A framework for the use of big data in the emergency response supply chain[1]

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***Abstract*—This paper sets out a framework for use in the overlapping fields of the emergency response supply chain and big data analytics. The framework comprises four dimensions. The first dimension relates to the useful purpose of big data analytics: descriptive, diagnostic, predictive and prescriptive. The second dimension relates the phase of the emergency or disaster within which the analytics are used: preparation, preparation, response or recovery. The third dimension relates to the characteristics of big data itself: volume, variety, velocity, veracity and value. The fourth dimension relates to the application area. While the following four areas have been identified from the literature it is likely that additional areas will evolve: logistics, social media, remote sensing and security. It is intended that this conceptual framework will be of use to researchers and practitioners in positioning their work in the field.**

Keywords—big data, analytics, supply chain, emergency, response

I. Introduction

World scale disasters and emergencies occur on a regular basis and indeed we have witnessed several major events in recent times. The world is still in the process of recovering from the global Covid-19 pandemic which led to significant illness and major restrictions in all countries of the world during 2020, 2021 and 2022 [1]. The earthquake that occurred in Turkey and Syria in February 2023 left over fifty thousand people dead and more than 1.5 million people homeless [2]. The Ukraine war which began in February 2022 is still ongoing with hundreds of thousands of casualties to date, major destruction of Ukrainian towns and cities and millions of civilians displaced [3]. Recovery, whenever it begins, will take many years.

The ability to cope effectively with large-scale disasters and emergencies is of crucial importance to worldwide well-being. The emergency response supply chain (ERSC) plays a crucial role in promoting the effective application of disaster management and differs from conventional supply chains in some explicit ways. ERSC operations must analyse all demands in a very short period, using limited resources. The compliance of a cold chain, for example, is an important element of ERSC to ensure the safety of food and pharmaceutical products; vaccines need to be kept within a narrow temperature range from the point of manufacture to their use in an immunization session [4, 5]. The application of different technologies is strongly dependent on the kind of natural disaster, climate, infrastructure and other conditions. There is currently no comprehensive emergency management methodology in existence that allows for rapid decision-making processes, sufficient to meet the needs of a cold chain and to ensure product integrity in the event of different natural disasters. Therefore, an effective and efficient ERSC must be designed, constructed and maintained in order to support continuous and smooth material and information flows. This must include a diverse set of plans, resources, authorities, agencies, and their associated human resources.

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II. Big Data Within Emergency Management

A. *Role of big data in emergency response*

In the introduction to their recent special issue on management of disasters and emergencies, the authors [6] suggest that four major research questions face researchers in this field, one of which is 'How can big data analytics capability powered by artificial intelligence help to improve the visibility in disaster relief chains?' (p.5). Highlighting the role of big data analytics in this way, in a special issue of well over a thousand pages, demonstrates the importance of this topic to the field of emergency and disaster management.

This paper aims to shed additional light on the roles that big data analytics can play in the field of emergency management and more specifically in the emergency response supply chain. Several roles stand out: the use of data in analysing and predicting major natural events [7, 8], the use of data in managing the logistics of the supply chain in responding to major emergencies [9], and the use of social media in expressing concerns about oncoming and ongoing emergency events and the large quantities of data contained therein [10]. The present paper examines in turn each of these uses of data in the emergency response supply chain and puts forward a research framework for the application of big data to the emergency response supply chain.

B. *Big data analysis*

Large sets of data (big data) can be analysed for descriptive, diagnostic, predictive and prescriptive purposes [11, 12]. For example, real-time mapping of road conditions during an emergency, drawing on data collected from a variety of sources including satellites, GPS sensors from moving vehicles, social media messaging and mobile phone networks, can provide intelligent support for emergency responders during an emergency response [13]; such data can also be used to improve practices with a view to responding better to future events.

Many different methods of analysis can be used on big data sets including statistics, operational research, data mining, artificial intelligence, machine learning and simulation. Data for these purposes can be drawn from many sources, including the internet of things [7]. Descriptive purposes include the analysis of the data to give summary information that is of use to a decision maker, for example gender and age profiles of a sample. Diagnostic purposes include the identification of patterns and the determination of relationships between entities contained within the data, for example analysis may reveal a relationship between age and vulnerability to a disease. For predictive purposes data may be drawn on using for example artificial intelligence, machine learning or neural network techniques to determine what may happen in possible futures. Prescriptive purposes may include the interrogation of data to determine useful policies and identify critical variables, parameters or threshold levels. Descriptive and diagnostic purposes are oriented to examine respectively what happened in the past and why it happened; predictive and prescriptive purposes are oriented to the future, respectively what might happen in the future and what ideally should happen. The intention behind these four purposes is to improve managerial decision making and to improve organizational performance. Ref. [12] points out the importance of minimising the gap between successful use of descriptive and predictive analytics to determine the occasion of an event and the successful use of prescriptive analytics to determine the action to be taken; long lags between these two stages of analysis lead to lost organizational value (p.58). These authors go on to conclude:

> Through distributed processing and data management and in conjunction with advanced algorithms, next generation analytics systems will be able not only to identify risks and potential problems in business situations, but also recommend mitigating actions, effectively delivering clear, definitive, real-time decision support to business users (p.68).

While they speak of business users, by analogy, the relevance of big data together with big data analytics to emergency and disaster responders is clear. The identification of risks, the mitigation of those risks, and the delivery of real-time decision support tools to emergency responders could provide enormous benefits.

C. *Emergency management phases*

The field of emergency management has identified four major phases to emergency and disaster management: prevention, preparedness, response and recovery [14]. The first two phases - prevention and preparedness - consider situations prior to the occurrence of a disaster, emergency or other major undesirable event. The latter two phases - response and recovery - deal with an event that has already occurred. The prevention phase aims to reduce the likelihood of a disaster or undesirable event happening in the first place. This phase focuses on identifying and mitigating hazards and vulnerabilities. The preparedness phase aims to develop a response capacity and ensure that it is in place in order to be able to respond quickly and effectively to any emergency, disaster or undesirable event that may arise. The response phase deals with a disaster, emergency or undesirable event that has already occurred and is very much an action phase. The recovery phase deals with the aftermath of an actual emergency, disaster or undesired event.

The present paper puts forward a framework that is intended to guide researchers and practitioners in the use of big data in supporting the phases of emergency management (table 1). The framework contains the four phases of emergency management on one axis and the four approaches to data analytical analysis on the other axis. This gives a sixteen-cell framework that this report has populated with some example starter research questions. The table is divided into four distinct quarters that are colour coded. The quadrants are created by noting that the emergency phases are relevant both prior to an event or post event and that the data analytics purposes are oriented to the past or to the future.

The top left quadrant deals with phases prior to an emergency event occurring and with data analytic tools that are oriented to the present. In this quadrant existing data about past events and existing environments can be interrogated in order to describe more accurately and more deeply the nature of previous events and the current environment. This quadrant is an area of active research.

The bottom left quadrant deals with phases prior to an emergency and with data analytical tools that are oriented towards the future. This is the realm of futurists whose aim is to predict the future and prescribe policies with respect to prevention, mitigation and preparedness of societies with respect to major disruptive events.

The top right quadrant deals with emergency, disaster or other events that are actually occurring and with tools that describe and diagnose. This is the quadrant in which active responders are at work. This is the quadrant of action and there is no time for delay. In this quadrant data analytic tools can support real-time decision making that may be of tremendous benefit. Analytical tools that interrogate data gathered through social media may be of particular significance in this quadrant.

The final quadrant is in the bottom right corner of the table. This quadrant represents events that have occurred and where the recovery operations are actually taking place. It also represents data analytical approaches that are oriented to the future. With regard to events that are actually occurring predictive tools can be used to determine the likely trajectory of the event. With regard to actual recover from an event, predictive tools can be used with real time data to determine the likelihood of recovery success or failure. Prescriptive tools could be used to prescribe responses to an actual event or to recovery from an event. This is a quadrant that is under-researched but will likely provide research opportunities into the future.

A review of the literature on big data and emergency response supply chain found that over one third of articles considered the prevention/mitigation phase, almost 30 percent of articles dealt with the response phase and 23 percent of articles dealt with the preparedness phase. However, less than three percent of articles dealt with the topic of data in the disaster recovery phase indicating a clear need for further research in this area. The review also found that extant literature has largely focused on the use of big data for descriptive and diagnostic purposes [8]. The implication of these findings is that there is significant opportunity for the use of big data analytics for predictive and prescriptive purposes, particularly in the recovery phase.

TABLE I Emergency management phases and data analytic purposes

		Pre-event		Post-event	
	Emergency Management phase/ Data Analytic approach	**Prevention**	**Prepared-ness**	**Response**	**Recovery**
Oriented to the past	Descriptive	What typically causes blockages in the supply chain?	What supports exist to improve the supply chain?	What is happening in this ERSC right now?	What is happening in this recovery that could impact on the supply chain?
Oriented to the past	Diagnostic	How are blockage elements likely linked together?	How can we improve existing ESRC processes?	How is the ERSC responding to what is happening?	How is the recovery unfolding?
Oriented to the future	Predictive	What issues will likely arise in ERSCs?	What can we do about these issues in ERSCs?	In what ways will this event unfold?	What will impact on recovery from this kind of event?
Oriented to the future	Prescriptive	How can we minimise supply chain issues in emergency response?	What typical supports can be put in place in the supply chain?	How can we improve this instance of the emergency response supply chain?	How can we improve the ongoing supply chain after this kind of event?

D. Big data characteristics

The use of big data in the emergency response supply chain can be furthered by considering the characteristics of big data and the uses to which big data can be put that are relevant to the supply chain. Authors [9] in their review of the use of big data in humanitarian supply chains consider five characteristics of big data (which they refer to as enablers): volume, variety, velocity, veracity and mindfulness [9]. The volume characteristic deals with the extent to which data is created and generated before, during and after an emergency event. The variety characteristic considers the multiplicity of sources and formats of the data and the nature of the data – whether it is structured, unstructured or semi-structured. The velocity characteristic considers the rate at which data is generated and transmitted along with the time required for data processing. The veracity characteristic considers the quality, accuracy, reliability and accessibility of the data. A fifth characteristic, value, is adopted from [8]; this characteristic considers how big data can add value to the organization or to society more generally. These five characteristics of big data form part of the structure of the second framework which is shown in table 2. Note that [9] uses the term mindfulness for the fifth enabler, referring to the ability of organizations to avoid potential accidents through instilling high levels of reliability into their operations. However, as this enabler has more to do with organizational processes than data itself, we do not include it in our analysis.

TABLE II Big Data Characteristics and Application areas

Application area/ Big data characteristic	**Logistics**	**Social Media**	**Remote Sensing**	**Security**
Volume	How much emergency response (ER) supply chain data are we dealing with?	To what extent is relevant social media data available?	How much data about the phenomenon is available?	Does the volume of data pose a security issue?
Variety	What are the sources of data about the ER supply chain?	What variety of media and kinds of messages are there?	What kinds of data about the phenomenon are available?	Does the variety of data pose a security issue?
Velocity	How often do we capture data on the ER supply chain?	How frequently are messages generated or updated?	How often is the data about the phenomenon refreshed?	Does the velocity of generation of data pose a security issue?
Veracity	What can we say about the accuracy of ER supply chain data?	How can we discriminate between truthful and misleading messages?	How valid or true is the data about the phenomenon?	Does the level of truthfulness of data pose a security issue?
Value	What benefit is analysis of big data to the ER supply chain?	How important is social media data for dealing with ER supply chain problems?	How useful are our analytical models of the phenomenon?	What can we do to alleviate privacy concerns regarding the data?

E. Application Areas

Four areas of supply chain concerns that have a correspondence with big data have been identified: logistics, social media, information security and remote sensing [9]. Logistics involves the movement of goods, materials and people from one place to another and data both determines and is created by such movements; in disaster and emergency situations such movements can be very numerous and complex. In an emergency much data is created on social media by people caught up in the situation. While there are privacy concerns with this data, it may be useful in understanding the nature of the emergency and in supporting emergency decision making. Indeed, examining the usefulness of data generated by social media in predicting disasters and responding to emergencies is an evolving research area [15]. For example, unstructured data generated by social media, primarily Twitter, was analyzed in the case of a specific disaster – the earthquake that occurred in Nepal in 2015 [16]; social media data generated from communication networks such as Twitter was used to support rescue attempts during the Japan earthquake, an unpredictable and dynamically changing disaster environment [17]; authors [18] provide guidance on use of an opportunistic communication network made up of mobile phones in responding to a disaster. Data security and reliability are critical issues in disaster or emergency situations as the information and communication networks themselves may be negatively impacted by the disaster or emergency. Remote sensors such as satellites may provide information that is useful in determining the nature, scale and movement of the disaster or emergency. These four application areas form the second dimension in the research framework shown in table 2. Note that the term application area is adopted rather than the term concern that was used by [9].

III. A FRAMEWORK FOR BIG DATA AND EMERGENCY MANAGEMENT

Combining the two elements depicted in tables 1 and 2 provides a comprehensive framework for future research in the overlapping areas of big data analytics and emergency management. The two frameworks provide four dimensions along which research efforts can be structured:

- Emergency management phases
- Data analytical purposes

- Big data characteristics
- Application areas

This creates a research space within the four dimensions comprising a total of 4*4*5*4 cells i.e., 320 different cells with each cell providing research opportunities that are distinctive in nature. This is a very large research space and will provide many opportunities to examine the potential role of big data in the broad area of emergency and disaster management and in particular in the emergency response supply chain. Note that while the emergency management phases, big data analytical purposes, and big data characteristics are relatively fixed the number of application areas could increase substantially beyond the four depicted in the framework. For each additional application area, the number of cells will increase by 80 creating an even greater number of distinct research cells. The research framework for one application area is depicted in figure 1. Note that [16] have recently identified six broad application areas relevant to the use of big data in emergency management (BDEM): mobile communication networks, social network analysis, remote sensing, resilient communication networks, human mobility and urban sensing, and knowledge graphs. The first four broadly correspond to the four application areas in figure 2 and the research framework can easily be extended to include the latter two. Using data gathered from social media to sense the emotions of people caught up in a disaster or emergency is an emerging research area [13].

Specific areas to examine within the ERSC include: (i) Conducting Big Data analysis with reference to hazard and threat identification. Big Data analysis from prior incidents can help identify the most effective response methods for various situations and enable the development and deployment of assistive infrastructures for effective responses to future disasters; (ii) Undertaking Big Data analysis and investigating ERSC failure modes, identifying causal effects of initiating events, and identifying human factors (HOFs) and their role in causing possible failures of ERSC; (iii) Investigating Big Data tools that can be used to support ERSC systems including statistical analysis, modelling and simulation tools.

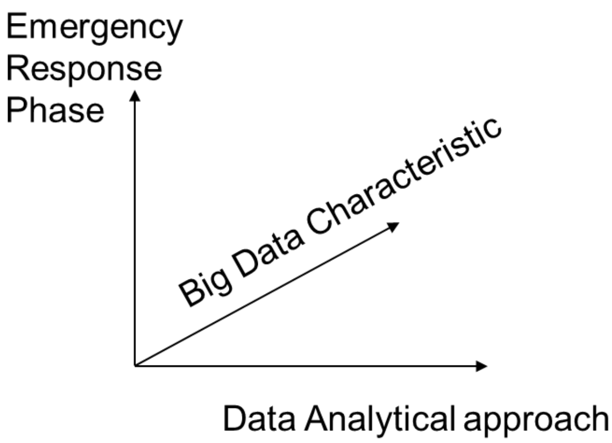

Fig. 1 Application area research framework for Big Data and Emergency Response Supply Chain

IV. Discussion and Conclusion

Data generation pre and post disasters and emergencies is increasing with the ongoing development of the internet of things on the one hand and with ever increasing use of social media on the other. However, research into the use of big data in emergency management is very much at an early stage. This leaves great opportunity in the future for further research in the overlapping areas of big data and emergency management. The present paper provides a framework to manage future research in this space. The framework sets out four dimensions for future research: the four phases of emergency management; the four purposes of data analytics; the five characteristics of big data; and (currently) four areas of application: logistics, phenomena, social media and security. The framework allows the areas of application to expand beyond these initial four areas. It is intended that the framework will act as a guide for researchers in these areas, allowing researchers to clearly position their work. The framework also allows fruitful areas for future research to be easily identified.

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