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Managing the humanitarian supply chain: a fuzzy logic approach

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Abstract

Purpose – Humanitarian supply chain management (HSCM) in today's environment faces the challenges such as information availability, inventory management, collaboration, logistics related issues and preparedness. The purpose of this paper is to evaluate the HSCM performance, considering the consequences in terms of operation, recovery and responsiveness based on the fuzzy estimates of the components presented.

Design/methodology/approach – In the study, triangulation approach was adapted for collecting data and developing a hierarchical structure for humanitarian supply chain performance assessment. The relationships between HSCM performance and its suddenness and required preparedness are depicted by cause and effect diagrams. The concepts of fuzzy association and fuzzy composition are applied to identify relationships.

Findings – In the hierarchy presented, the performance in a disaster situation, preparedness and suddenness of the situation and factors that influence the above are modeled. The taxonomy is developed for describing the relationship between factors, their likelihoods and impacts to achieve consistent quantification.

Research limitations/implications – The study considers case studies from Indian conditions; however, conditions in other countries and their practices for the disaster management may vary to certain extent.

Practical implications – A methodology presented for evaluating the exposures in considering the consequences in terms of responsiveness, operations, recovery, mitigation and emergency response. The study may help the humanitarian relief practitioners to understand the insights of the disaster situations using the proposed framework.

Originality/value – A common language for describing the different factors of HSCM is presented, which includes terms for quantifying likelihoods and impacts. The concept of fuzzy association and fuzzy composition has been applied to identify relationships between sources and consequences on HSCM performance. The use of descriptive linguistic variables is ensured through the implementation of fuzzy logic.

Keywords Building performance, Disaster response, Disaster management, Disaster mitigation, Natural disasters, Crisis management, Fuzzy logic, Performance management, Humanitarian supply chain management, Humanitarian assistance

Paper type Research paper

Introduction

In the past two decades, our world has faced several hundred disasters. On the basis of analysis of the increasing trend in the past 100 years natural disasters are expected to increase by five fold in the next 50 years (Thomas and Kopczak, 2005). When the system fails to effectively respond during disaster by using the regular resources and conditions and requires new strategies, it turns into crisis (Tomasini and Van Wassenhove, 2004). However, an effective humanitarian supply chain (Van Wassenhove, 2006) effort can respond quickly with the right amount of resources at the right place and time, which ensures that more lives are saved (Van Wassenhove, 2006). Occurrence of disasters has brought the attention of various academicians and practitioners to the humanitarian

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operations (Kovacs and Spens, 2011); although not very significant, theoretical or empirical studies applying the supply chain principles in the specific humanitarian supply chain (HSCM) stages have been found (Cozzolino *et al.*, 2012).

Disasters cause social and psychological harm among people (Nirupama *et al.*, 2015). It damages the physical infrastructure including transport infrastructure, i.e. railway tracks, roads, bridges and air fields, as well as electricity networks and communication infrastructure. The major challenge in the disaster situation is the uninterrupted supply of timely relief materials including food and financial and medical aid. However, it is very difficult to predict and identify the major challenges of the suddenness of demand occurrence, timeliness of deliveries and scarcity of resources (Kovacs and Spens, 2009). To be able to deal efficiently with these challenges, an effective supply chain system for humanitarian relief is needed.

In humanitarian relief logistics, it is important to optimize the flow of supplies with their distribution networks (ROH *et al.*, 2013). Mainly in case of natural disasters, most of the local infrastructure and inventory of supplies are destroyed, and what can be used as the part of response are the small amount of remaining and sometimes the partially destroyed supplies (Holguín-Veras *et al.*, 2012). Flow of the crucial resources such as food, medical aid and shelter is very important (Argollo da Costa *et al.*, 2012). They are subject to three separate parts of the relief distribution system, i.e. the supply point, which is the point of collection, the demand point which is the devastated area and the transportation (Roh *et al.*, 2013).

In the above discussions, it is clear that the assessment of the performance in humanitarian supply chain is a complex subject, shrouded in uncertainty and vagueness. In this paper, a scheme for classifying the responsiveness level is described, including terms of likelihood and impacts. Fuzzy set theory is used to represent the heuristic knowledge of the stake holders. The relationships between preparedness, the related factors and their consequences are represented. The concepts of fuzzy association and fuzzy composition are applied to identify the relationships between the factors and the consequences. A methodology for assessing the performance is presented, which considers the consequences in terms of responsiveness, operations, recovery, mitigation and emergency response based on fuzzy estimates.

Literature review

Beamon and Balcik (2008) described the study of humanitarian relief chain as an important domain for supply chain which needs more attention from the supply chain practitioners. In an extensive review work by Adriana *et al.* (2012), Kunz and Reiner (2012) and Leiras *et al.* (2014), a detailed humanitarian logistics (HL) work is presented, which aims to identify trends in HL and suggests some directions for future research. Humanitarian supply chain includes all upward and downward activities and members involved from the source of the aid and resources to the disaster victims, whether linked directly to the benefits of satisfying demand (Scholten and Scott, 2010; Oloruntoba and Gray, 2006; Ernst, 2003). The supply network during disasters is huge and complicated, which consists of numerous players and thus creates difficulties in coordination (Ergun *et al.*, 2009). Different organizations and different situations require diverse supply chain designs and strategies (Beamon and Balcik, 2008). Humanitarian efforts interact with operational, social, legal and environmental challenges (Pathirage *et al.*, 2012). The system requires interdependency and integration of efforts (Espada *et al.*, 2015). It is very important to have proper coordination both vertically, i.e. with the various members in the supply chain from upstream to downstream and horizontally, i.e. among the actors within the area of operation (Jahre *et al.*, 2009, Bealt *et al.*, 2016; Noori and Weber, 2016).

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Logistics consists of the managed flow and storage of goods, services and information from a point of origin to a point of consumption in an efficient manner (Bowersox and Closs, 1996; Ballou, 1999). Vega and Roussat (2015) explored the role of logistics service provider in relief supply chains. A resilient approach (Sheffi, 2005) in the logistics system is required to make the supply chain more effective, and to help in recovering from the disaster effect in a faster and responsive way (Jahre *et al.*, 2016). Resilience is driven by visibility, flexibility and collaboration (Mandal *et al.*, 2016).

A collaborative supply chain focuses on information sharing, goal congruence, decision synchronization, incentive alignment, resource sharing, collaborative communication and joint knowledge creation (Cao *et al.*, 2010). McLachlin and Larson (2011) state that, in general, there has been a lot of criticism of humanitarian community for their lack of coordination and collaboration. Balcik *et al.* (2010) described that factors like inherently chaotic post-disaster relief environment, involvement of plenty of different actors in disaster relief and the lack of sufficient resources contribute to coordination difficulties in disaster relief. Establishing communication is a major challenge during crisis (Helsloot, 2005). Besiou *et al.* (2011) applied system dynamics for addressing the HSCM issues. Nitesh Bharosa *et al.* (2010) have described the importance of information sharing for establishing coordination during disasters. They have combined information sharing with coordination in multi-agency disaster management context, where they have discussed the community level issues, agency level issues and individual level issues.

Paton (2003) described preparedness as an essential requirement to sustain individual resilience. It is important to improve preparedness to make the supply chain more responsive to the disasters (Tomasini and Van Wassenhove, 2009; Jahre *et al.*, 2016). Hale and Moberg (2005) emphasize on disaster preparedness to reduce the supply chain disruptions caused by the unpredictable and inevitable external events.

Characterization of humanitarian supply chain management factors

Characterization of HSCM is important for the purpose of assessment and analysis. The responsiveness in the disaster situation is influenced by the preparedness and suddenness of the disaster. The preparedness is influenced by factors such as logistics, collaboration among related parties and availability of information. The suddenness, on the other hand, depends on the type of disaster and previous information. An assessment of the probability or likelihood of the factors and their impact is needed. The key attributes of the factors are likelihood and severity.

The assessment of the factors is often highly subjective, and the decisions taken are influenced by the decision makers and their desire to avoid poor performance. Many of the related factors are not well defined and are not easy to quantify. Very often judgement and heuristic rules are used to combine these factors. The subjective opinion and imprecise non-numerical definition of the likelihood adds to this complexity. Therefore, a common language for describing likelihood and severity is necessary to achieve a consistency in any type of quantification. The severity should be considered in terms that are near to the objectives at the time of assessment and can be expressed through performance measures.

Humanitarian supply chain issues: insights from Uttarakhand (India) disaster

India has suffered a lot from natural disasters. The Himalayan terrain, especially in Uttarakhand, is highly prone to earthquakes, floods, landslides and natural fires (Ganguly and Rai, 2016). However, the strike of flash floods and cloud burst in June 2013 also named as Himalayan Tsunami (CNN, 2013) was one of its kinds, which was never experienced before by the inhabitants in their lifetime. The disaster was an eye-opener for the authorities

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to be more prepared in the future for such kind of calamities. It defied all the government preparations and claims and revealed the weaknesses of the system. A more improved humanitarian supply chain framework to meet similar challenges in the future requires a separate attention on the major issues faced during such situations including the Uttarakhand disaster.

The study was done in the affected regions in Uttarakhand, and effort was to assess the ground level challenges faced throughout the disaster. During our study, we first adapted the triangulation approach (Jack and Raturi, 2006). We created a triangulation of the respondents, who we interviewed and whose responses helped us in building our model toward the proposed solution of humanitarian supply chain. The key respondents forming triangulation were: disaster management authorities, armed forces and non-government organizations (NGO), as shown in Figure 1. The authorities/agencies were National Disaster Management Authority (NDMA), National Disaster Relief Force (NDRF) and Indo-Tibetan Border Police (ITBP).

Availability of information

Information is the common denominator of all the disaster prevention and response activities that are sought in the form of – timely description of the happening, its aftermath requirements and the gaps in the national capacity, which result in decision-making by the rescue staff having an expectedly lasting impact (Bui *et al.*, 2000). Information plays a vital role in the humanitarian operations (Figure 2). It is always the first information that attracts the first humanitarian relief response. The government takes necessary steps to manage the disaster based on the first information from the local community. It is after this that media and authorities communicate with the public and make them aware about the situation and actions taken.

Preparedness

Preparedness is the phase consisting of various operations and strategy formulation activities before the disaster strike to confront its challenges, where various mechanisms for physical network, communication and information system and collaboration are developed (Cozzolino, 2012). In India, though the government has made a lot of effort to control the disaster situations, it has miles to go in terms of preparedness. Apart from the discussed challenges, there is the requirement of capacity building and training of manpower. During Uttarakhand disaster, low capacity was a major constraint which slowed the rescue and

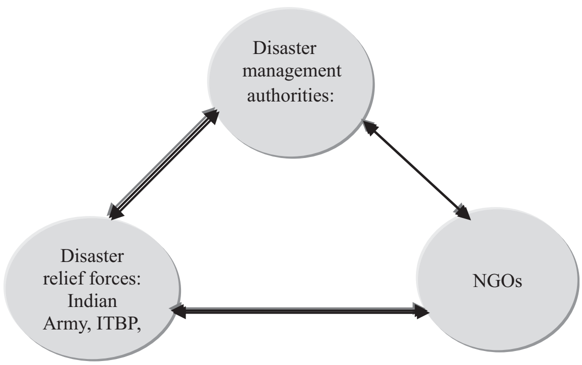

Figure 1.
Triangulated respondents

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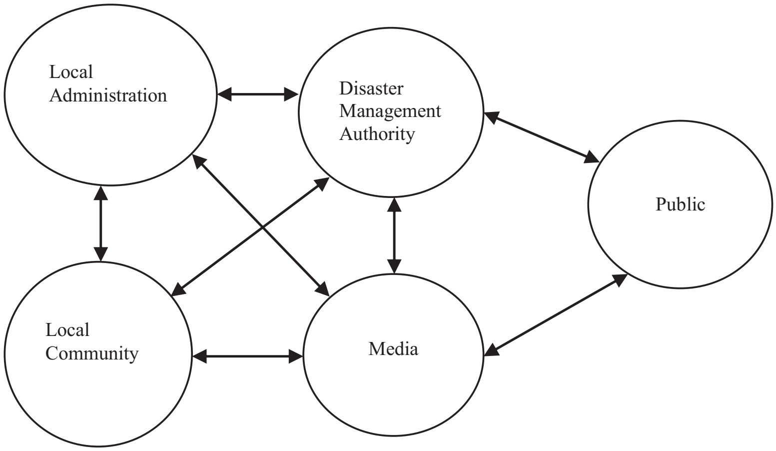

Figure 2.
Information flow during the disasters

relief work. Although, a lot is said on preparedness and capacity building in the policy documents of government and NDMA but practically disasters are responded once they have struck, i.e. based on the requirements of the situation. However, the response would be better if preparation is made well in advance, which lacks in the studied system.

Logistical issues

Logistics includes the process of planning, executing and monitoring the efficient flow and storage of resources and information from point of origin to point of consumption (Thomas and Kopczak, 2005). During disasters when there is the large amount of logistical infrastructure damage as well as space and setup constraints for the warehousing, responsiveness of the humanitarian supply chain is highly affected. In India, where logistics network still needs to be improved, in disaster situations, it creates a huge challenge for the humanitarian supply chain actors. From the warehouses, the supplies are either directly sent to the affected areas or it is sent to the onsite temporary storages which are created at the nearby less affected areas for a short duration (Figure 3). Materials are collected at these temporary storages from where they are distributed through available limited means of transport such as helicopters, which can create a passage and move in the most affected

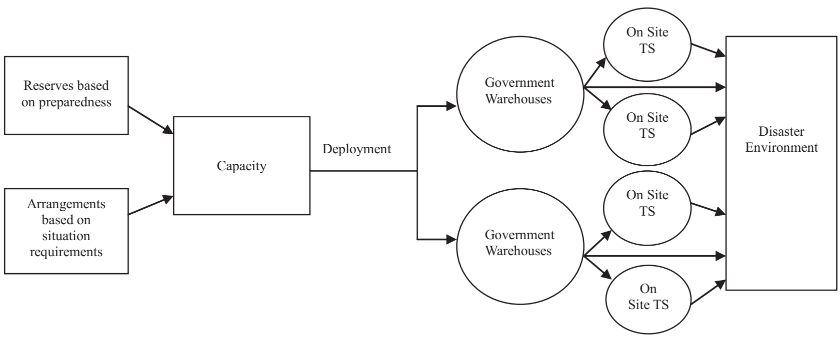

Figure 3.
Logistics in disaster situation

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areas. Some less affected regions where the regular transport vehicles can enter, warehouses have an option of direct supply in those areas.

Collaboration

There are various independent bodies and organizations including aid agencies, donors, NGOs, governments, military and logistics providers (Kovacs and Spens, 2007) who are actively involved in relief works in a disaster situation. All the organizations work separately guided and governed by their respective independent leaderships. The major challenge that arises here is related to the collaboration and coordination among them (Akhtar *et al.*, 2012). Although, these separately working organizations vary in terms of their respective objectives, but they complement each other and a coordinated effort can make the supply chain more responsive (Figure 4). Responsiveness of the supply chain toward meeting the needs of its beneficiaries can be improved at the same or even lower costs if there is cooperation among the various phases of the supply chain (Swann, 2010).

The above discussion focuses on the various issues and challenges in the humanitarian supply chain and is depicted in Table I.

The necessity is creating a strategic fit between the suddenness of disaster, the related preparedness and responsiveness of supply chain. Degree of predictability of strike should match with the degree of responsiveness. A strategic fit between disaster type and the response type is very crucial. A mismatch will create a gap which will result in more humanitarian loss. A sudden strike of disaster with zero predictability such as Uttarakhand disaster requires the immediate attention and fastest possible response. The reserved resources with the disaster management authorities and organizations play very important role in responding to these kinds of situations. Thus, it is important to address the relationship and interaction among the factors and develop a model to assess the HSCM performance.

A fuzzy risk analysis model

The relationships between HSCM performance and preparedness are depicted by cause and effect diagrams. The concepts of fuzzy association and fuzzy composition (Durkin, 1994) can be applied to identify relationships. Similar concepts have been used by Tah

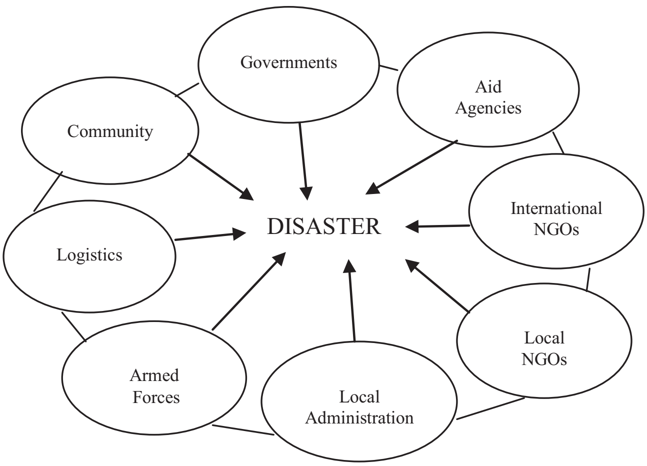

Figure 4.
Key players in disaster relief operations

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Issues	Observations
Information	Dependence on the local community
	Limited means of information sharing
	Vulnerability affects information sharing
	Initial information through local community
Preparedness	There is the challenge of available low capacity
	Trained manpower is insufficient in availability
	Unavailability of enough resources during disaster
	Dependence on the varying government policies
	No ready-made solutions available
	Existing policy is to prepare according to situation and provide situation based response
Logistics	Challenges related to infrastructure
	Limited means of logistics alternatives
	Restricted flow and storage of resources
	Increased dependability on the situation
Collaboration	Lack of unified command
	Separate organizations make their separate decisions, i.e. independent from others
	Low coordination and collaboration creating limited response
Disaster type	No specific supply chain principle suggested or applied so far for a specific disaster type
	No strategic fit between the disaster types and the supply chains required
Other limitations	Inability to respond despite being prepared
	Priority of allocation of resources
	Priority of responding

Table I. Observations based on various humanitarian supply chain issues

and Carr (2000) for risk assessment in construction projects. In the hierarchy represented in Figure 5, the top node represents the performance in a disaster situation; the second level represents preparedness and suddenness of the situation while the third level represents the factors that influence the above. The dependence link represented by the directed arcs shows the cause and effect relationships. The main objective is to evaluate the risk exposures considering the consequences in terms of responsiveness, operation, recovery and emergency response.

A disaster acts as a disturbance which affects the functional behavior of the system in terms of responsiveness. The approach to HSCM performance taken here assumes that several factors influence preparedness and suddenness of the situation, which in turn causes change in the HSCM performance. By analyzing the causality between the HSCM performance and its ultimate effect on responsiveness, the changes induced can be determined.

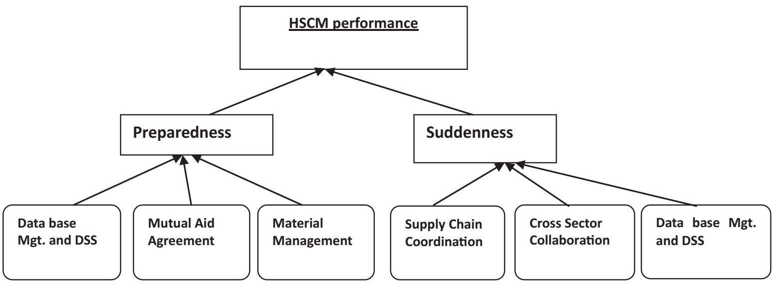

Figure 5. Identification of cause–effect relationship

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Fuzzy theory

Linguistic expressions such as high, medium, low, etc., are usually used to represent risk. Therefore, scientific and engineering domains have widely used fuzzy-based approach to risk assessment in the past. Fuzzy logic could quantify imprecise data as shown by Kosko (1993) through approximate linguistic expressions – high, good, bad, etc. Unlike a classical set (crisp set) which defines membership of elements bivalent as either member or nonmember, a fuzzy set uses a membership function to define degree of membership in 0 to 1 range (fuzzification).

As discussed about different factors of HSCM in previous sections, the causality between preparedness, the related factors and their consequences can be determined. It is imperative to develop a common language for describing the likelihood and severity so as to achieve consistent quantification. The terms for quantifying likelihoods may be defined as shown in Table II.

The severity should be considered in terms that are as close as possible to the objectives at the time of assessment. The severity terms are expressed in Table III. The values are only indicative, and the actual values should be determined by the objectives during assessment.

Let a relationship exist between the likelihood of occurrence L, the severity V and the resultant effect E. This can be represented by a double premise rule such that:

$$\text{IF L and V Then E} \quad (1)$$

Many such relationships may exist with varying values of L, V and E. Fuzzy associative memories (FAMs) are used to represent such relationships using the method suggested by Kosko (1993). This involves assembling two FAM matrices M_{LE} and M_{VE}. This is done to relate each premise to the conclusion for each of the two premises in the rule. For a factor with likelihood L' and severity V', the effect on E can be found independently through composition, thus:

$$L'^{\circ} M_{LE} = E_{L'} \quad (2)$$

Table II. Standard terms for quantifying likelihood

Likelihood	Description
Very very high	*Absolute certainty*
Very high	Expected to occur
High	Very likely to occur
Medium	Likely to occur
Low	Unlikely to occur
Very low	Very unlikely to occur
Very very low	*No possibility of occurring*

Table III. Standard terms for quantifying severity

Severity	Responsiveness	Operations	Recovery mitigation	Emergency response
Very high	*>20% above target*	*Very Poor*	*Very Poor*	*>20% above target*
High	10% <target <20%	Poor	Poor	10% <target <20%
Medium	5% <target<10%	Average	Average	5% <target<10%
Low	1%<target<5%	Above Average	Above Average	1%<target<5%
Very low	1%<target	OK	OK	1%<target

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$$V'^{\circ} M_{VE} = E_{V'} \tag{3}$$

The fuzzy logic intersection operator is used to join or recompose the two induced fuzzy sets such that:

$$E' = E_{L'} \wedge E_{V'} \tag{4}$$

This gives the effect E′ for an individual FAM. If m rules exist then the total effect E can be determined by aggregating the individual effects using a fuzzy union operator, resulting in:

$$E' = E'_1 \cup E'_2 \cup \ldots\ldots.E'_m \tag{5}$$

The value of E is the effect with a defined likelihood and severity value. The traditional technique of using a fuzzy union operator (t-conorm) for aggregating the effect of various factors produces an average value and dilutes the predominant factors. It is quite possible that effect of single factor of magnitude "high" will be lower than one effected by two factors, one of magnitude "low" and one of magnitude "high". Thus, any thinking that more factors leads to comparatively less impact is wrong. There are many different t-conorm formula for performing fuzzy union aggregation (Klir and Folger, 1988). Each of them may produce different resultant fuzzy sets, but the end result post defuzzification will always be the same, as it is an average of the aggregate value. Therefore, it is necessary to investigate an alternative method of calculating the total effect of different factors. The value of the factor with the greatest effect, E_{max}, would provide a starting point in this calculation, such that:

$$E_{max} = \max(E_1, E_2, \ldots\ldots.E_n) \tag{6}$$

There are other methods of selecting, comparing and defuzzifying fuzzy sets depending on various criteria. Here, it is considered that the factors which has greatest impact, is a good starting point for the prototype system. Next, the changes the factors induce in the final consequence, i.e. the responsiveness are considered. For a severity effect computed in equation (6), the changes in Responsiveness R, Operations O, Recovery and Mitigation RM and Emergency Response ER induced on a task can be represented by following rules:

$$\text{If E Then R} \tag{7}$$

$$\text{If E Then O} \tag{8}$$

$$\text{If E Then RM} \tag{9}$$

$$\text{If E Then ER} \tag{10}$$

There exist many such relationships with varying values of R, O, RM and ER. These relationships are rules that can be obtained from the real situation and can be represented as fuzzy associative memories (FAMs). This involves assembling FAM matrices, M_{ER}, M_{EO} M_{ERM}, M_{EER} for each rule. Given the effect $\ddot{E}$, the changes induced in R, O, RM and ER are *R′, O′, RM′* and *ER′*, respectively, and are determined by composition such that:

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$$E'\circ M_{ER} = R' \quad (11)$$

$$E'\circ M_{EO} = O' \quad (12)$$

$$E'\circ M_{ERM} = RM' \quad (13)$$

$$E'\circ M_{EER} = ER' \quad (14)$$

If there are n FAMs for each effect then R, O, RM and ER can be determined by performing the fuzzy union of the resultant fuzzy sets, such that:

$$R = R'_1 \cup R'_2 \cup \ldots\ldots.R'_n \quad (15)$$

$$O = O'_1 \cup O'_2 \cup \ldots\ldots.. O'_n \quad (16)$$

$$RM = RM'_1 \cup RM'_2 \cup \ldots\ldots.. RM'_n \quad (17)$$

$$ER = ER'_1 \cup ER'_2 \cup \ldots\ldots.ER'_n \quad (18)$$

where the final consequence is affected by many factors, the traditional fuzzy technique for calculating the total changes to Responsiveness R, Operations O, Recovery and Mitigation RM and Emergency Response ER is to perform a fuzzy union. However, this technique tends to produce average results, which are not suitable, and so the values of R, O, RM and ER, which have the greatest impact will be used, such that:

$$R_{max} = \max(R_1, R_2, \ldots\ldots.R_n) \quad (19)$$

$$O_{max} = \max(O_1, O_2, \ldots\ldots.O_n) \quad (20)$$

$$RM_{max} = \max(RM_1, RM_2, \ldots\ldots.RM_n) \quad (21)$$

$$ER_{max} = \max(ER_1, ER_2, \ldots\ldots.ER_n) \quad (22)$$

Case example

An example for the case is illustrated using application of the fuzzy risk assessment model. The first step is the identification of the sources using a HSCM structure map as shown in Figure 5. In the figure, it is shown that preparedness and suddenness are affecting the responsiveness. In the bottom hierarchy, the risk factors are shown that tender preparedness and suddenness active. Preparedness is affected by the factors like data base management, mutual aid agreement and material management. On the other hand, suddenness is affected by the factors like supply chain coordination, cross-sector collaboration and database management. Although these factors affect the preparedness and suddenness both in the

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site as well as the control center, but they have been defined as separate factors, each of which is treated independently. This allows the effects of the same factor to be modelled more realistically. Database management and decision support system (DSS) have been identified as a risk factor for both preparedness and suddenness.

In this paper, we maintain that a fuzzy logic-based approach to HSCM might represent a valid tool in supporting a decision-making process. One of the most salient features of fuzzy logic is that subjective information that is available only as a linguistic statement (this is frequently the case in disaster) can easily be made quantitative. We maintain that fuzzy set theory can provide a valuable tool to cope with three major problematic areas of humanitarian logistics: imprecision, randomness and ambiguity. As far as imprecision is concerned, it provides a powerful tool to weigh the importance of the criteria. As far as randomness is concerned, it is more effective than probabilistic approaches in that the disasters should not use prediction based solely on previous events, as each case is not repeatable. As far as ambiguity is concerned, it copes better than other methods with the treatment of linguistic variables. The fuzzy associative memories that relate the factors likelihood and severity are shown in Table IV. This shows the rule set which defines the likelihood and severity with its magnitude value. The letters L, M and H in the table refer to the linguistic variables low, medium and high, respectively. In our case, we present an exhaustive set of the rules, which were derived logically on consultation with the experts. All possible combinations of interactions effects are presented and effort made to present all the rules, which are mathematically possible. The fuzzy associative memories which relate the risk magnitude value with the changes it induces are shown in Table V. These FAMs are elicited from the important stakeholders as discussed in the earlier section. However, these FAMs must be continuously refined through experience gained over time. The FAMs are context dependent and the current context is the experience from the recent deluge in the Uttarakhand region in India.

For the current example, the membership functions for the linguistic terms set to be used as shown in Figure 6 and the corresponding fuzzy sets are defined as:

Severity	H	M	M	MH	H	H
	MH	LM	M	M	MH	H
	M	LM	LM	M	M	MH
	LM	L	LM	LM	M	M
	L	L	L	LM	LM	M
Effect		L	LM	M	MH	H
				Likelihood		

Table IV. Bank of FAM rules

No	Description	Consequence	Change in responsiveness	Change in operation	Change in recovery and mitigation	Change in emergency response
1	Preparedness	Low	Very low	Very low	Very low	Very low
		Medium	Low	Low	Very low	Very low
		High	Medium	Medium	Very low	Very low
2	Suddenness	Low	Low	Low	Low	Low
		Medium	Medium	Medium	Low	Medium
		High	High	High	Medium	High

Table V. Subjectivity determined FAMs for consequences and the effect of the performance measures

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- Low = L = {1, 0.67, 0.33, 0, 0, 0, 0}
- Low to Medium = LM = {0, 0, 0.5, 1, 0.5, 0, 0, 0}
- Medium = M = {0, 0, 0, 0, 0.5, 1, 0.5, 0, 0}
- Medium to high = MH= {0, 0, 0, 0, 0, 0.5, 1, 0.5, 0, 0}
- High = H = {0, 0, 0, 0, 0, 0.33, 0.67, 1}

Membership functions reflect the extent to which a certain real number is associated with each of the subjective categories. Hence, the shape of the membership function must be carefully chosen. Many different shapes of membership functions are proposed in scientific literature. The triangular fuzzy set membership corresponds to the fuzzy sets of input variables, namely, low, medium and high. By encoding the research specific data into a triangular membership function, reasonable and acceptable results are obtained. The second step involves the subjective assessment of the likelihood of occurrence and severity of the individual factors as indicated in the Figure 7. The third step involves computing the severity due to the effects of the factors which have been assessed previously. Equations (1)-(5) are applied in computing the magnitude and equation (7) is used to compute the total effect of all the factors. The results are shown in Figure 4 in italics. The fourth step involves computing the changes induced using equations (7)-(18). The results of the computation are shown in Figure 7 in bold.

Conclusion

Humanitarian supply chain has been facing the challenges in terms of availability of information, preparedness, collaboration, unpredictability of various types of disasters and inability of the systems to respond to the particular situation. These are crucial issues to be managed by taking the right steps in the supply chain and improving the situations where required. In this work, a hierarchical structure has been proposed, which can facilitate the identification of factors and their classification in HSCM. The taxonomy is developed for describing the relationship between factors, their likelihoods and impacts to achieve consistent quantification. The relationship is depicted first through a cause and effect diagram. The concept of fuzzy association and fuzzy composition has been applied to identify relationships between sources and consequences on HSCM performance measures. The use of descriptive linguistic variables is ensured through the implementation of fuzzy logic. Finally, a methodology presented for evaluating the exposures in considering the consequences in terms of Responsiveness R, Operations O, Recovery and Mitigation RM and Emergency Response ER.

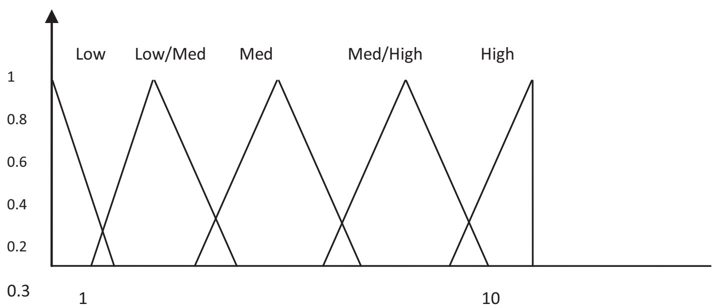

Figure 6.
Membership functions

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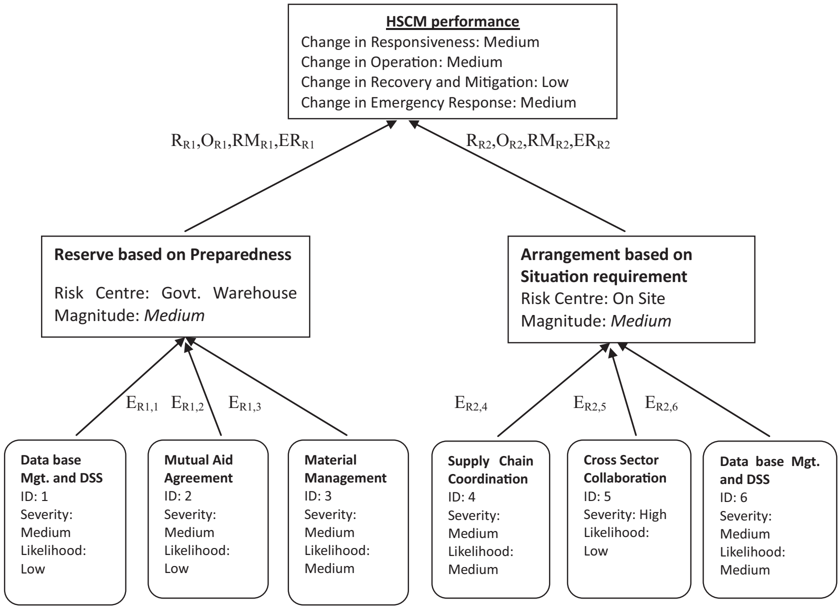

Figure 7.
Performance assessment of HSCM

In the future course of action, the prototype of the system is to be developed in a software package. The other issue is to consider extra factors which affects HSCM performance and accommodating them. The extra effect of each of these factors has to be investigated. Within the system, the maximum effect is likely to be achieved with a finite number of factors and calculations can be performed using both algorithms and heuristics. The other scope of work is to determine the nature of the fuzzy associative memories which link performance measures with the magnitude of the sources. This may be context specific, but a repository of standard values specific to a particular context may be helpful. This will help in development of a more dynamic system which can be both generic and scalable.

The research has considered only the natural disasters, not the manmade ones. It also takes the case examples from Indian conditions, specially the disaster in Uttarakhand; however, the conditions in other countries and their practices for the disaster management may vary to certain extent. The research initiates further work in this area on the various issues explored in the study. There is the scope of paying separate attention on each of the issues discussed. The study can be useful to the humanitarian relief practitioners to understand the insights of the disaster situations using the proposed framework. The study also aims at helping the participating agencies and policy makers in strategizing the prompt response to the disaster environment and minimizing the damages to the social system.

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