criteria and appropriate techniques; 4th - Interpretation of the outcomes and integration of the result of grouping with the experimental evidence (Halkidi, Batistakis and Vazirgiannis, 2001). In general, clustering techniques calculate the partition of a matrix $[u_{kj}]_{K\times n}$ where represents the degree of which belongs of the j-th point , j = 1,...,n, and to the cluster C_k, k = 1,..., K. Thus, μ_{kj} = 1 if the point x_j belongs to C_k or μ_{kj} = 0 otherwise (Bandyopadhyay, 2011). This matrix contains the frequency of each type of natural disasters by region. The matrix then becomes the database to be explored by the K-means algorithm aiming at the formation of clusters based on the number of municipalities impacted by natural disasters. Given this context, this work contributes to Humanitarian Logistics by employing a methodology to generate profiles based on historical events of natural disasters. Therefore, the frequency of occurrences is combined with the affected municipalities in order to identify regions with similar characteristics. The aim is to further assist in the strategic coordination by defining priorities and exchanging experiences in these regions. This will allow for a standardization of a method for prevention and response in humanitarian relief operations, which also allows relief organizations to adapt and create standards for different kinds of events. The method will help the competent operational agencies in decision-making regarding the necessary training, investments in infrastructure, forecasts of demand or inventory, and partnerships.

(b) Definition of the best set of suppliers with respect to demand and delivery: It is considered that there are some types of private firm partnerships with humanitarian organizations where the organizations commit themselves to inform and update their data regularly. It should whether to use the system Cost Insurance and Freight or the system. Also, it needs to be analyzed which elements regarding cost of inventory and the modal type should be considered. Public authorities, for example, firefighters, military or aeronautics, are also considered as suppliers. Based on these considerations potential suppliers that will be activated by the humanitarian organizations during the response phase will be searched. We consider that, in practice, the demands of the affected areas are met in the shortest time possible, lest lives not be lost. The modeling should be flexible enough to consider time as variable and thus adversely consider possible delays. With this, the solution will enable the organizations to choose suppliers who deliver the supplies as quickly as possible. The selection is being made regardless of the arising costs, since, under the circumstance of lives being at risk, a timely delivery is clearly to be prioritized. Thus, the model must contain some index of penalty per missed day so that the solution procedure seeks those suppliers with product availability at the requested time, or the nearest location. We propose to model a graph where represent available suppliers, are the places of disaster and represent dates in a horizon given of *m* days. We then form a graph composed of its nodes and arcs respectively, where the set of nodes is defined by represented by pairs and the set of nodes represented by pairs The set of the arcs is defined as representing the paths between nodes as follows:

$A_1 = \{(i_1, i_2) | F_1 = F_2 \text{ and } t_2 = t_1 + 1\}$ represents flows associated with stock;

$A_2 = \{(j_1, j_2) | D_1 = D_2 \text{ and } t_2 = t_1 - 1\}$ determines the flow of penalty $A_3\{(i_1, j_2) | F_1 \varnothing D_2 \text{ any } t_2 = t_1 + d(F_1, D_2)\}$ the transport flow. The Fig 1 represents the considered graph. With this, the node of demand (places of disaster) represents the required amount of products in the disaster site on the requested day. Each node of supply (suppliers) represents the amount of the product available on that day. The goal is to determine which suppliers will supply which area so that the total cost to ship the available product (goods) across the network is minimized. Modeling to solve the problem follows the classic structure of stream networks (Kennington and Helgason, 1980), where the objective function minimizes the total transportation cost of available supply across the network. The given demand is subject to the constraint conservation of flow:

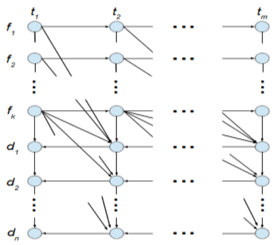

Fig. 1:Model of Proposed Graph

Minimize
$$\sum_{(i,j)\in A} c_{ij}\, x_{ij} \tag{1}$$

subject to
$$\sum_{(i,k)\in A} x_{ik} - \sum_{(k,j)\in A} x_{kj} = r_k \qquad \forall\, k \in N \tag{2}$$

$$0 \le X_{ij} \le u_{ij} \qquad \text{for each arc } i \to j \tag{3}$$

Where c_{ij} is the unitary cost per flow through the arc; $i \to j$ represents the flow through the arc ;$i \to j$ defines the net flux demanded on node *k* and u_{ij} is the given capacity in the arc $i \to j$. Considering also that if $r_k > 0$, the node *k* is a demand node with demand equals r_k; if $r_k < 0$, the node *k* is from offer with offer equal to $|r_k|$ and finally, if $r_k = 0$, *k* is a transshipment point. Through this proposed model, we determine the represented graph flow, as defining the space-time dimension. We consider the flow through a network with limited capability-arcs where each node represents a point in space and time. The objective function can fully include the important requirements in humanitarian logistics by introducing a set of appropriate penalties. When appropriate weights are chosen, it is possible to obtain a solution which satisfies all demands on a daily basis, prioritizing short delivery times above delivery costs. Additionally, the weighting could be used to further emphasize the first 48 hours after the occurrence of a disaster, which is the most critical time during disaster response. The penalty index determining the days lost influences the choice of supplier in the sense that, when the supplier does not have the requested amount for a specific date, this index of weighted penalty costs is applied to the transportation cost. Thus, the model defines those suppliers with product availability as close to the requested time as possible and considers the lowest total cost. Such an adaptation of the penalty weights further allows humanitarian organization to adapt this standardized model to different disaster situations. One exapmple for an organization using such a network flow model is the State Civil Defense, which is responsible for natural disasters in Santa Catarina, Brazil. Numerous windstorms and tornadoes exist in the state, turning the procurement process into a great challenge, as suppliers with a sufficient material quality, material quantity and ability to deliver in a short timeframe have to be chosen (Lima et.al.,2012).

SECOND PHASE: INTEGRATION OF THE SPM TO RTM.

The integration of the reference model (RTM) for humanitarian logistics developed by Blecken (2010) into the SPM ensures an adequate consideration of the humanitarian operations setting within the quantitative model. RTM is a tool that supports the standardization of tasks and functions performed by the organization and its humanitarian partners in the supply chain. The RTM was developed with more than 30 humanitarian organizations and thus reflects the real world activities in humanitarian supply chain management. As previously stated, the agility in decision-making of humanitarian organizations is a factor of great importance for the performance of humanitarian organizations. The reference processes of the RTM can figure as an adequate modeling framework for the network flow problem of the SPM. Thus, both the real world awareness of the SPM as well as the network design task become supported thanks to the integration of the RTM. The integration itself is divided into three phases. In the first phase, the RTM was analyzed in each of its tasks spanning the overall planning horizon and its functions (assessment, procurement, warehousing, transport). In the second phase new activities to RTM were proposed in order to enable the entire SPM support by the RTM. In the third phase, the referred quantitative model is suggested and applied. To exemplify the modeling of the proposed phases, two tasks are presented exemplary. The assessment task "Emergency Preparedness Plan" describes "(…) *works with basic activities that need evaluation and records any type of activity or non- emergency in humanitarian operations. In addition to identifying the types of disasters and where they can occur, the task also identifies if the organization is already performing operations in the region or if there is the possibility to perform operations.*" (Blecken, 2010) In the second phase a new activity "Analysis of Historical Data for Disaster / Region" should use historical analysis of natural disasters by region in order to identify similar regions and assist in the strategic coordination, in the definition of priorities, and the sharing of experiences. This will allow to standardize the method for prevention and response, helping the agencies in operational decision-making regarding the necessary training, investments in infrastructure, forecasting and partnerships. In the third phase, the utilization of data mining as a quantitative method is proposed as presented in first stage of the SPM. Another example could be reference task "Select Supplier" during the procurement phase. For the selection of suppliers several variables need to be considered, mainly deliverability, deliver time and quality and costs. Besides, it is necessary to consider other aspects, e.g. pre-qualification of suppliers by a comparative analysis or through a regular process of bidding. In the second phase the new activity "Definition Suppliers" humanitarian organizations determine their supply network. It is essential that the required goods reach the affected areas as fast as possible, wherefore the solution will choose suppliers who deliver the products fastest, even if the total costs are higher than offers of other providers. Based on the relevant tasks and corresponding activities adequate quantitative methods can be identified in the next step.

OUTLOOK

With the implementation of the SPM into the RTM and using the Business Process Management (BPM) concept, a methodology can be developed to assist organizations responsible for disaster response. This can be considered as an approach to improve the response time, adaptability and flexibility in humanitarian supply chains through efficient management of material and information flows along the supply chain in humanitarian operations. It is worth emphasizing that, in humanitarian logistics, the modeling can only be estimated and not fully standardized and, therefore, we need to find a modeling tool flexible enough for this reality. Widera and Hellingrath (2011) used a meta modeling tool with which the designs of process models developed by the modeler can be adjusted based on subjective and intuitive preferences of the end users. Thus, the modeler can define an organization- and user-specific perspective for the end-user. In order to understand how this model can facilitate the decision making for different individuals and to extract general conclusions and discuss the limitations and opportunities to support decision making during emergencies, it is intended to use simulation and optimization techniques that attempt to emulate the functioning of the system, to study the impact of applying the SPM model in the management of business processes throughout a humanitarian supply chain.

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