A framework for performance measurement of humanitarian relief chains: a combined fuzzy DEMATEL-ANP approach

S. Ali Torabi[1] (satorabi@ut.ac.ir), Mohsen Aghabegloo[1] and Amirhossein Meisami[2]
1: Department of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran

2: Department of Industrial and Systems Engineering, Texas A&M University, USA

Abstract
Given a competition among humanitarian organizations, this paper proposes a systematic framework for measuring humanitarian relief chain's performance. After categorizing some performance indicators, a hybrid method combining fuzzy DEMATEL and fuzzy ANP is developed. An illustrative example is also provided to show how the framework can be implemented in practice.

Keywords: Humanitarian organizations; Performance measurement; Fuzzy DEMATEL-ANP.

Introduction
The number of people affected by natural disasters is rising dramatically and at the same time, the competition among humanitarian organizations (HOs) to provide required financial and non-financial supports is also expanding. In such competitive environment, the importance of humanitarian organizations' performance has also an increasing trend since if they cannot do well in the eyes of media, donors and government, they will lose their reputation and donors and without financial support they will break soon (Davidson, 2006).

Logistics operations have always been an important part of humanitarian aids, to the extent that logistics efforts account for more than eighty percent of disaster relief. Humanitarian logistics includes the planning and preparedness, procurement, transportation, inventory pre-positioning, distribution and recipient satisfaction for which humanitarian relief chains (HRCs) are required to be established with the aim of ''getting the right relief items to the right places and distribute to the right people at the right time''.

As a result of more recent disasters (e.g., the 2010 earthquake in Haiti and the 2011 floods in Pakistan), humanitarian logistics has received increasing interest both from logistics academics and practitioners. The efficiency and effectiveness of humanitarian aids after a disaster is highly dependent to the ability of humanitarian logisticians to procure, transport and distribute relief supplies to beneficiaries in the best way.

A major conclusion from the literature is that many of the tools and techniques used in commercial supply chains, despite the challenges posed by the differences, can be applied in the humanitarian arena. Therefore, just as the science of logistics and supply chain management has become critically important for commercial sectors, it is also becoming very essential for humanitarian logisticians (Van Wassenhove, 2006).

Generally speaking, supply chain performance measurement is a multi-criteria problem by incorporating various performance dimensions such as resources, outputs, and flexibility. For this, several performance metrics are used that are typically categorized in different ways. For example, they can be classified into the strategic, tactical, and operational levels according to their scope and the timeframe covered by each measure. They may also categorized to internal process-oriented, customer-oriented, learning and growth-oriented and financial measures in accordance to different perspectives of the balanced scorecard (BSC) framework.

There are a number of frameworks proposed for performance measurement in commercial supply chains (e.g., see Bhagwat and Sharma, 2009) among them the BSC framework is the most applied one. Notably, with the BSC framework, an organization can manage its performance through four strategic perspectives: (a) learning and growth, which focuses on an organization's ability to change and improve for achieving its vision, (b) internal process, which focuses on the business processes that an organization must excel at in order to satisfy its shareholders and customers, (c) customer, which focuses on the strategy for creating value for customers, and (d) financial perspective, which focuses on the strategy for satisfying the shareholders. Measuring performance in humanitarian relief chains (HRCs) is considerably different than commercial supply chains. However, surprisingly there is no systematic framework for measuring and managing the performance of whole HRC by taking into account the most important and critical quantitative and qualitative measures.

To fill this gap and in order to implement an effective performance measurement framework for humanitarian relief chains, in this study, the concerned performance indicators are first categorized in some classes and then, a hybrid MCDM method by combining the fuzzy DEMATEL and fuzzy ANP techniques is developed. Furthermore, the total performance of a HRC which can be used for comparing HRC's performance with future efforts and other HRCs, is calculated in the proposed model based on the categorized indicators.

Literature review

In the last decades there have been wide efforts in the context of supply chains and because of their complexity and multi-dimensionality, many authors have emphasized controlling and therefore, measuring performance of supply chains (Allesina et al., 2010). However, there still are few attempts in collecting appropriate measures for evaluating the supply chains performance (SCP) in a systematic way and there is no unanimous manner in categorizing them. Some authors classify the indicators according to their time scope, i.e., strategic, tactical, and operational ones, some other consider what they measure and so on (Shepherd and Günter, 2006). Therefore, more studies in identifying appropriate metrics for measuring performance of supply chains are needed while filling the lack of a balanced approach and making a clear difference between indicators at strategic, tactical, and operational levels (Gunasekaran et al., 2001).

(Beamon, 1999) emphasized the inadequacies of a supply chain performance measurement system in which there is just a single performance measure and developed a performance measurement system involving several resource, output, and flexibility based measures. (Gunasekaran et al., 2001) discussed some performance metrics which have the most impact on SCP, and then categorized them into strategic, tactical, and operational levels and also identified whether they are financial or non financial. In another classification they represented the metrics at four basic links of a supply chain i.e., plan, source, make, and deliver according to SCOR model.

Since there is a large number of metrics used for evaluating SCP, and because of the complexity derived from the hierarchical nature and dependency of the indicators, employing some methods for prioritizing and modeling the metrics are needed (Arzu Akyuz and Erman Erkan, 2010). In this respect, (Bhagwat and Sharma, 2009) used AHP to rank strategic, tactical, and operational metrics and attributes where BSC perspectives were used as alternatives in a hierarchical manner. They also applied a goal programming model based on the prioritization derived from the AHP for performance improvement. Some papers propose a fuzzy AHP model for evaluating the SCP (for example see: Adel El-Baz, 2011; and Ganga and Carpinetti, 2011). (Kocaoğlu et al., 2011) criticizes some disadvantages of AHP and applies TOPSIS method with AHP to rank different scenarios. The model is based on SCOR model. A hierarchical conceptual model for evaluating the SCP is proposed in (Najmi and Makui, 2011). They apply the AHP to rank the metrics and Decision Making Trial and Evolution Laboratory (DEMATEL) method for identifying the interdependency between them.

As the circumstances in which a humanitarian relief chain operates are more complex than a commercial supply chain, measuring its performance is much more complex. However, researches for measuring performance of humanitarian relief chains are very limited and there is still no comprehensive and systematic framework for doing do. (Beamon and Balcik, 2008) based their research on NGO's relief chains by focusing on relief activities arising from "large-scale emergencies". They compared for-profit and nonprofit organizations and applied some performance metrics in three categories i.e., resources, output, and flexibility for measuring performance of humanitarian relief chains. (Schulz and Heigh, 2009) set some indicators for each of the four perspectives of BSC based on some interviews with IFRC's Logistics and Resource Mobilization Department's (LRMD) staffs and developed an improved performance measurement system through feedbacks received from RLUs (Regional Logistics Units). Critical success factors in humanitarian aid supply chains were studied in (Pettit and Beresford, 2009). They discussed the relevance of some commercial supply chains' CSFs that could be used in humanitarian aids as well. (Zhou et al., 2011) considered twenty factors out of them, identified five critical success factors using fuzzy DEMATEL method for continuous improvement purposes. (Davidson, 2006) defined four key performance indicators, i.e., Appeal Coverage, Donation-to-Delivery, Financial Efficiency, and Assessment Accuracy for humanitarian aid supply chains through comparing them with commercial supply chains.

Proposed Performance Measurement Framework for HRC's

This study proposes a hybrid fuzzy MCDM approach based on fuzzy DEMATEL and fuzzy ANP techniques for measuring performance of humanitarian organizations. Fig. 1 depicts the general view of the proposed HRC's performance measurement framework.

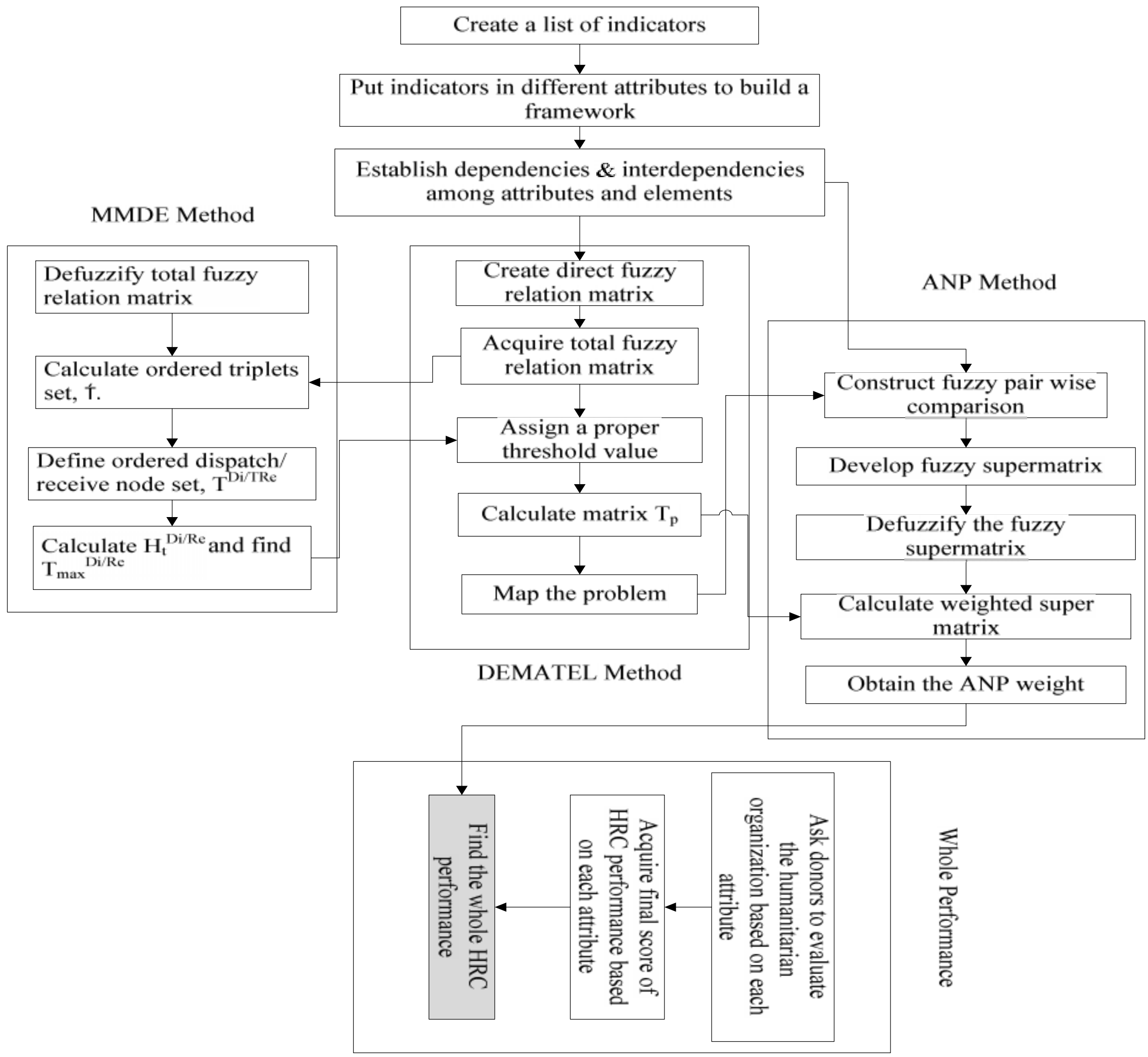

Figure 1- Proposed Performance Measurement Framework for HRCs

Brief explanation of the main steps of the proposed framework is as follows:

Gathering appropriate indicators

A number of relevant indicators to HRC's performance should be gathered according to literature and then classified according to SCOR model as it is shown in tables 1 and 2. Also, lots of interdependencies among the indicators have been discussed in the literature for which implementing a MCDM approach for selecting the most important interdependencies is needed.

Table 1- HRCs' indicators

P1 : Reliability		P2 : Responsiveness	
Delivery Performance	C_1 :delivery lead time	Order fulfillment lead times	C_{12}: purchase order cycle time
	C_2: Response to number of urgent deliveries (Tie)		C_{13}: Supplier rejection rate
	C_3: Number of faultless deliveries		C_{14}: supplier lead time
			C_{15}: Stock out probability
	C_4: Number of on time deliveries	C_{16}: Inventory range	
	C_5: Amount of disaster supplies delivered to each recipient	C_{17}: Total amount of inventory of each type	
C_6:Fill rates		C_{18}: Number of wrong products supplied	
Perfect order fulfillment	C_7: Order lead time	C_{19}: Time required to supply Tier1	
	C_8: Late/Wrong supplier delivery		
	C_9: Level of suppliers' defect free deliveries	C_{20}: Assessment accuracy	
	C_{10}:Order entry method		
C_{11}:Rate of complaint			

Table 2- HRCs' indicators

P3 : Flexibility		**P5 : Cost**
Response time	C_{21}: Average response time	C_{29}: Cost of goods supplied
		C_{30}: Variation against budget
	C_{22}: Minimum response time	C_{31}: Inventory cost
		C_{32}: Warehouse cost
C_{23}: Transport flexibility		C_{33}: Inventory obsolescence
C_{24}: Mix flexibility		C_{34}: Dollars spent per aid recipient
C_{25}: Volume flexibility		C_{35}: Donor dollars received per time period
P4 : Asset		
C_{26}: Vehicle capacity utilization		
C_{27}: Space utilization		
C_{28}: Tons shipped per person per hour		

Fuzzy DEMATEL

The DEMATEL method was developed by Science and Human Affairs Program of the Battele Memorial Institute of Geneva between 1972 and 1976. The foundation of

DEMATEL is based on graph theory and helps the process of analyzing by visualizing the problem. It uses matrix calculation to get the casual relationships and the impact strength (Tzeng et al., 2007, Chen et al., 2011). DEMATEL method is applied in many areas but it rarely has been used in disaster management context. In this paper the fuzzy DEMATEL is used to find the strongest interdependencies among the attributes defined for performance measurement of HRCs and the corresponding impact strength. The fuzzy DEMATEL with uncertain linguistic terms is applied in this paper. The interested readers may consult with (Hiete et al., 2011, Suo et al., 2012) for further information. Furthermore, in order to defuzzify the fuzzy numbers, a modified ranking method introduced by (Xu et al., 2012) for generalized fuzzy numbers, is applied in this paper.

Fuzzy ANP

ANP, introduced by (SAATY, 1996), is the general form of AHP. It provides a more general framework for decision making in the presence of various qualitative and qualitative criteria while accounting for both outer and inner dependencies. ANP generalizes AHP by allowing replacing the hierarchical structure to a network system which includes all the possible connections between elements. Since the results of pair-wise comparisons in ANP method are somehow uncertain and vague, the linguistic terms are used for them in the form of triangular fuzzy numbers leading to a fuzzy ANP approach. Furthermore, according to the total relation matrix derived from DEMATEL method, the novel cluster weighting proposed by (Yang and Tzeng, 2011) is applied into the fuzzy ANP.

Measuring the overall performance

A committee of donors is asked to score the performance of the concerned HRC in respect to various attributes with the range of 1 to 9. Then, the final score of the HRC performance with respect to attribute i can be derived from Eq. (1)

$$n_i = \left[\left(\prod_{k=1}^{h} n_{i_k}^{m_k} \right) \right]^{\frac{1}{\sum_{k=1}^{h} m_k}} \quad (1)$$

Where n_i is the final score in respect to attribute i, n_{ik} is the score given by donor k to the HRC's performance with respect to attribute i, and m_k is the importance of k-th donor for the organization. Consequently, the overall performance of the HO can be derived from Eq. (2)

$$OP = \sum_{i=1}^{n} n_i W_{fi} \quad (2)$$

Where OP denotes the overall performance of HO, and W_{fi} is the final weight of indicator f related to attribute i, which is derived from ANP method.

Numerical Example

In this section a numerical example is provided to demonstrate how the proposed framework can be implemented in practice. The indicators used in this example are those represented in Tables 1 and 2. It is also assumed that there are 3 donors whose quoted data are expressed as trapezoidal fuzzy numbers in the DEMATEL phase and triangular fuzzy numbers in the ANP phase.

The initial matrix for attributes (i.e. reliability, responsiveness, flexibility, asset and cost) provided by first donor and the average matrix are shown in Tables 3 and 4, respectively.

Table 3- Initial matrix provided by donor 1

	P_1	P_2	P_3	P_4	P_5
P_1	_	[H,VH]	[H,VH]	[VL,M]	[M,H]
P_2	[M,H]	_	[L,M]	VL	[L,M]
P_3	[M,H]	[VL,L]	_	[H,VH]	[L,M]
P_4	[L,M]	VL	[L,M]	_	VH
P_5	[VL,L]	[L,M]	[L,H]	[L,M]	_

Table 4- Average matrix $\widetilde{A}$

	P_1	P_2	P_3	P_4	P_5
P_1	(0,0,0,0)	(.63,.741,.926,.963)	(.556,.667,.926,.963)	(.148,.222,.556,.667)	(.333,.444,.778,.889)
P_2	(.407,.518,.852,.926)	(0,0,0,0)	(.037,.074,.556,.667)	(.037,.074,.333,.444)	(.111,.222,.556,.667)
P_3	(.333,.444,.778,.889)	(.074,.148,.482,.593)	(0,0,0,0)	(.556,.667,1,1)	(.111,.222,.63,.741)
P_4	(.074,.148,.482,.593)	(.037,.074,.259,.37)	(.185,.296,.556,.667)	(0,0,0,0)	(.704,.815,1,1)
P_5	(.037,.074,.482,.593)	(.111,.222,.556,.667)	(.259,.37,.778,.889)	(.185,.296,.556,.667)	(0,0,0,0)

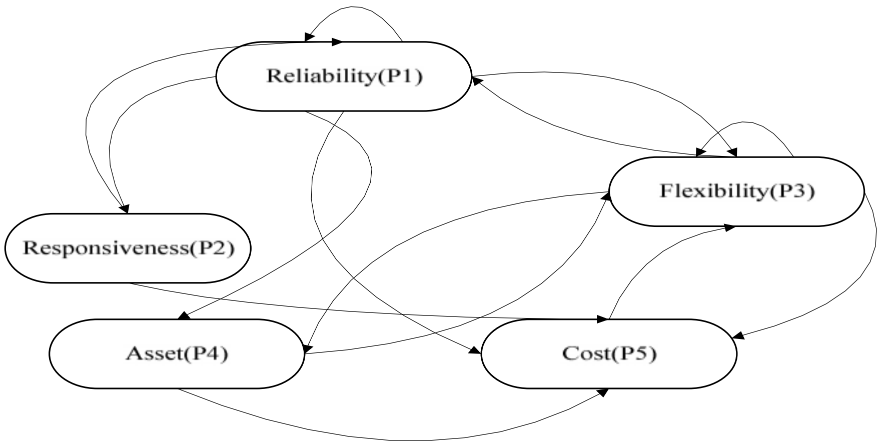

Figure 2- The network derived from DEMATEL

Using matrix T_P derived from DEMATEL, we can map the problem like a network which is shown in Figure 2. The pair-wise comparison have then constructed based on the network map. The matrix $\widetilde{W}$ derived from pair-wise comparisons using linguistic variables is first defuzziffied and then multiplied with normalized T_P to obtain the weighted super matrix. The last step of ANP method is calculating the final weighted super matrix whose result is partially shown in Table 5.

Table 5- Weight of indicators derived from ANP

Indicator	Weight	Indicator	Weight	Indicator	Weight	Indicator	Weight
C_{11}	0.152418	C_{23}	0.030152	C_{30}	0.006124	C_{13}	0
C_{22}	0.125238	C_{6}	0.024124	C_{16}	0.005124	C_{14}	0
C_{35}	0.11674	C_{4}	0.018847	C_{10}	0.0036	C_{20}	0
C_{21}	0.115149	C_{25}	0.016764	C_{15}	0.002458	C_{27}	0
C_{2}	0.090997	C_{5}	0.013534	C_{29}	0.001225	C_{31}	0
C_{24}	0.081811	C_{19}	0.01204	C_{3}	0.000686	C_{32}	0
C_{1}	0.075384	C_{7}	0.010817	C_{8}	0.000653	C_{33}	0
C_{12}	0.050256	C_{26}	0.007435	C_{18}	0.000271	C_{34}	0
C_{17}	0.031539	C_{28}	0.006473	C_{9}	0.000178		

Suppose that set N shows the final score of each attribute based on information gathered from the three donors where the first element of each triplets is the score given by first donor and so on.

$$N = \{(6,5,7),(2,4,1,),(3,6,7),(2,5,1),(3,4,2)\}$$

Accordingly, given the importance weight of each donor for the organization out of 5 as vector $M = \{3,1,2\}$, the final score of attributes are calculated by using Eq. (1) whose corresponding vector has been shown by set N'.

$$N' = \{6.1273, 1.7818, 4.4663, 1.8493, 2.7495\}$$

Finally, the overall performance of concerned HO is derived from Eq. (2) as 4.59 which can be used for comparison purposes with the future performances of the HO (i.e., analyzing the trend of the HO's performances) and also with performance of other HOs.

Conclusion

A performance measurement framework was proposed in this paper in which a hybrid fuzzy DEMATEL and fuzzy ANP was applied to map the problem and finding the final priorities of performance indicators considering interdependencies among them and finally calculating the overall performance of the HO.

In order to set a proper threshold value when constructing the attributes interrelationship map, the maximum mean de-entropy (MMDE) algorithm developed by (Li and Tzeng, 2009) could be applied as an improvement to this framework.

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