Disaster Management Operations – Big Data Analytics to Resilient Supply Networks

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Abstract

Natural Disasters have affected 377 million people with worldwide economic damage of $92.38 billion in 2016 – both numbers are increasing over years (CRED, 2016). Whenever there is an earthquake, flood, heat wave or heavy snow, disaster management (response-recovery-mitigation-preparation) organisations provide medicine, food, water and shelter. However, a particular challenge is that the disaster management operations (DMOs) are disrupted due to disconnectedness between commercially established and ad hoc disaster management supply networks requiring future-proof DMOs aimed at saving lives, rebuilding infrastructure and society. This paper proposes a novel framework of considering resilience, supply network integration and big data analytics in DMOs.

Keywords: Supply network mapping, resilience framework, big data analytics

1. Introduction

Disaster operations management is getting substantial attention from practitioners and academia – some operations management journals have recently organized / are organizing special issues on the topic e.g. Journal of Operations Management and International Journal of Production Research (Pedraza-Martinez and Van Wassenhove, 2016, Samuel et al., 2017). This is partly a response to a series of natural or man-made disasters worldwide in past 5-year period, which have affected many countries including Pakistan, China, India, Philippines and USA (Dubey and Gunasekaran, 2016).

The concept of supply network resilience for DMOs and its quantification is still novice in operations management due to its high complexity, so there is still substantial confusion about what it means (Cimellaro et al., 2010, Edwards, 2015). The level of high complexity is in the supply logistics, network management, integration, lack of supply network modelling, control, and awareness of roles and responsibilities in DMOs (Blecken, 2010). Hence, bringing resilience to supply networks for DMOs is still a big challenge partly due to disconnectedness between commercial and disaster supply networks. Even though commercial supply chain operations have been well studied, studies of DMOs are still in their infancy (Balcik et al., 2010).

Creating supply network resilience is imperative in responding to disruptions. Typically response to disruptions in the supply networks is mainly focused on effectiveness and agility during disaster relief and military action while it is focused on efficiency and lean during peace and preparation for emergency phase (Kovacs and Tatham, 2009). Resilience has been defined in many ways but most authors agree that it is closely related to the concepts of robustness, adaptability, change management capability and flexibility (Masood et al., 2016, Cimellaro et al., 2010, Scholten et al., 2014, Chalupnik et al., 2013, McFarlane, 2017). Supply network resilience can be defined as 'the ability of the supply network to predict, react to and continue or resume operations following an unforeseen disruption' (Carvalho et al., 2012).

The resilience in disaster supply network operations deals with two main issues: (1) bouncing back to the original functionality of supply network operations following exposure to a natural disaster e.g. national rail network following heavy flooding, wind storm or snow event; and (2) change management by the supply network due to anticipated or unanticipated changes in demand e.g. meeting product and service demands post earthquake.

The aim of this paper is to explore the overarching question of *"how can resilience be designed in disaster supply network operations?"* – ensuring that a commercial supply network can cope with a pull from a disaster supply network. We propose a disaster resilient supply chain operations (DROPS) framework, which includes a set of resilience factors, elements of supply network mapping and disaster (big) data analytics. The scope is limited to natural disasters e.g. earthquakes, floods, heat waves, snow storms, cyclones and tsunamis.

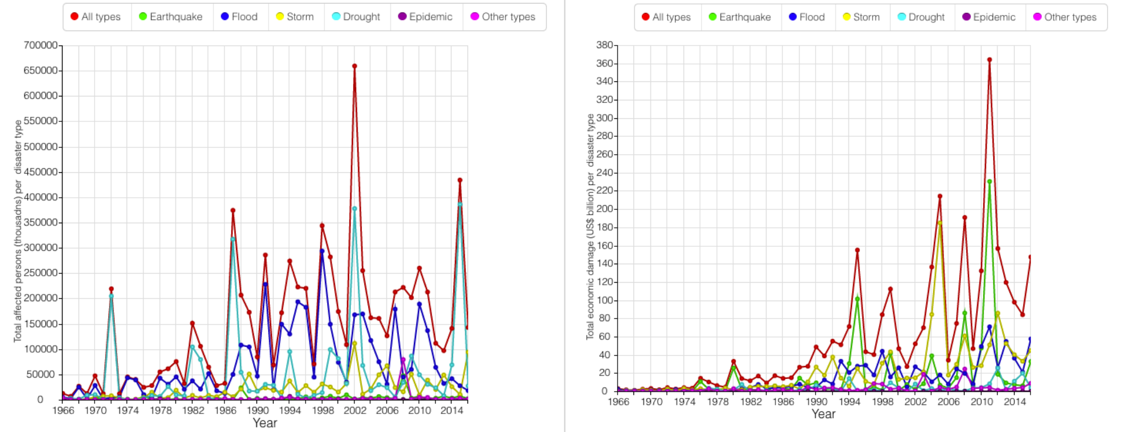
The rest of this paper is organized as follows. Motivation to consider resilience in the face of disasters is presented in sections 2. Section 3 presents approaches to disaster management. Research methodology and empirical background are provided in section 4. Framework development is presented in section 5. Results are discussed in section 6, which includes requirements for disaster (big) data analytics, disaster supply network operations map, and a resilience framework for supply network operations. This is followed by conclusions in section 7.

2. Why consider resilience in supply networks of DMOs?

Three key issues that motivate the need to enable resilience in supply networks of DMOs follow.

2.1 Increasing damages due to disasters

Disasters have affected 377 million people in 2016 out of which 94.77% were from Asia while 60.26% out of 7600 people who died in disasters last year belonged to Asia – the numbers are increasing over years (CRED, 2016). The economic damages due to disasters are also increasing – last year worldwide damage was $92.38 billion 49.9% of which was for Asia (CRED, 2016). Disaster trends per continent for years 1900-2016 are presented in Figure 1, where the data is based on the EM-DAT International Disaster Database managed by the Centre for Research on the Epidemiology of Disasters (CRED), Belgium. CRED records a disaster when at least one of these criteria is met: 10 or more people reported killed; 100 or more people reported affected; a state of emergency is declared; and/or a call for international assistance issued (CRED, 2016).



a) Total affected people (1000s) per continent

b) Total economic damage (US$ Billion) per continent

Figure 1 - Disaster trends per continent for years 1966-2016 (these graphs are based on The International Disaster Database of CRED, EM-DAT) (CRED, 2016)

2.2 Lack of connectivity between commercial and disaster supply networks

In response to a natural disaster, matching supply and demand can be very challenging for anyone endeavoring to provide goods or services (Morrice et al., 2016). In responding to disasters, the value of an organization's stock deployment is dependent on others' decisions, however decision makers lack evidence regarding sector capacity to assess the marginal contribution (positive or negative) of their action partly due to lack of metrics that describes the system capacity across many agents including commercial and disaster supply networks (Acimovic and Goentzel, 2016). Accessibility, co-location, security, and human resources are crucial to the practice of disaster operations management especially for integrating (commercial) supply chains for emergency response, however such contextual factors have not been included in existing network models before (Jahre et al., 2016). Hence, disaster response requires integrated supply networks with the foremost goal of providing aid and supplies for those affected, and then rebuilding infrastructure and society.

2.3 New opportunities and emerging technologies

New opportunities and emerging technologies needs to be understood for the betterment of disaster operations management. For example, with the technological advancements, it is understood that big data tools can process large amounts of disaster-related data (traditional humanitarian data as well as user generated data) to provide insights into the rapidly-changing situation and help drive an effective disaster response (Qadir et al., 2016). Big data analysis can help test particular frameworks of resilient supply chains in the context of disaster relief activities (Papadopoulos et al., 2017).

3. Disaster management approaches

Major approaches focussed on disaster management during last twenty five years of international commitments to disaster risk reduction includes: International Decade for Natural Disaster Reduction (IDNDR) (1989), Yokohama Strategy and Plans of Action (1994), International Strategy for Disaster Reduction (ISDR) (1999), Hyogo Framework for Action 2005-2015, Sendai Framework for Disaster Risk Reduction (SFDRR) 2015 – 2030 (UNISDR, 2015), UN Framework Convention on Climate Change (1992), Paris

2015 (COP21-CMP11), and Millenium Development Goals (2015) (Aitsi-Selmi et al., 2015). The SFDRR is the first global policy framework of the United Nations' post-2015 agenda. This represents a step in the direction of global policy coherence with explicit reference to health, development, and climate change, and has helped to put people's mental and physical health, resilience, and well-being higher up the disaster risk reduction (DRR) agenda compared with the Hyogo Framework for Action 2005-2015 (Aitsi-Selmi et al., 2015).

Some countries have developed disaster management plans at national, regional and local levels while also incorporating some of the UN frameworks e.g. National Disaster Management Authority in Pakistan (NDMA, 2012). Asian Disaster Risk Reduction Centre facilitates disaster management activities and issues natural disaster data books focussed on Asian region on regular basis (ADRC, 2015). Introducing absorptive capabilities such as location separation, physical robustness, redundancy and collaboration can help reduce supply network vulnerability (Craighead et al., 2007, Wang et al., 2016), but with a trade-off with cost. This necessitates to balance supply network resilience capability and vulnerability (Burns and Butt, 2015). Even though there is a consensus amongst practitioners on the need to address disaster-led disruptions, there is still a lack of structured, common approach for considering resilience, integrated supply networks and emerging technologies as part of the DMOs strategies and plans.

4. Research Methodology

Research Method - A 5-day International Workshop was conducted in Cambridge. The workshop gathered leading practitioners, government officials and academics involved in disaster preparedness, mitigation and relief with expertise in aspects of supply chain operations, resilience and big data analytics, mainly from the UK, USA, New Zealand, Turkey, Pakistan, Bangladesh, India, Nepal and Sri Lanka to understand current supply network challenges and approaches in the face of disasters especially earthquakes, floods and diseases. Following step-wise research methodology was followed:

1) Identify requirements of disaster (big) data analytics;
2) Model supply networks (commercial and DMOs); and
3) Develop a resilience framework for integrated supply networks for DMOs.

Data collection - A concurrent, mixed-method data collection approach was used for individual case studies through semi-structured interviews which allowed for the collection of specific answers whilst simultaneously covering implicit and contextual data areas. Qualitative data was gathered from the presentations and breakout sessions of the workshop. Current practices, issues, challenges and key factors related to DROPS were explored for: i) big data analytics, ii) mapping of supply networks for DROs, and iii) resilience frameworks in enabling DROPS. Case studies and lessons learnt related to earthquakes, floods, tsunamis and disease related disasters and supply chain operations mainly in Pakistan, Nepal, Bangladesh, Sri Lanka, India, New Zealand and USA were analysed.

Data Analysis - The data gathered allowed for a critical examination of the following aspects (1) big data flows and analytics, (2) supply network mapping – factors, issues and dependencies, (3) resilience factors and frameworks, across following disruption scenarios – earthquakes, floods and disease outbreaks.

5. Framework development

Keeping in mind the foregoing challenges, framework development is discussed in the following related to requirements of disaster (big) data analytics, a disaster supply network operations map, and a structured disaster resilience framework to address the disruptions.

5.1 Disaster (big) data analytics

Disaster (big) data analytics is a candidate DROPS strategy for understanding the disaster impacts amongst many other applications. Communication / information including data mapping and analytics can play a vital role in dealing with disasters e.g. in inventory needs assessment (models from national databases vs. real-time) to learn and make informed decisions. A clear logical organisational structure is imperative that allows for information flow both from the top-down, bottom up and outside the system (big data). For disaster (big data) analytics, following questions may be relevant:

- What is the role of (big) data analytics in enabling resilient supply networks for DMOs?
- What are the data requirements for disasters?
- What are the critical decisions in disaster operations management?
- How analytics can provide 'informed' decision support for disaster operations management?

Requirements of disaster (big) data analytics for distributors/manufacturers are identified for earthquakes/floods, where supplies of bottled water and energy biscuits are needed keeping in mind that a disaster has happened in the last 24 hours (see Table 1).

Table 1 – Requirements of disaster (big) data analytics for distributors/manufacturers (earthquakes/floods, supply of bottled water and energy biscuits; scenario: a disaster happened in the last 24 hours)

Critical Decisions	***Key Drivers***	***Key Information required***	***Key Suppliers***
Production volume Access to capital Availability of trained HR Availability / Procurement of raw material / inputs Stocks of spares and consumables Logistic arrangement	Additional machinery Additional shifts Additional HR Balance sheet Markup on credit Lead time Additional cost (including additional HR cost) Availability Time	Expected demand Existing capacity Expansion capacity Credit lines Management for No. of HR Type / no. of skills required Current inventory Required quantities Supplier information Frequency of maintenance No. of shifts to upgrade Transportation option Cost of logistics	Distributors DMAs Media Marketing agents Banks Suppliers Management HR agencies Production department Logistics contractors Market Manufacturers

5.2 Disaster supply network operations map

A disaster supply network operations map was developed using multiple case knowledge of earthquakes and flood events (see Figure 2). The map shows information and material flows between commercial and disaster supply networks as well as identifies commercial and disaster supply operations. Top five identified supplies are also listed as evacuation machinery, communication devices, water, food and medicines.

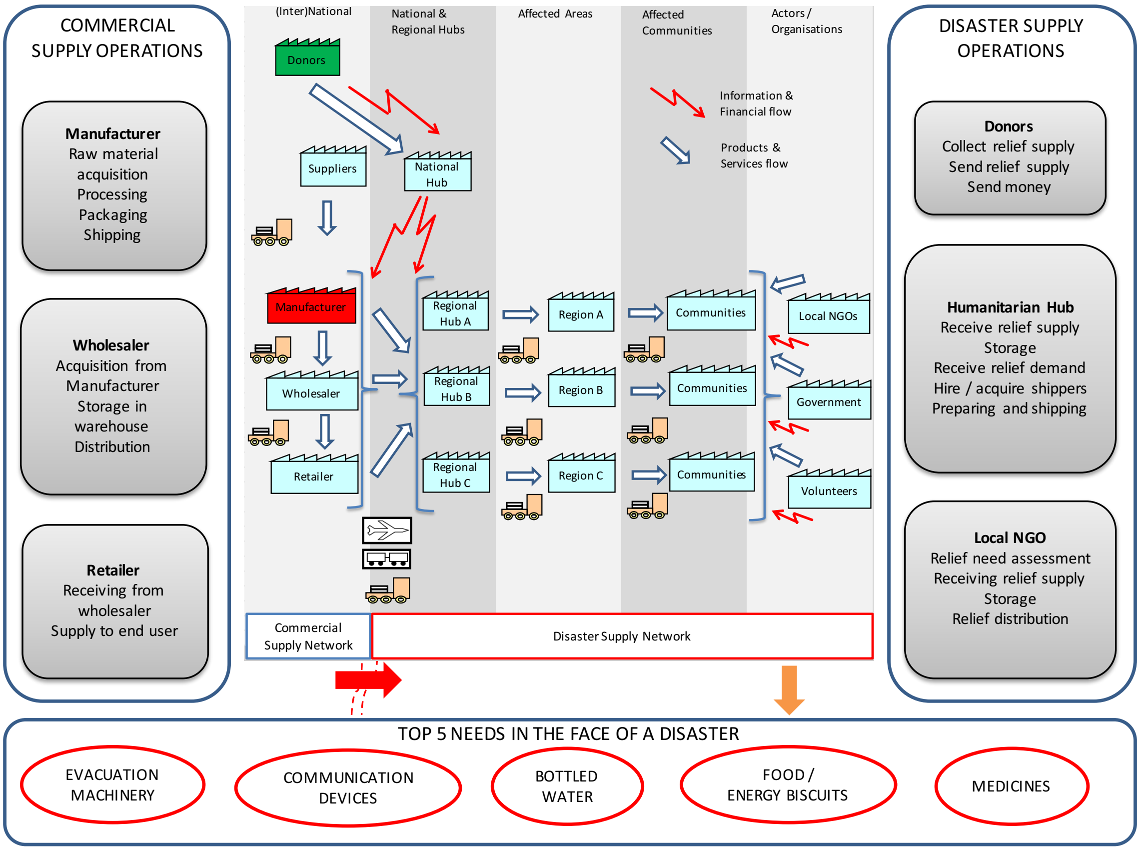


Figure 2 - Disaster supply network operations map (for earthquakes and floods)

5.3 DROPS framework (for resilient supply networks in DMOs)

A systematic approach to resilience for supply networks in DMOs, the DROPS framework, is proposed in this section (see Figure 3). It is proposed that, as a minimum, following should be considered when considering resilient supply network for DMOs across disaster management cycle (response-recovery-mitigation-preparedness): conducting requirements analysis (including identification of requirements for big data analytics), analysing current DMOs practice, identifying and analysing DROPS considerations, identifying and analysing DROPS strategies (including disaster big data analytics and integrated supply network resilience models), and developing a contextualised DROPS model for organisations.

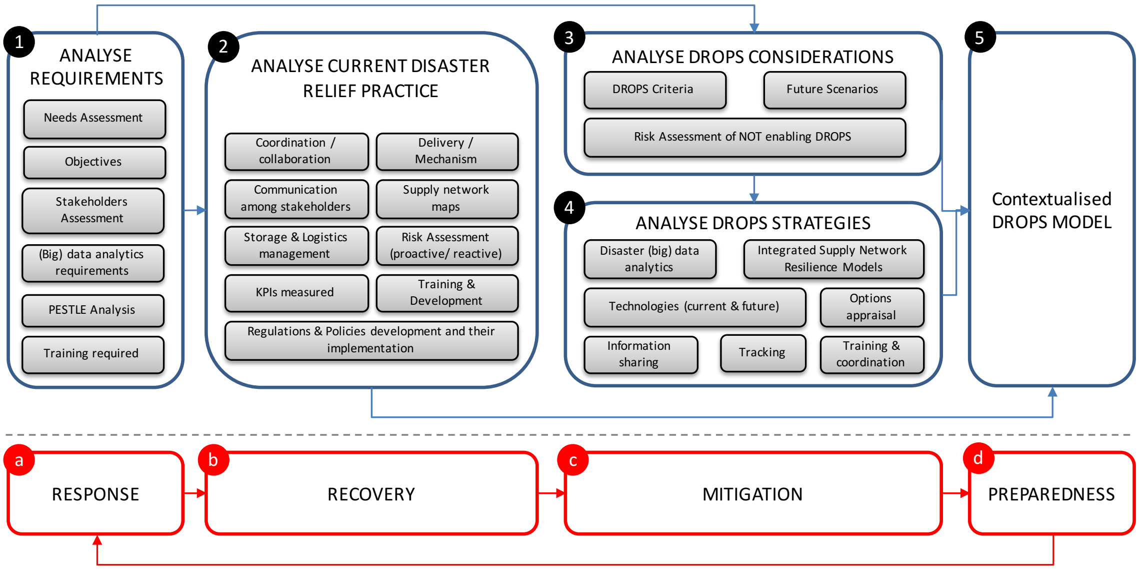


Figure 3 – DROPS Framework

6. Discussion of results

Results are discussed in the following.

1) *Analysing Requirements* – Requirements of (big) data analytics are identified at this stage as requirements for distributors and manufacturers have been discussed in the previous section. This stage also includes identifying (internal and external) stakeholders and assessing their needs. Nurturing a culture of communication and cooperation in the preparedness phase is very important. This necessitates better use of national institutions e.g. disaster management authorities, supply networks, manufacturers, research and development institutions and universities.
2) *Analysing Current Disaster Supply Network Operations Management Practice* – Analysis of the existing DMOs would include key natural disasters, focussed on key supply operations, and knowing KPIs, variations, their impacts and drivers. Supply network mapping has been discussed in the previous section.
3) *Analysing DROPS Considerations* – It is important to define what resilience means in specific DROPS scenario, while also resilience criteria. Overall, following key areas are identified for considering resilience for supply chain operations under disasters: stakeholder / need assessment, capacity building/planning, communication / information, management functions/supply chain, financing, resilience, and community / social. Operations preparedness need to be continuously assessed and monitored against some KPIs including capacity building / planning and gap analysis. Mapping of main (supply) networks and facilities, and their vulnerability in relation to exposure to different hazards is also important. For example, identifying key priorities for preparedness and immediate relief operations (infrastructure and other engineering / non-engineering solutions), and how does political stability impact on these operations, both are important to consider.

   Resilience thinking includes community / social resilience, where a proactive and not a reactive approach is needed while learning from past events. Focus should not only be on physical resilience but also on people e.g. training them on DROPS.

   Flexible dynamic infrastructure is imperative in handling disaster scenarios at different geographical scales and socio-economic backgrounds. It is important to consider what the triggers should for infrastructure related decisions. Best time to incorporate future-proofing into the infrastructure is at design stage (Masood et al., 2016). For example, taking an opportunistic approach to prepare for flexible dynamic infrastructure e.g. using significant Chinese investment (more than $1 trillion) on One Belt One Road / Silk Road / CPEC mega projects as an opportunity to prepare for disasters and embedding the resilience thinking in these projects.

Financial infrastructure/ financing is crucial in terms of long-term commitment of the government but also involvement of the private sector is vital. Policies in support of financial flow and their implementation is needed. Global taxation may be needed to act as a ready resource for disaster management and humanitarian relief operations. It's worth exploring the role of emerging technologies, e.g. block chain, in financial transactions under a disaster situation (Ko and Verity, 2016).

4) *Analysing DROPS Strategies* – A number of DROPS strategies may be adopted including supply network modelling and disaster (big) data analytics as discussed earlier. While analysing DROPS strategies, it is imperative to simulate various future scenarios based on current integrated supply network models, with following in mind: existing DMOs for key natural disasters, key commercial supply network operations, KPIs, variations, their impacts and drivers.

   Some other examples of such potential strategies include insurance-for-all model for financial flow under disasters, use of block chain technology for agile financial transactions of donations under disasters (Ko and Verity, 2016), use of 3d printing for 3d printable products and infrastructure (Tatham, 2014). DROPS implementation areas are identified across different disaster management phases, as presented in Table 2.

Table 2 – DROPS strategy implementation areas

	Preparative (Awareness, Preparations)	**Response (Management, Response capabilities)**
Disaster Relief	Govt policies, Strategic planning for emergency relief supply systems, Robust information systems/processes, Risk assessment, Inventory management, Continuous improvements in preparedness & response practices, Agile humanitarian supply networks, Building a culture of risk management, Improved alert/warning systems, Knowledge management, and Trained human resource	Communication among stakeholders, Organisational structure, Coordination and collaboration among stakeholders, Need assessment, Transparency, Procurement, Agile humanitarian supply networks, Social resilience, Availability of raw materials, and Trained human resource
Transition Phase	Govt policies, Capacity building of institutions, Continuous improvements in preparedness & response practices, and Trained human resource	Communication among stakeholders, Coordination and collaboration among stakeholders, Transparency, and Trained human resource
Disaster Recovery	Govt policies, Disaster resilient infrastructure & transport facilities, Risk assessment, Donation management (planning), Capacity building of institutions, Continuous improvements in preparedness & response practices, Building a culture of risk management, Knowledge management, Latest machinery, and Trained human resource	Communication among stakeholders, Coordination and collaboration among stakeholders, Need assessment, Donation management, Procurement, Social resilience, Implementation of policies, Latest machinery, and Trained human resource

5) *Contextualised DROPS Model* - While analysing DROPS strategies, focus would be to create a contextualised DROSP model for organisations answering the questions of how to build resilience and how resilience considerations can be incorporated into DMOs.

7. Conclusion

In pursuit of manufacturing a better world, disaster response requires better operations and supply networks with the foremost goals of bringing aid and supplies to those affected, and rebuilding society and infrastructure. In this paper, we have proposed a novel DROPS framework with key elements of supply network mapping, resilience criteria/factors and big data analytics of DMOs. This has in effect provided insights into designing resilience in supply networks for DMOs.

The DROPS framework has a potential to improve delivery of products and services to those affected by natural disasters especially in Asia (including Pakistan, Nepal, Bangladesh, China and India where most damages from natural disasters occur in that region) and generally making an impact by contributing to worldwide knowledgebase of natural disaster operations management. The research outcomes will be beneficial for organisations working on DMOs, planning & development, and higher education institutions. The DROPS framework, can improve the national to local supply networks, and in effect DMOs leading to social and economic resilience.

Lack of (big) data availability for supply networks of both commercial and DMOs is a major limitation. Future work includes conducting further specific case studies in various disaster scenarios.

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