Data Fusion and Information Transparency in Disaster Chain

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***Abstract*—Information extraction has attracted the attention of many researchers. Some studies have addressed practical uses of information extraction and scientific challenges arisen from it. Researchers have proposed approaches like as information fusion to address it. Information fusion includes a process of transmitting information from multiple heterogeneous sources into single one. On the other side, using on time, accurate and strict information affects disaster chain management, efficiently. In this case, obtained information from multiple heterogeneous sources should be fused properly to produce transparent reports. Therefore, we study different researches for information fusion to show significance of transparency in disaster chain problem. Then, we do a literature review on disaster chain studies to show how previous studies have done in absence of transparent information. Finally, the conclusions and suggestions for the future studies are proposed. The study of information flow in disaster chain reveals that besides traditional approaches which has focused on imprecise or inconstant information, new methods should be developed to deal with other aspects of information uncertainty like as inconsistency, vagueness and ambiguity.**

***Index Terms*—Disaster chain, transparency, information fusion, heterogeneous data, imperfect data, uncertainty.**

I. Introduction

Humanitarian logistics as a part of disaster chain problem has become an important upcoming field of study for researchers. According to the report of UN disaster risk-reduction office, disasters have affected about 2700 million people since the beginning of twentieth century. About 1300 thousand people are been killed and 3100 million dollars have been only spent due to the natural disasters. The Indian Ocean Tsunami in 2004 has been recorded as the one of the ten greatest earthquakes from 1990. With about 280 thousand dead people and 1700 million people evacuated from their home, it is among the deadliest disasters of the century. Many researches have addressed humanitarian logistics since 1990s up to now. They propose different mathematical models as a single or hybrid location, vehicle routing, inventory management, network flow and logistics problems in order to model humanitarian logistics mechanism more detailed. These problems study disaster chain management in terms of single / multi-objective, deterministic / uncertain, single / multi-stage mathematical models based on the static or dynamic nature of the problem. Some other researchers have done literature reviews about disaster chain studies focusing on different aspects of the problem. Information transparency in disaster chain is one of key parameters which significantly threats disaster relief management. During the early hours of disaster, decision makers receive various news and reports about the casualties from different sources. They have to make immediately vital decisions based on this combined information, which sometimes contradict each other.

Manuscript received May 10, 2018; revised August 10, 2018.

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II. Data Fusion

Data fusion is an integration process that extracts reliable data and information from incomplete and uncertain data obtained from different sources. Information fusion deals with the inconsistency between various sources without removing or ignoring any one. It is applied in many fields of study like as expert opinion fusion in risk analyses, image fusion, sensors fusion in robotics, database integration, target detection, logic etc.

Data fusion is often in concern with mathematical modeling of uncertainty. Most of the time, the data sources produce imperfect and unreliable data. Even if the data are accurate, the fact that analyzers receive data from multiple sources threats the system and may lead to uncertainty. Many studies have addressed information fusion in presence of insufficient data. There are several data fusion strategies with different approaches. These strategies may have in common, but differ each other on the other hands. Generally, data fusion process follows the principle listed at Table I.

TABLE I: Most Common Principles Followed by Data Fusion Approaches

Principle	Definition
Unanimity	The results of fusion must provide data that are confirmed by all data resources and reject those that are rejected by all resources
Information monotonicity	When a set of sources provides data less informative than another set of sources, the information fusion of first set cannot be more informative than the second se
Consistency enforcement	The fusion of individual consistent inputs results in consistent output
Optimism	In absence of information about the unreliability of sources, in agreement with their mutual compatibility, the sources should be considered as reliable sources
Fairness	The information obtained by fusion process should keep a part of each input
Insensitivity to vacuous information	Sources that provide absurd information do not effect data fusion results
Symmetricity	Process input data from multiple sources similarly and the combination procedure must be symmetrical.

Data fusion usually arises from two types of data: “hard data” produced by electrical sensors and “soft data” produced by human beings. The main differences between these two types of data are usually in accuracy, bias and Inference taken

doi: 10.18178/ijimt.2018.9.4.805

by each of them. In some cases, like as complex robotic detections problems an electrical sensor would perform more precise than a human would. In other cases, in which it requires deduction or identifying the relationship of individuals, human being performs better. By studying recent studies, it becomes clear that some researchers have addressed information fusion considering hard data, but few studies have focused on soft data fusion. A brief research on literature reveals that many definitions are defined for information fusion. Some studies define it as the process of information integration from multiple source, while the others define it as the combination of large amounts of dissimilar During 1990th, some studies have compared and categorized the operations that fuse imperfect or contradictive data from multiple sources. [1] addressed both military and civilian applications of data fusion. They described the data fusion process and proposed process structures for it. On a more comprehensive study about data fusion, [2] reviewed the use of ontologies to fuse data obtained from different sources. [3] described fusion theory considering reliability. They also explored approaches to incorporate reliability in public operators of data fusion. They introduced reliability factor as a measure that determine how much each of beliefs reflect reality. [4] studied different definitions and introduced a comprehensive definition: "Data fusion presents efficient methods for automatic and semi-automatic data transfer from multiple sources into a single source of display which provides useful tools for decision makers". The authors explained that transition in their definition refers to any kinds of data combination and integration. They also mentioned that data sources can be vary from databases to sensors, simulators, humans and so forth. [5] presented web information fusion as a mean to combine all sorts of data and information available on the web. [6] study the effect of information fusion in computer security. [7] work on information fusion applications in different fields of intelligent transportation systems. [8] explained some advantages of information fusion on military services and extended it to other areas. They discuss the effect of art in multi-sensor data fusion. They also explained the work done by [9] as one of the earliest successful efforts to formalize data fusion theory. [8] focused on hard data and its related algorithms. Authenticity and availability of information are two main characteristics of data obtained from fusion. Authentication results in better identification of data, conformity, reliability, and reduces data ambiguity. Availability brings in wider coverage and presence every time every place. [10] applied data fusion with a focus on multi-source domain compliance, in which the training data should be adapted with test data. Reciprocity (interaction) is a mechanism in which you react to the participant regarding his behavior. Participation requires explanation. [11] studied the effect of imperfect data on reciprocity reformation. [12] showed that disclosure of imperfect information interacts the reputation and credibility in certification institutions and market. They expressed that the disclosure of imprecise information threats certification issuing and reduces the revenue obtained from certification sale. [13] provided basic rules and principles to fuse incomplete or uncertain information regardless of information formalism from multiple sources. The formalism could be based-on logic, probability theory, belief functions or imprecise probabilities. For more information on literature review of information fusion, look at work done by [14].

III. Information in Disaster Chain

The importance of timely, accurate and effective use of disaster information is addressed extensively in the disaster literatures. In large-scale disasters like as hurricanes and earthquakes, decision makers receive or extract information from different sources like as media, local governments and emergency centers. The extracted heterogeneous information from multiple sources requires to be integrated before making any decision. Disaster information integration is usually challenging due to some reasons like as; number of information producers/consumers, information time-dependency, reliability levels of information producers, lack of common terminologies, and integration of statistic information with dynamic and streaming information. This integrated information should be filtered and prepared properly to be useful for information consumers like as emergency centers. On the other hand, researchers and data analyzers require to access information straightforwardly. More to this, data consumers should be able to retrieve the information easily. Therefore, an efficient disaster information system should follow a process to store the integrated information appropriately for a quick accesses and upcoming purposes. Considering these steps, [15] present the required process for a better information flow management in disaster chain. Fig. 1 extracted from their work, depicts information management in disaster chain.

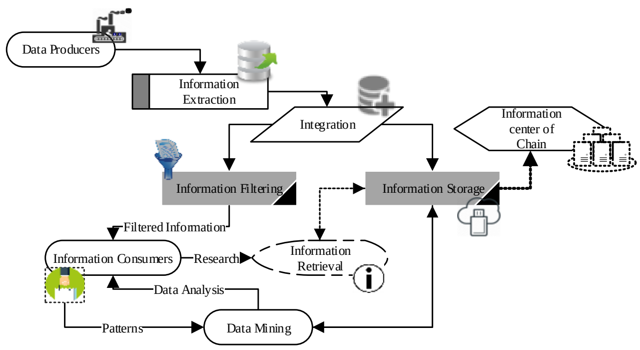

Fig. 1. Information flow management in disaster chain.

Generally, Information is categorized into two main types of strict and uncertain information. Strict information is deterministic and does not change during the time. Decision makers are sure about this information and prefer to manage system using strict information; but it is not possible all the times. Most of the times, information and disaster reports are time dependent or uncertain. In fact, the extracted information is not reliable or may change from time to time. Information feedbacks and uncertainty affect managerial decisions and threats the efficiency.

To be clear, see Fig. 2 that shows different types of uncertain information in disaster chain problem. As shown in Fig. 2, it is obvious that uncertain information in disaster can be categorized into three main types of imprecise, unclear and inconstant information. If there is information variations and feedbacks during the time, it means that the system faces with inconstant information. Sometimes the obtained information is constant but not precise due to the technical or surrounding environmental issues shown as imprecise information in Fig. 2. The third type of disaster information is imperfect or unclear information.

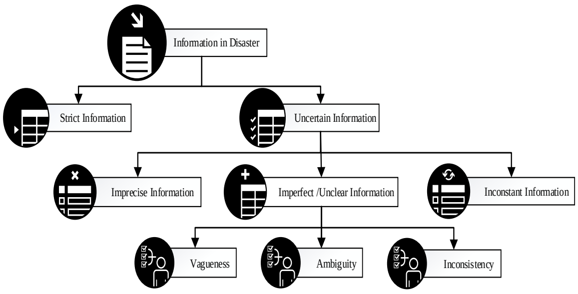

Fig. 2. Different types of information managing disaster operations.

Imperfect/unclear information can be divided into vague, ambiguous and inconsistent information. Vague information is lack in detail and the listener will not understand it precisely. Ambiguous description transfers more than one meaning and the listener would have difficulty to notice exactly what has been described. An emergency report may have one of these two uncertainty types or include both. More to this, the received information from different sources may contradict each other that are categorized as the inconsistent information. These three types of information shape imperfect information and confuse decision makers.

IV. Uncertainty in Disaster Chain

Due to the nature of disaster chain problem, many input parameters play role in it. These parameters include information that are diverse and could be determined or uncertain. Subsequently, the proposed mathematical models of disaster chain fall within one of these two groups. Many studies have proposed different optimization approaches to deal with uncertainty in disaster chain problem. We review the recent studies in disaster chain uncertainty to know how they have dealt with uncertainty. Table II shows some of the recent studies in this field. As presented in Table II, Stochastic programing, fuzzy optimization, robust optimization approaches and dynamic mathematical models are main approaches applied in recent studies to deal with uncertainty.

Listed studies in Table II, it reveals that stochastic and robust optimization approaches have respectively own the majority of uncertain studies in disaster chain. Some other studies proposed dynamic mathematical models to deal with inconstant parameters. Although these approaches have attempted to deal with uncertainty of disaster problem, but they only have modelled parts of it that are related to the imprecise or inconstant information.

Fig. 3 indicates some incoming parameters of disaster chain problem based on studies in Table II. To manage this information, the decision makers have to know about the uncertainty of information. If the information is strict, the researcher applies deterministic mathematical models. The flowchart shows that for inconstant and imprecise information researchers have applied pre-mentioned approaches. We claim that considering imperfect/unclear information, just few studies have proposed novel approaches, which is studied through a literature review in the following sections. The proposed approaches should be able to fuse different information like as heterogeneous or inconsistent information.

TABLE II: Recent Uncertain Disaster Chain Papers Listed by Optimization Approach

Optimization approach	Researcher
Stochastic Optimization	[16]; [17]; [18]; [19]; [20]; [21]; [22]; [23]; [24]; [25]; [26]; [27]; [28]; [29]; [30]; [31]; [32]; [33]; [34]
Fuzzy Optimization	[35]; [36]; [37]; [38]; [39]
Robust Optimization	[40]; [41]; [20, 42]; [43]; [43, 44]; [45]; [46]; [47]; [48]; [49];[50]; [51]
Dynamic Optimization	[52]; [53]; [54]; [55]; [56]

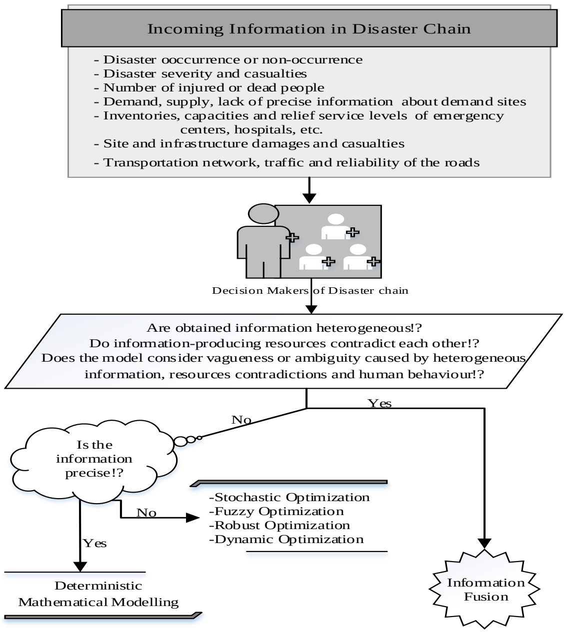

Fig. 3. How do researchers deal with input parameters in disaster chain.

V. Information Fusion in Disaster Chain

As discussed previously, information transparency plays an inevitable role in disaster operations management. Managers and decision makers have to look for relief strategies that can deal efficiently with all types of information. Besides inconstancy and imprecision; ambiguity, vagueness and heterogeneity are three types of unclearness which fade information transparency. Disaster information obtains from different sources and sometimes this information contradicts each other. Accordingly, new developed approaches should be able to help managers to make correct decisions regarding information contradiction. Developed approaches should fuse different information without ignoring any one. Fig. 4 shows that the proposed approaches under uncertain information should follow information fusion principles. Recently, some researchers have focused on information flow in disaster chain. [40] are among the pioneers who address data fusion in disaster chain. They develop a robust method to dispatch and route emergency vehicles after disaster occurrence. [15] conducted a literature review to organize existing knowledge about information management in disaster chain problem. Their study is impressive because few significant studies were taken before their work in disaster information flow problem. [57] pointed that many events like as the recent casualties around the world, show the importance of quick respond in disaster management. Relief items should be transported and be delivered on time and sufficiently, which requires precise information about the chain. The complexity to inform about the disaster occurrence, its severity, strike probability and infrastructure disruption may complicate information coordination and management in disaster chain. [58] studied information visibility in a two echelon supply chain which reveals that it can reduce system costs. [59] addressed the literature review in disaster chain operations considering the uncertain parameters of chain. They described factors in disaster chain operations obligating to develop efficient approaches to reduce casualties. Number of injured or dead people, complexity and unpredictability of disaster events, and all other unclear issues occurring in planning and response phase are among those factors. They declare that proposing an efficient approach is difficult because of uncertainty and imperfect information about parameters like as different scenarios proposed to locate facilities, disaster occurrence probability and its severity, demand prediction complexity, intricacy in determining the exact location of demand and information about damaged infrastructures. [38] believe that in order to estimate the vague parameters we often have to rely on judgmental data. This judgmental data could be obtained from different decision makers like as experts. This data is naturally based on the experiences of experts, opinions and comments of them. Some of them could also be objective evidence and information. They propose a mathematical model for these uncertain parameters using possibility theory. [60] do a comprehensive literature review on information and data management in the supply chain. [61] study two different strategies to show how information sharing in supply chain affects both information producer and information user. They state that under information visibility, information producers benefit more than information users. As we study the recent studies with a focus on information flow, it seems that information transparency and information fusion own small proportion of studies in disaster chain. Although some studies have proposed uncertain mathematical models to cope with imprecision and inconstancy, but few studies have addressed heterogeneity and information fusion in their study. Table III includes a comprehensive literature review that has been conducted to confirm this claim. It becomes clear that information fusion under multiple sources is one of the vital fields of study that has been neglected in disaster chain problem.

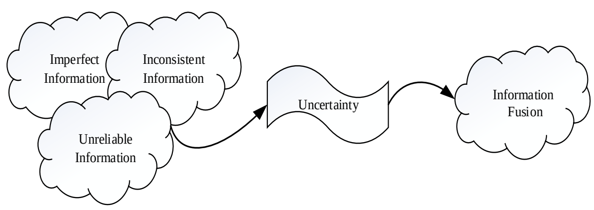

Fig. 4. Uncertainty and information fusion.

VI. Conclusion

Information flow plays an inevitable role in disaster chain management. Uncertain information may confuse decision makers and increase casualties. Shown in Fig. 1, we discuss the importance of transparent information flow in disaster chain. Generally, inconstant, imprecise and unclear information are three main types of uncertainty depicted in Fig. 2.

Information obtained from different sources may contradict each other or be heterogeneous. Vagueness, ambiguity and contradiction are three main types of unclear information that threaten information transparency. As shown in Fig. 4, we categorized unclear information as an uncertainty type but it completely differs from imprecision or inconstancy. Unclear information significantly threatens the disaster chain and disappears information transparency, which is vital for making right decisions. Fig. 3 presents the incoming information of disaster chain that cause uncertainty. It shows how the researchers in recent decades deal with imprecise, inconstant and unclear information.

To cope with imprecision, most of recent studies have proposed stochastic, fuzzy and robust optimization approaches in their models. More to this, due to the dynamic nature of disaster chain, information becomes stricter and transparent as time goes on. Some other researchers have presented dynamic approaches to consider feedback by inconstant information in their study. Table II have listed some of recent studies that have applied common optimization approaches for uncertain disaster chain problem. Despite these recent studies, the proposed models should be able to deal with ambiguity, vagueness and inconsistency arisen from unclear information. The proposed approaches should be able to fuse various information without omitting or ignorance of any source. To the best of our knowledge, few studies have addressed unclear information as the lack of transparency in their papers. Most of proposed mathematical models have ignored information fusion to cope with inconsistency.

In this paper, we present different definitions for information fusion and study the basic principles of information fusion to know how these methodologies deals with different heterogeneous data. Consequently, we discuss the information flow in disaster chain, the factors that threaten information transparency in a system, and the role it plays in reducing disaster casualties. Considering information transparency, we do a comprehensive literature review on more than 75 studies from 2000 so far to show how previous studies have dealt with uncertainty.

Given in Table III more than two-thirds of the studies have focused on operation management field of study to develop mathematical models. Besides, at about one-third of the studies have considered uncertainty in their study through stochastic, fuzzy, robust and dynamic approaches. These studies have only focused on two uncertainty types i.e., imprecision and inconstancy and have ignored ambiguous, vague and heterogeneous information. In addition, presented in Table II, most of proposed uncertain models have applied stochastic and robust approaches compared to the fuzzy and dynamic approaches. Regarding vagueness, ambiguity and inconsistency arisen from multiple information sources it becomes clear that these common approaches cannot guarantee information transparency in early days of disaster occurrence. Only a few studies (less than five percent) of studies have focused on information fusion in disaster chain without any mathematical or operational approach. Table III reveals that although some of the studies (about 15 percent) have proposed their mathematical model regarding a real case study, but ignoring heterogeneity makes their study far away from real world circumstance. It seems that future studies have to focus on information inconsistency more precisely to be able to fuse and deal with all types of information.

TABLE III: RECENT STUDIES IN DISASTER CHAIN PROBLEM CONSIDERING TRANSPARENCY AND INFORMATION FUSION

Research /study	M	Field of study	IT	U	OA	IF	TS	LR	CS
[51]	*	Location-allocation		*	R.O				
[34]	*	Emergency medical services network design		*	S.O				*
[31]	*	Literature review of logistics		*	S.O		*	*	
[56]	*	Logistic operations		*	D.O				*
[62]		Literature review					*	*	
[60]		Literature review	*				*	*	
[32]	*	Location-allocation		*	S.O.				
[33]		Literature review		*	S.O		*	*	
[39]	*	Logistics operations		*	F.O				
[38]	*	Logistics operations		*	F.O	*	*		
[50]	*	Logistics operations		*	R.O				*
[63]	*	Literature review of mathematical models					*	*	
[49]	*	Location-allocation		*	R.O				
[64]		Literature review						*	
[59]		Literature review	*	*			*	*	
[65]	*	Literature review						*	
[66]	*	Logistics in humanitarian l relief chain					*		
[57]	*	Location-allocation					*		
[67]	*	Early warning system and disaster management					*		*
[68]	*	Managerial research on the pharmaceutical supply chain						*	
[69]		Literature review						*	
[70]		Literature review					*	*	
[37]	*	Location-allocation		*	F.O				
[71]		Recovery operations in Humanitarian Logistics						*	
[47]	*	Logistics operations		*	R.O				
[72]	*	Disaster risk management							*
[73]	*	Institutional pressures and heterogeneity							*
[74]		Literature review						*	
[45]	*	Logistics operations		*	R.O				
[44]	*	Location-allocation		*	R.O				
[55]	*	Logistics operations		*	F.O				
[75]		Literature review of disaster objective functions					*	*	
[76]	*	Blood supply management						*	
[77]	*	Humanitarian supply chain management							*
[78]		RFID implementation in health care	*						
[79]		Information systems	*						
[80]		RFID application in health care apparel inventory control	*						*
[81]		Epidemics control and logistics operations						*	
[82]		Literature review in logistics operations					*	*	
[83]		Literature review						*	
[43]	*	Logistics operations		*	R.O				
[84]	*	Two-echelon multi-product location-allocation							
[25]	*	Facility location							
[26]	*	Dynamic allocation		*	S.O				
[52]	*	Logistics operations		*	D.O				
[53]	*	Dynamic vehicle routing with anticipation		*	F.O				
[54]	*	Location-allocation		*	F.O				
[85]		RFID-generated information in health care system	*				*		*
[86]		Information system for patient tracking	*				*		
[87]		Disaster chain versus supply chain					*		
[88]		Literature review					*	*	
[23]	*	Emergency facility location		*	S.O				
[89]	*	Allocation and re-storage							
[90]	*	Location-allocation							
[20, 42]	*	Two stage evacuee flow and relief items distribution		*	R.O				
[90]	*	Coordination in humanitarian relief chains					*		
[15]		Information management in disaster	*				*	*	
[91]	*	Preparedness and recovery					*	*	
[92]	*	Public-private partnerships in disaster chain					*		
[40]	*	Dispatching and routing of emergency vehicles	*	*	R.O	*			
[93]	*	Last mile distribution in humanitarian relief		*	S.O		*		*
[94]	*	Two-stage multi-criteria goal programming		*	S.O				
[95]		Disaster actors, phases and logistics operations					*	*	
[35]		Emergency logistics management					*		
[96]	*	OR/MS research in disaster operations						*	
[97]		Private sector logistics to improve disaster logistics					*		
[98]		Logistics in supply chain management					*		
[16]	*	Two stage relief items transportation		*	S.O				
[99]	*	Logistics operations		*	S.O				
[100]	*	Medical Items allocation		*	S.O				

(for a better understanding of Table III, please note the following abbreviations: M=Mathematical model; IT= Information technology; U=Uncertainty; OA= Optimization Approach; IF= Information Fusion; TS=Theoretical Study; LR=Literature Review; CS= Case Study; S.O =Stochastic Optimization; R.O =Robust Optimization; F.O =Fuzzy optimization; D.O =Dynamic Optimization)

We express that uncertainty in absence of transparent information completely differs imprecise-type one. Finally, it became clear that researchers should develop new methods that can solve inconsistency of received information in disaster chain management without any ignorance about heterogeneous information sources.

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