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ABSTRACT

Disaster relief operations rely on reliable real-time information sharing during disasters to coordinate scarce resources and save lives. The Internet of Things (IoT) has recently been regarded as an important technology for enhancing information sharing in disaster response operations to achieve effective coordination, accurate situational awareness, and comprehensive visibility of operational resources. Despite its relevance, its adaptation and implementation have been fraught with complexity. This research aims to understand the IoT enablers of humanitarian supply chain coordination. Seven dimensional enablers have been formulated by reviewing the literature and validating with practitioners' opinions. A structural model is then developed using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique that addresses the interdependencies of IoT enablers in humanitarian supply chain coordination. Finding provides insights into the interplay between management support, IT infrastructures, and third-party logistics service providers as key enablers towards adaptation and implementation of IoT in humanitarian supply chains. Results provide important implications and insight to decision-makers in international humanitarian organizations toward adaptation and implementation of IoT systems in humanitarian supply chains.

Keywords: Humanitarian Supply Chain, Internet of Things (IoT), Coordination, Enablers, DEMATEL

INTRODUCTION

Natural and man-made catastrophes have both become more common in recent decades (Banomyong et al., 2019). According to the latest projections, man-made and natural catastrophes are expected to rise fivefold in incidence and intensity over the next 50 years (Agarwal et al., 2019; Chen et al., 2020). Recent catastrophes have highlighted the importance of humanitarian supply chain management (HSCM) in meeting beneficiaries' demands and ensuring effective long-term recovery following disasters. According to Thomas and Kopczak (2005), humanitarian supply chains entail "the process of implementing, planning, and controlling an efficient flow and cost-effective storage of information, goods, and materials and from the point of origin to the end of the affected area, to alleviate the suffering of the affected population". Managing and implementing such an efficient flow and cost-effectiveness of relief products necessitates the systematic coordination of specific operations and stakeholder collaboration to achieve humanitarian goals (Dubey et al., 2018; Li et al., 2019). The lack of coordination within the humanitarian supply chain may lead to inefficiencies that have a detrimental influence on the welfare of beneficiaries, i.e., an increase in the number of victims (Anjomshoae et al., 2022). Governments, humanitarian aid organizations, and other aid providers have become more aware of humanitarian logistics and the importance of coordination for successful and efficient relief item transport, procurement, and warehousing in recent years (Kovács & Spens, 2007).

The Internet of Things (IoT) based systems have recently been regarded as enablers of efficient coordinated environment in which humans, objects, machines, and software can efficiently interact with one another with limited human instructions (Alon et al., 2019; Zhong et al., 2015). The Internet of Things (IoT) systems are managed by sensors that are located remotely and can communicate over the internet (Ben-Daya et al., 2019; Devi & Kumari, 2013). Recently there has been considerable attention towards IoT-based supply chain systems to tackle the HSC coordination challenges. IoT-based HSC coordination system promotes the traceability of information and increased logistics and monitoring operations among humanitarian actors to maintain efficient and cost-effective planning, implementation, and control process (Aranda et al., 2019; Haavisto & Goentzel, 2015). Despite the growing relevance and importance of IoT systems in business and industrial systems, the humanitarian supply chain is still lacking in understanding the application and ramifications of IoT systems in managing relief chain coordination. To this end, understanding IoT enablers for creating a coordinated relief chain helps to achieve effective coordination, accurate situational awareness, and comprehensive visibility of relief operational resources. This research thus aims to identify key IoT enablers that facilitate efficient humanitarian supply chain coordination.

BACKGROUND

Role of IoT in Supply Chain Coordination

IoT is defined by Botta et al. (2016) as a network with sense-based entities. Cloud computing, data management, and data networking are the three essential components of IoT technology (Chandrakanth et al., 2014). IoT enables physical objects to connect and share data in the real time to achieve coordination. Implementing associated technologies such as cloud computing, networking, data collection, IoT protocol, and other applicable technologies makes these entities smarter (Al-Fuqaha et al. 2015). The deployment of IoT technology may result in an efficient and resilient coordinating system through the transmission of data and resources in a transparent and observable manner between supply chain partners. In addition, IoT adoption provides precise and monitored dynamic data across the upstream and downstream flows of service-oriented businesses, which is necessary for HSC resilience (Wellington and Ramesh 2017). IoT adoption can be achieved in inventory management, improving different relief practices and integrating their strategies and improving operations performance by improving resilient capabilities in the event of an HSC disruption (Reaidy, Gunasekaran, and Spalanzani 2015).

METHODOLOGY

This research adopts the DEMATEL methodology to formulate the relationships among barriers. DEMATEL was first introduced by the Geneva Research Centre of the Battelle Memorial Institute in 1971. This technique visualizes complicated, structural, and causal relationships with matrices or digraphs. It formulates the relationship between criteria into a structural model (Guo et al., 2015; Mangla et al., 2020; Sahebi et al., 2022; Shahin et al., 2019). To collect data, a field survey was conducted in major Iranian humanitarian organizations such as the Iranian Red Crescent society. DEMATEL incorporates experts' opinions using interviews. Two experts from the IT industry, two from IoT solution companies, one from a non-governmental organization (NGO), two government experts from the Iranian Red Crescent Society, and one from academia participated in this research. All of the specialists have a minimum of ten years of expertise in their field. Experts were requested to rank the enablers. The enablers' judgment matrix is constructed based on the experts' ratings. Figure 1 depicts the research structure.

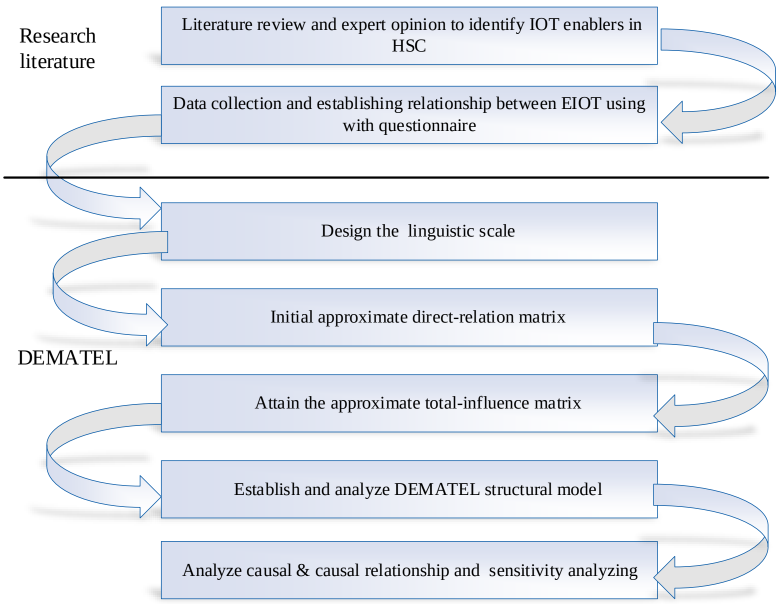

Figure 1: Research methodology framework

The structural diagram was created by measuring correlations among seven primary enablers using the DEMATEL approach. The DEMATEL technique consists of five phases to formulate causal relations between enablers. The DEMATEL calculation stages are given here, with just the enablers-level results being revealed. About identification, primary facilitators in HSC (Table 1), and questionnaire recovery:

Step 1: Using the survey average to calculate the first relationship matrix

Based on case managers and experts, an initial relationship matrix for criterion was created, as shown in Table 2.

Step 2: Calculation of normalized direct relationship matrix (See Table 3).

Step 3: Calculation of the total influence matrix (See Table 4).

Step 4: Calculation the sum of rows and columns

The sum of columns and rows from the entire influence matrix must be determined. The sum of columns and rows is represented by the vector's 'D' and 'R,' respectively. Table 5 displays the total number of columns and rows.

Step 5: Setting up the causal influence diagram

The last step in using the DEMATEL model is to create an influential graph, which aids decision-makers in identifying the most critical element.
The mean value of the total relation matrix is used to compute the threshold value, which is 0.11 at the criteria level. When the impacts of the criteria in the "total influence matrix" surpass a certain threshold, they should be represented in a causal diagram with arrows. "The influence network relation map" is another name for it. Similarly, if enablers' overall influence matrix impact is less than the threshold value, they have limited influence on other enablers.

RESULTS

Formulating IoT Enablers of Humanitarian Supply Chains Coordination

A literature survey was conducted using search keywords such as the IoT-based coordination system, HSCs, and IoT-based coordination in major scientific databases to formulate IoT enablers. Nineteen enablers have been identified as listed in Table 1. The enablers are then classified into seven dimensions after several interviews rounds with humanitarian practitioners.

Table 1: IoT enablers for HSC coordination

Classification	Enablers	References
Management Support (EIOT1)	Investment of time and money for resource development like IoT-based infrastructure and other training programs within the organization $(EIOT^{11})$ Ready to adopt new technology, e.g., IoT, cloud computing, and big data computational, for improving the information sharing within the SC $(EIOT^{12})$ Employees' training and empowerment to enhance the skill and knowledge needed in IoT-based technical environment of work culture $(EIOT^{13})$ Focused on the communication system of the HSC during managing logistics, warehousing, and other service-providing activities $(EIOT^{14})$	(Anjomshoae et al., 2017, Söderberg & Bengtsson, 2010; Sun et al., 2009)
Supply chain accountability (EIOT 2)	Quick organization's reactions to meet the continuing changing demand of the injured people for achieving resilience capabilities$^{21)}EIOT($ Fast exchange of real-time information in HSCM to provide flexibility/resilience and awareness among the actors in the SC$(EIOT^{22})$ The resilience of HSC to adapt new technology during the relief of basic practices and the interpretation of data generated$(EIOT^{23})$	(Anjomshoae et al., 2021; Aranda et al., 2019; León-Bravo et al., 2019)
Supply chain integration (EIOT3)	Integration along with multiples SC with heterogeneous technologies for sharing the technical facilities across the inter and intra-organization boundaries $(EIOT^{31})$ Information integration among the members for monitoring or controlling the activities $(EIOT^{32})$ Process integration means complete collaboration among the SC system members in strategically, tactically, and operational decision-making$(EIOT^{33})$	(Flynn et al., 2010)
Internet of things infrastructures (EIOT4)	A proper cloud computing system for better IoT network availability to access the services regarding information exchange $(EIOT^{41})$ A proper security support system to avoid unauthentic data sharing for misusing the information$^{42)}EIOT($ Proper technical human resources for managing IoT-based disasters and actors' controlling mechanisms $(EIOT^{43})$	(Leong et al., 2011; Bo & Wang, 2011; Channe et al., 2015; Kaewkitipong et al., 2012)
Data subscription (EIOT5)	Use of IoT technology for subscription to the local and outer data of the organization by different members of the SC based on local Object Naming Service (ONS), global ONS, and Electronic Data Exchange (EDI) $(EIOT51)$ Knowledge subscription between the supply chain members with the help of research and development programs in the organizations $(EIOT^{52})$ Tracking of logistics information by the managers during the transportation of products regarding the condition of the products and avoid the disorder$(EIOT^{53})$	(Tim et al., 2017; Marić et al., 2021; Zhang & Chen, 2013)
Trust development (EIOT 6)	Trust development in SC members so that all of the activities are executed to achieve a common goal without any conflicts of interest among the members $(EIOT61)$ Agreed vision and goals of members of the SC so that a shared effort of every actor leads to overall performance improvement for the organization. $(EIOT^{62})$ Share standard protocols in IoT-based systems for efficiently interpreting the information generated from new technologies of IoT. $(EIOT^{63})$	(Bianchi & Saleh, 2010)
Third-party logistics service providers (EIOT7)	3PLs for IoT-based infrastructure support by providing different equipment and hardware.$^{71)}EIOT($ 3PLs for warehouse management for managing the tracking of shipment planning and distributing the required demands. $(EIOT^{72})$	(Aguezzoul, 2008; Göl & Çatay, 2007)

Modeling IoT Enablers for Humanitarian Supply Chains Coordination Using DEMATEL
According to $D + R$, important network relation maps are graphed in Figure 2, and $D - R$ values are provided in Table 5. We can now clearly see if an enabler is an effect or a cause and the amount it impacts or is influenced by others in the IRM.

Table 2: Initial relationship matrix at the enablers level

	EIOT1	EIOT2	EIOT3	EIOT4	EIOT5	EIOT6	EIOT7
EIOT1	0	3.5	2.5	3.5	3	3.25	3
EIOT2	1	0	2	2.75	3.25	3	0.5
EIOT3	1.75	1.75	0	2.5	3.25	3	2.25
EIOT4	1	3	3.25	0	2.75	2.75	3.5
EIOT5	1.75	2.25	3.25	2	0	2.75	2
EIOT6	0	2.5	3.5	2.25	1	0	1
EIOT7	1.5	3	2.75	3.25	1.5	1.75	0

Table 3: The normalized direct relationship matrix

	EIOT1	EIOT2	EIOT3	EIOT4	EIOT5	EIOT6	EIOT7
EIOT1	0	0.186	0.133	0.186	0.160	0.173	0.160
EIOT2	0.053	0	0.106	0.146	0.173	0.160	0.026
EIOT3	0.093	0.093	0	0.133	0.173	0.160	0.120
EIOT4	0.053	0.160	0.173	0	0.146	0.146	0.186
EIOT5	0.093	0.120	0.173	0.106	0	0.146	0.106
EIOT6	0	0.133	0.186	0.120	0.053	0	0.053
EIOT7	0.080	0.160	0.146	0.173	0.080	0.093	0

Table 4: Total influence matrix

	EIOT1	EIOT2	EIOT3	EIOT4	EIOT5	EIOT6	EIOT7
EIOT1	0.219	0.620	0.629	0.626	0.577	0.634	0.501
EIOT2	0.199	0.311	0.449	0.442	0.449	0.472	0.276
EIOT3	0.258	0.449	0.407	0.485	0.493	0.522	0.393
EIOT4	0.243	0.533	0.591	0.403	0.506	0.546	0.469
EIOT5	0.253	0.456	0.540	0.453	0.336	0.500	0.372
EIOT6	0.130	0.373	0.449	0.369	0.306	0.277	0.255
EIOT7	0.242	0.489	0.516	0.506	0.413	0.456	0.276

Table 5: Centrality degree and cause-effect influence relations among the enablers.

Criteria	**D**	**R**	**D+R**	**D-R**	**Rank**
EIOT1	1.546	3.807	5.354	-2.260	7
EIOT2	3.233	2.602	5.836	0.632	4
EIOT3	3.584	3.010	6.593	0.576	1
EIOT4	3.286	3.2933	6.579	-0.007	2
EIOT5	3.083	2.914	5.996	0.169	3
EIOT6	3.411	2.161	5.570	1.250	5
EIOT7	2.542	2.902	5.442	-0.359	6

Values (i.e., D+R) represent the overall influence of each critical enabler on the whole management system in terms of 'prominence'. The relative or preference importance order for these identified enablers is presented as non-adoption of the Basel ban amendment based on the (D+R) values: Supply chain integration (EIOT3), IoT infrastructures (EIOT4), data subscription (EIOT5), SC responsiveness (EIOT2), and trust development (EIOT6). Despite the importance of each enabler, Supply chain integration (EIOT3) and infrastructures in the IoT (EIOT4) are placed first and second, respectively, with the greatest (D+R) values. Similarly, the 'relation' values (i.e., D-R) are utilized to arrange enablers into cause-and-effect groups based on the negative (net receive) and positive (net cause) values in the total relationship matrix. Following that, we used the values of the entire relationship matrix to calculate the threshold value (0.42217) of the detected criterion (Table 4). HSC policymakers should promptly address the enablers under the cause group when determining the enablers under the effect group. Experts classify the above criteria based on the distinct facilitators, importance, and proportional weight in the whole connection matrix. These enablers impact the effective implementation of the IoT in Iran.

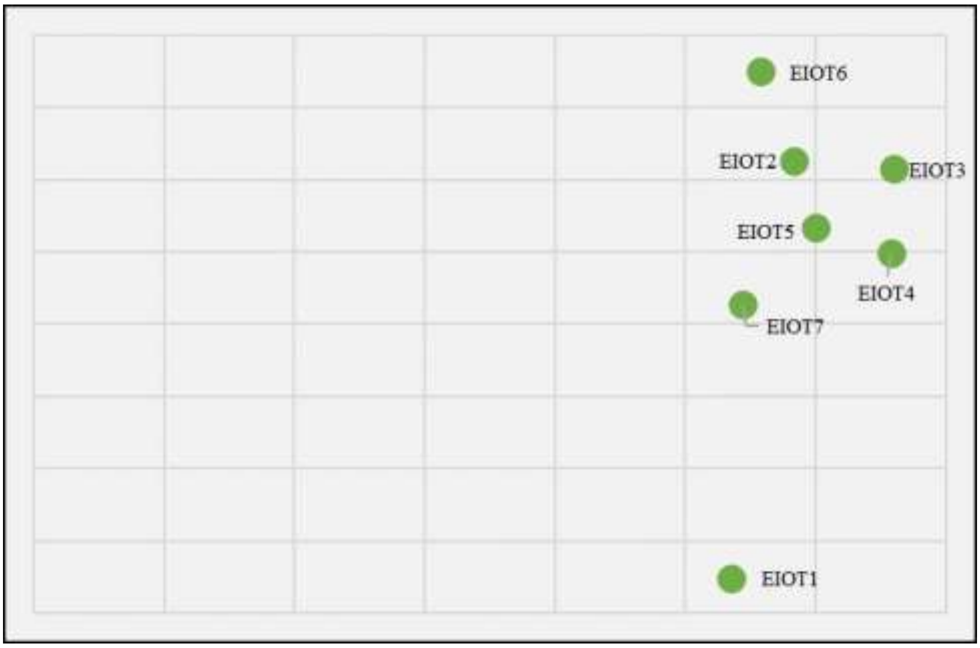

Figure 2: The overall degree of influence of IoT enablers in HSC

DISCUSSION

Management support (EIOT1) is the most significant cause enabler based on (D-R) value as an investment by Senior Managers in creating new technology such as IoT that is continually related to particular business practices. As a result, just a few IoT implications in HSC showed firms embracing new technologies and focusing on communication. This supports the findings of this study since top management support is the most critical enabler. The significant crucial aspects are senior managers' investment in relief programs, solving the issues of wounded individuals (hazard analysis and critical control point), and staff training in urgent situations.

Third-party logistics service providers (EIOT7) are the second most significant cause enabler in building IoT-based coordination for HSC. Third-party logistics providers are external service providers specializing in processing, logistics, and storage during the shutdown of logistics and other organizations' operations due to a natural HSC interruption. 3PLs are satisfying the time-sensitive needs of wounded individuals at a lower cost, delivering services to organizations (Domingues et al., 2015). SC's logistics operations were mostly outsourced to third-party logistics service providers, inventory management, human services, and IoT-based infrastructure.

IoT infrastructures (EIOT4) are the third impact enabled by other factors for constructing an efficient coordination system. A suitable security support system, followed by a qualified technical workforce for HSC activities such as safe storing of products and equipment, secure logistics activities using IoT-based traceability, network availability support with an appropriate cloud computing system, and a suitable automation system for traditional relief procedures, play a significant role in IoT based infrastructure systems. IoT-based SC operations, big data analytics, and other protocols inside HSC are examples of integrating IoT technologies or establishing IoT-based infrastructure (Aranda et al., 2019).

Data subscription (EIOT5) is the fourth effect enabled by other factors for constructing an efficient coordination system. IoT technology in information sharing is critical because it facilitates cooperation between HSC's upstream and downstream operators by providing a significant volume and delivery flexibility in response to demand changes (Deak et al., 2013).

Supply chain integration (EIOT3) is the fifth effect enabled by other factors for producing an efficient coordinating system. It primarily depends on integration and numerous SC with diverse technology to integrate supplier-related information and activities. Integrating relief efforts is not a one-way street; it entails understanding multiple strategic, operational, and tactical procedures at organizational levels, affecting most of the criteria (Vallet-Bellmunt & Rivera-Torres, 2013).

Supply chain accountability (EIOT2) is classified as a sixth key cause enabler that affects the whole coordinating system. It promotes resilience or flexibility, improving HSC adaptation to risk management during natural disasters (COVID-19). The responsiveness of SCs impacts obtaining dependability, agility, and speedy data transmission, among other things, which helps to improve various procedures (Cohen, 2020).

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Supply chain accountability (EIOT2) is classified as a sixth key cause enabler that affects the whole coordinating system. The fast interchange of real-time information in the HSC is the most critical factor in SC responsiveness. It promotes flexibility or resilience, improving HSC adaptation to risk management during natural disasters (COVID-19). SC responsiveness impacts obtaining dependability, agility, and speedy data transmission, among other things, which helps to improve various procedures (Cohen, 2020).

Trust development (EIOT6) is the seventh key cause facilitator impacting other criteria. A slew of sub-enablers also accompanies it. Mutual understanding and trust aid in developing shared ideas and goals among HSC actors and wounded people and the sharing of standard protocols in an IoT-based system. As a result, trust development is required to effectively implement new technologies to establish a better HSC coordination system.

CONCLUSION

In humanitarian supply chains sharing accurate information in real-time during disasters is crucial for coordinating limited resources and preventing further loss of life. Recently, the Internet of Things (IoT) has gained recognition as a pivotal tool for improving communication during emergencies, allowing for better coordination, better situational awareness, and greater visibility into available resources. Despite its relevance, the process of adapting it and putting it into practice has been difficult. The purpose of this study is to gain an understanding of the Internet of Things enablers that are necessary for the coordination of humanitarian supply chains. Seven dimensional enablers have been formulated by reviewing the literature and validating with practitioners' opinions. A structural model is then developed using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique that addresses the interdependencies of IoT enablers in humanitarian supply chain coordination. These enablers help HSC integrate IoT more effectively. Management support (EIOT1) is a critical influencing facilitator; this indicates that management must take a proactive and policy-driven approach. This research contributes to practice by increasing the awareness of relief procedures and incorporating IoT into the relief coordination system. It will also increase awareness of the technological relief difficulties that IoT adoption will almost certainly encounter. The study was based on a small number of experts and respondents. The DEMATEL approach is highly dependent on the expert panels decision. Using statistical techniques such as structural equation modeling may provide additional insights.

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