

ORIGINAL ARTICLE

The role of concurrent engineering in resilient critical infrastructures during disasters

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ABSTRACT

The world has complex mega-cities and interdependent infrastructures. This complication in infrastructure relations makes it sensitive to disasters and failures. Cascading failure causes blackouts for the whole system of infrastructures during disasters and the lack of performance of the emergency management stakeholders is clear during a disaster due to the complexity of the system. This research aimed to develop a new concurrent engineering model following the total recovery effort. The objectives of this research were to identify the clustered intervention utilized in the field of resilience and developing a cross-functional intervention network to enhance the resilience of societies during a disaster. Content analysis was employed to classify and categorize the intervention in the main divisions and sub-divisions and the grouping of stakeholders. The transposing system was employed to develop an integrated model. The result of this research showed that the operations division achieved the highest weight of information interchange during the response to improve the resilience of the system. The committee of logistics and the committee of rescue and relief needed the widest bandwidth of information flow in the concurrent engineering (CE) model. The contributed CE model helped the stakeholders provide a resilient response system. The final model and the relative share value of exchanging information for each workgroup can speed up recovery actions. This research found that concurrent engineering (CE) is a viable concept to be implemented as a strategy for emergency management. The result of this research can help policymakers achieve a collaborative teamwork environment and to improve resilience factors during emergency circumstances for critical infrastructures.

Keywords: *resilience; critical infrastructures; concurrent engineering; incident command system; cross-functional collaborative teamwork*

1. Introduction

Nowadays, business continuity and the continuity of the performance of critical infrastructures have become important issues for policymakers especially when manmade threats, such as terrorist acts or sabotage actions, become additional threats on top of natural hazards. Moreover, infrastructure efficiency in all conditions have a direct effect on the economy of each society (Pontes and Pais, 2018). The academic area is also witnessing new research studies on mitigating the side effects of recent events, such as the blackouts from Hurricane Katrina (2005) and

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Hurricane Sandy (2012), the flood in South Carolina (2015), or even ISIS' destructive actions in Europe and the Middle East (Guidotti et al., 2016). Various incidents, such as cyber-attacks, natural hazards, and terrorist attacks, reinforce the need for planning for emergency management procedures and simultaneously illustrate the inherent nature of emergency management (Davison, 2014). Emergency management is a multi-disciplinary field of service. It is engaged by different departments and agencies during a disaster. All of these agencies and departments have their organizational structures and routes of communication. The efficient engagement of responsible stakeholders is very important to reduce damages and casualties. This is the initial principle of hazard adjustment during the pre-disaster planning process (Alexander, 2002; 2005). Thus, organizational behavior under conditions of uncertainty and emergency is one of the fields of emergency management, which is presently receiving increased interest in the research community (Bhakta Bhandari et al., 2014). The need for the collaboration between different stakeholders of emergency management especially for infrastructure is evident when the role of interdependencies is highlighted for infrastructure protection (Guidotti et al., 2016).

In 2005, resilience became a new approach advocated by US Department of Homeland Security (DHS) Secretary Chertoff by forming the Critical Infrastructure Task Force (CITF) based on Critical Infrastructure Resilience (CIR) (Homeland Security Advisory Council, 2006). The importance of resilience policies is clear among leaders and policymakers following disaster management, together with sustainable development strategies (Gu et al., 2020). The preliminary concept of resilience is defined during hazard impact, i.e., normally the first assets and properties affected that could be the first to “bounce back to their normal state” (Lewis, 2011; Reghezza-Zitt et al., 2012; Levine et al., 2012). On the other hand, some researchers focused on resilience as the recovery effort that promotes post-disaster rescue and rehabilitation approaches on which disaster risk reduction (DRR) measures and policies should be focusing, rather than reducing the underlying risk factors or prevention (Lewis and Kelman, 2010). Resilience is also identified as the overarching strategic objective to stimulate synergistic actions that are balanced across components of risk and protection (Vugrin et al., 2010; Fang and Sansavini, 2019).

Three system capacities have been defined to formulate how the inherent properties of a system can determine system resilience. System resilience is constructed on two main concepts, which are systematic impact and total recovery effort (Labaka et al., 2015). These capacities are defined as absorptive capacity, adaptive capacity, and restorative capacity (Vugrin et al., 2010). These capacities are affected by resilience

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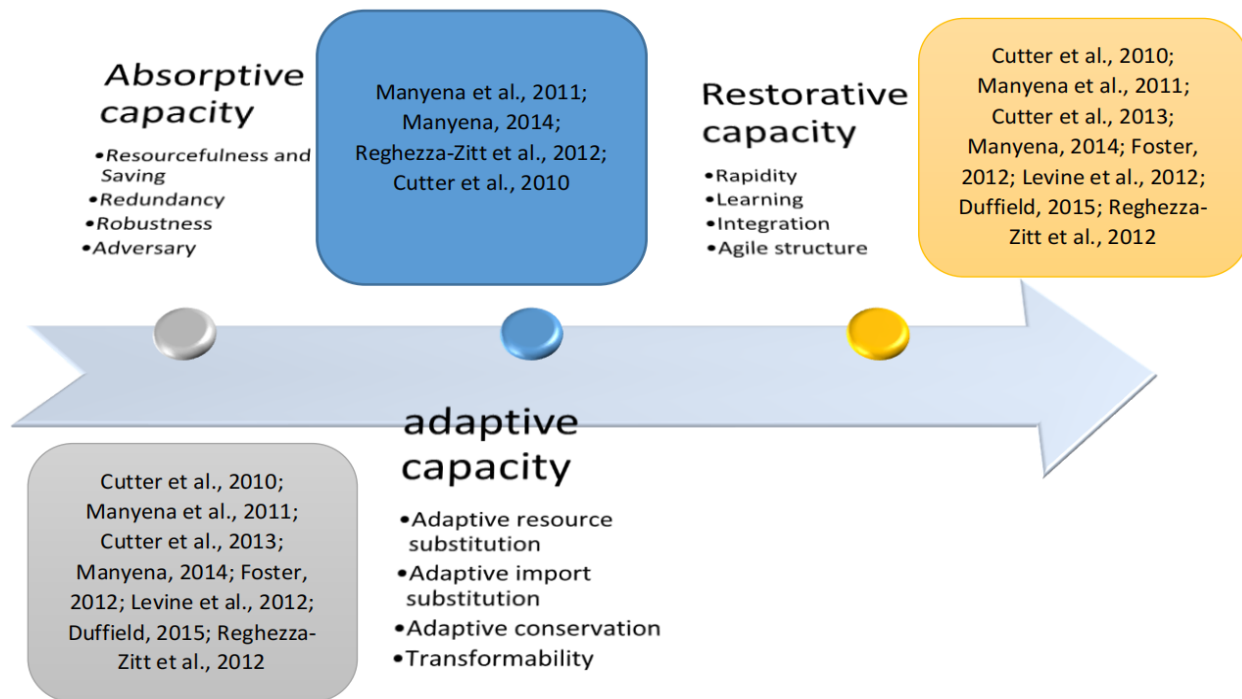


Figure 1. Trend of enhancement of infrastructures and systems towards a resilient system

enhancement features. The features of the system can increase one or more system capacities. From 2013 onwards, most research studies on emergency management have focused on improving different capacities by the enforcement of sub-capacities. **Figure 1** illustrates the trend of the enhancement of infrastructures and systems towards a resilient system based on the three main capacities and their sub-capacities.

The concept of resilience could become a new sense of motivation in disaster management, as recent researchers believe that resilience marks a shift away from the more traditional liberal ideas of security. Resilience has been indicated as the art of living dangerously (Duffield, 2015; Reiner and McElvaney, 2017; Adekola et al., 2020). However, absorption and adaption are two systematic approaches often considered by various researchers (Manyena and Gordon, 2015; Matyas and Pelling, 2015; Vedeld et al., 2015). Otherwise, restorative capacities need new achievements to speed up the recovery effort. Thus, supporting tools for increasing the performance of the emergency stakeholders' network by using cross-functional teams and collaborative systems strengthens the recovery effort process (Huizar et al., 2017). Disaster management is a complicated field of work, which should intervene before, during, and after major disasters. Coordination of different segments of emergency management has been recognized as a critical issue due to the number of individuals and organizations involved in emergency and disaster management (Jaeger et al., 2007; Rehak et al., 2019). Social networks and the cyber environment are making mass collaboration easier. A network's collaborative environment increases the efficiency and effectiveness of disaster management stakeholders. A collaborative environment allows residents and responders to share information, communicate, and coordinate activities in response to major disasters (Jaeger et al., 2007; White et al., 2009). Usually, effective inter-organizational coordination capable of encompassing a wide variety of interests is the main requirement of disaster management work (Bhakta Bhandari et al., 2014). Thus, using a collaborative and effective inter-organizational system

is very critical.

In industrial emergency management, the response services are the production of the system, and the people are the customers. Managers and relevant organizations are the other stakeholders in the system. The highly sensitive nature and the specialization of emergency management show the need to provide a platform for close cooperation among the response participants. All of the participants have their agenda and objective towards saving people and properties. It is very important to note that 85% of commonly associated problems are process-related and not product-related. These findings explain the growing awareness of the value of information technology (IT) to bring together major parties in the management process (Mohamad, 1999). The sensitivity of emergency management to conflicts between stakeholders has been highlighted in previous incidents. For instance, Spellman (2007) mentioned the terrorist incident at a water treatment plant, which started as simple revenge, ended up as a disaster with five victims and extreme environmental damage. The incident could be controlled with an appropriate collaborative system. The analysis showed the weak points of the stakeholder network, summarized as:

- The penetration factor for critical and sensitive areas was not estimated.
- The model of threats for the water treatment plant was not assessed precisely.
- Sabotage actions were not anticipated.
- The relevant agencies were not well trained for sabotage events.
- The emergency agencies and response teams were not familiar with the secondary impacts and vulnerability of the water treatment plant.
- There was no appropriate collaboration in the inter-organizational system of the water treatment plant.
- There was no appropriate communication between the organization of the plant and other relevant or neighbor organizations and agencies, such as a university, to conduct a training course, simulation, etc.
- There were not any standard operating procedures (SOP) for multi-agency intervention.
- There was not any appropriate information system among households, security agencies, and emergency and relief agencies, such as fire departments, police departments, and emergency medics.

Figure 2 illustrates the cross-functional intervention among disaster management stakeholders in the aforementioned incident.

The issue of the lack of collaboration among stakeholders can be evident during disasters, such as the dust storm in Tehran. In the early days of June 2014, while the people of Tehran were spending a hot day, a massive dust storm engulfed Tehran, killing at least five people, injuring about 30 people, and creating an apocalyptic scene in the Iranian capital. Normally, emergencies can refer to imminent threatening events, such as dust storms. An emergency may not yet occur, but the consequences are likely to be major with the lack of planning, and many community agencies would be needed to mount a coordinated response (Alexander, 2010). The Tehran dust storm showed that the lack of enough collaboration between stakeholders, the lack of familiarity and awareness, the

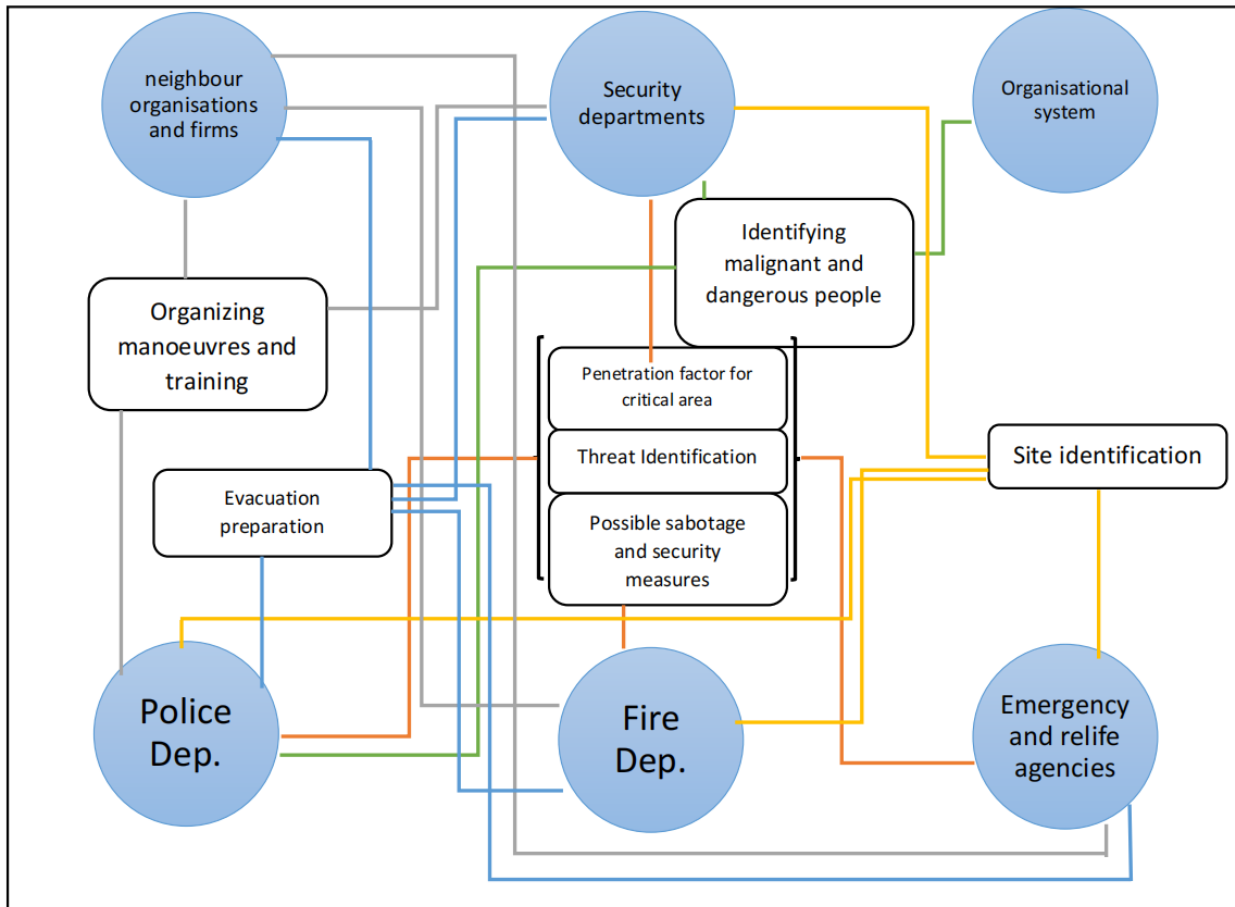


Figure 2. The cross functional intervention among disaster management stakeholders

lack of appropriate alerting systems, and the lack of a cross-functional collaboration system were the main factors that turn a controllable incident into an uncontrolled emergency. **Figure 3** illustrates the necessary cross-functional intervention model among different engaged organizations.

The other lesson that should be learned is on the conflict of interest of the stakeholders, as evident in the experience of the 2019 flood in Iran due to climate change. The armies' intervention in the efforts by the Red Crescent and other volunteer teams and NGOs provided complete confusion during the disaster and also affected recovery time. The lack of operational cross-functional teamwork is observed among all stakeholders of emergency response. A community's capacity to cope with natural hazards, such as floods, i.e., the community's hazard resilience, emerges from the interplay of technical and social processes. Adaptive strategies that dynamically adjust protection levels through close monitoring of damages and social memories of hazard risk can help the community deal with various disturbances (Sung et al., 2018; Pasche and Geisler, 2005).

Concurrent engineering (CE) is one of the emerging management philosophies that have a strong potential to be applied in various production and service systems, such as construction or disaster management (Mohamad et al., 2014; Mohamad, 1999). The importance of CE philosophy is that it prescribes how to realign the traditional way of work processes based on a fragmented and sequential product development system into a new paradigm of an integrated life-cycle process using a multidisciplinary teamwork approach (Sapuan and Mansor, 2014; Singhry et al., 2014). Otherwise, disaster management consists of different players and actors. These actors should be

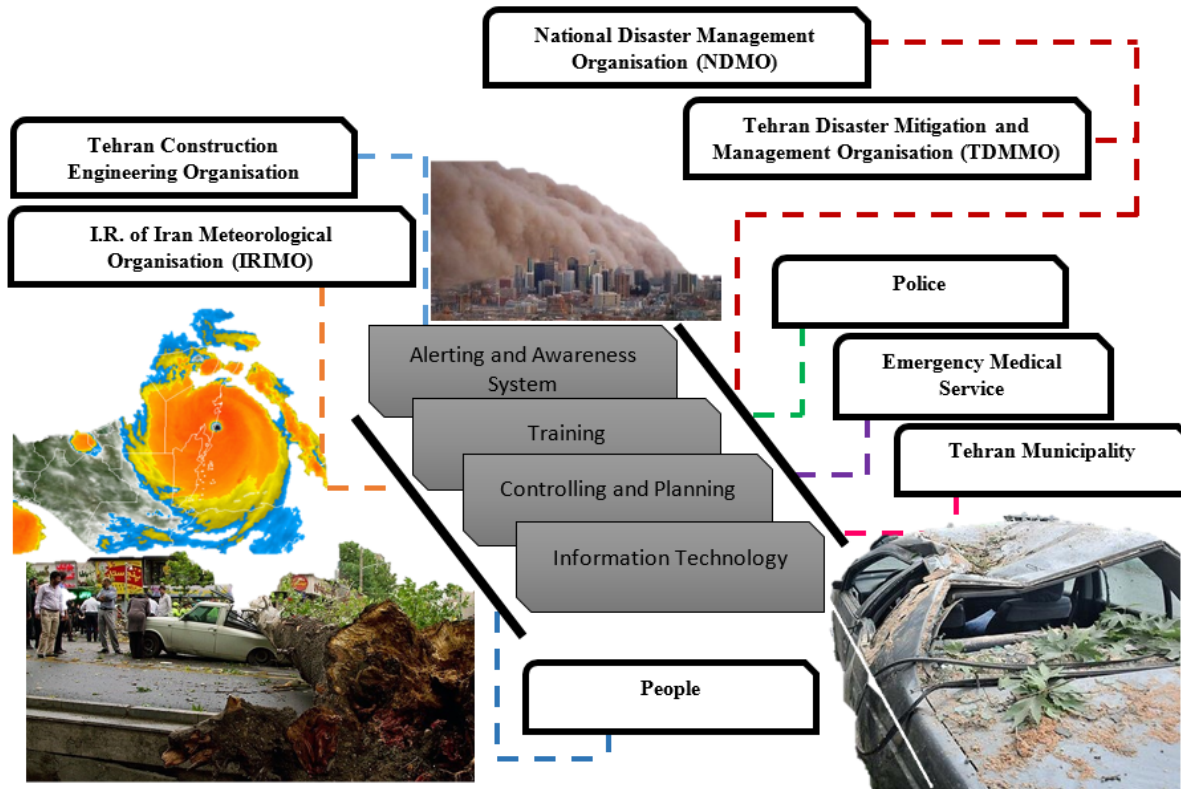


Figure 3. Conceptual model for organizational cross-functional intervention

aggregated based on a discursive framing of the incident command system (ICS) to illuminate the different positions (Aldunce et al., 2014). The strategic objective of concurrent engineering is to integrate the development and production management and replace the traditional department-specific divisions (Kraus and Ochs, 1992). This integration process must be coupled with the integration of human expertise and knowledge through the platform of collaborative teamwork, and it should be supported by information technology (IT) tools. Applying this concept to any organization means that all life-cycle requirements of the project must be considered early in the design and planning phases. This will enable the reduction of the length of iterative loops in the planning cycle and minimize error and rework (Reidsema and Szczerbicki, 1999; 2002).

Collaborative efforts, local-area details, local culture, geographic information, and emergency plans are five important aspects of preparing and planning in emergency management. However, collaboration is the most complex and effective issue. There are a certain need and an important opportunity for human-computer interaction systems to play a more central role in understanding the needs of communities in emergency preparation and management (Schafer et al., 2008). Turoff et al. in 2004 discussed the criticality of the communication and organizational structure and the flow of information concerning whether it encourages or inhibits rigidity. The authors introduced a flat organizational structure, which allows equal participation to access whatever information they feel they may need to consider. This encourages the flexibility of response (Turoff et al., 2004). Computer-based systems in emergency management automate the common practice from the physical world to make optimal use of the technology. However, the ICS approach would probably work well during a one-dimensional emergency and the occurrence of conflict is increased for a multidimensional crisis (Turoff et al., 2004). Collaborating organizations and their staff

need any available information relevant to their task. The distribution of relevant information to collaborating partners in emergencies is a complicated problem, for which collaborative network and concurrent engineering are viable solutions. Effective response coordination is highly dependent on information sharing based on the quality and amount of information. It is also very important for the practitioners to be able to adapt their organization's culture, structure, and processes to the collaborative environment of emergency management (Zagorecki et al., 2010; Comfort et al., 2004; Kapucu et al., 2010; Kapucu, 2006). The best tool, for this reason, is concurrent engineering.

Based on the literature, there are two main concepts in concurrent engineering, which are life-cycle and cross-functional teamwork. Life-cycle in emergency management covers all steps of disaster mitigation, preparedness, response, and recovery. The ICS model identifies the impact points of these steps in its divisions as operations, planning, logistics, and finance. Thus, any collaborative network should be implemented in this model, especially during response time. However, concurrent engineering has been never applied in emergency management yet. This research aimed to develop a new concurrent engineering model using cross-functional intervention among emergency management stakeholders to enhance recovery capacity based on the concept of resilience. The objectives of this research were to identify effective factors of the concurrent engineering model as clustered intervention utilized to speed up recovery effort and restorative capacity towards the resilience approach. It could also help develop a cross-functional intervention network based on the mass of output-input data for sharing information. Finally, this research developed a concurrent engineering model among stakeholders' workgroups. This model can be implemented during the planning process, and it can operatively work during the response and recovery periods.

2. Methodology

Different methodologies were employed to generate qualitative and quantitative data at different stages of the research. These methodologies were literature review and its content analysis, structured interview, and analysis of the multi-attribute decision-making method using the Analytic Hierarchy Process (AHP). Different types of data collected are also used to support the triangulation approach of this research. Fellows and Liu (1997) defined triangulation as the use of two or more research methods to investigate the same thing. Moreover, Jakob (2001) added that triangulation is the application and combination of several research methodologies in the research of the same phenomenon used to obtain confirmation of findings through the convergence of different perspectives taken from both quantitative and qualitative methodologies. The procedures of this research are summarized in **Figure 4**.

In the first step of this research, the grouping of stakeholders and their intervention were based on the literature, documents, and codes in Iranian emergency management organizations. Content analysis was employed to classify and categorize the intervention in the main divisions and sub-divisions. Since different organizations participate in a specific area of expertise, it is very important to have workgroups consisting of related divisions in each organization. For instance, based on governmental rules, the security workgroup needs the participation of the army, the police, the Intelligence Ministry, and the National Guard during emergency conditions. Thus, content analysis was used to identify the participants in the subject-based workgroups to categorize all stakeholders.

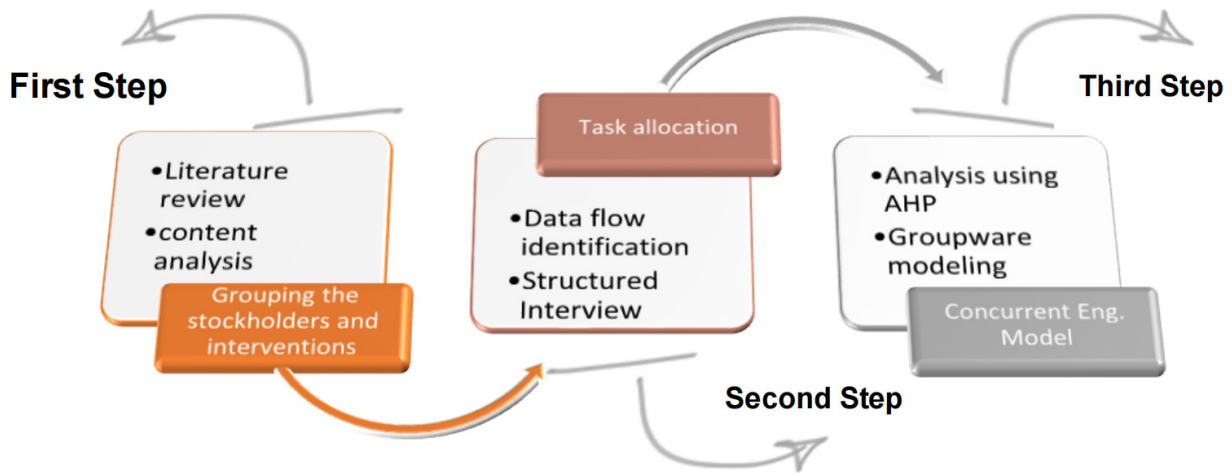


Figure 4. Summary of reasearch methodology

In the second step, structured interviews were designed. Structured interviews are closed and quantitative, in which questions and response categories are determined in advance. Responses are fixed, and interviewees choose among the fixed responses or respond in terms of a number. In this study, the interview answer sheet was a table that consists of different workgroups against divisions and sub-divisions of emergency management intervention. As shown in **Figure 5**, the interviewees would assign 0 or 1 to show production or need of any sharing information for each workgroup under each type of intervention.

Moreover, they should indicate the access level of each workgroup based on their members' access level. The other important task was to transpose these ratings to the acceptable rating system that can be used in the AHP. Thus, a transposing system was employed, as indicated in **Table 1**. **Table 2** illustrates the transposing system when the workgroups were compared with each other. The interviews were conducted with 15 experts, of which three of them were from emergency management headquarters of the army, three from the police, two from public participants'

Main divisions of intervention Sub-divisions of intervention Produced sharing data Needed data

Main Division : Operations												INFORMATION	GROUPWORKS
IT	Building and services		Health and safety		Rescue and relief		Public security		Medical facilities				
												output data	Workgroup 1: Hazards and threat monitoring
2	1	2	1	2	1	2	1	2	1	2	1	Input data	
												Access level	Workgroup 2: Households and public participation
												output data	
												Input data	
2	1	2	1	2	1	2	1	2	1	2	1	Access level	

Figure 5. Answer sheet description

organizations and NGOs, three experts from academia, and two experts from rescue and relief organizations, which was the Red Crescent. In the third step, the AHP method was employed to identify the amount of data and the needed space in the ICS data center for each workgroup under emergency circumstances. **Figure 6** illustrates the conceptual model of this research based on AHP principles.

Table 1. Transposing answer to numbers for the structured interview

Type of information	Code	Answer
Output data	0	There is not any important production of information in this sub-division
	1	There is important information produced in this sub-division
Input data	0	This workgroup does not need any important sharing information from this division
	1	This workgroup needs sharing information from this division
Access level (Applicable if the input data is not 0)	1	Limited access
	2	Unlimited access

Table 2. Qualitative transposing system

Difference	Qualitative transposing value
0	E (Equal)
1	S (Strong)
2	V (Very strong)
3	X (Extreme)

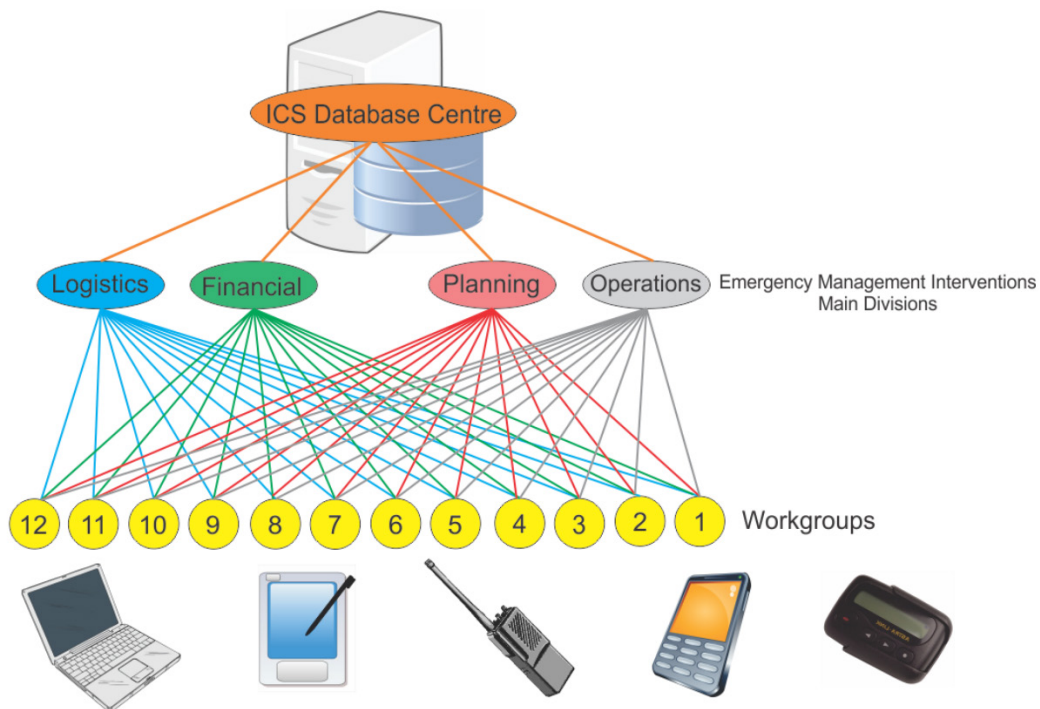


Figure 6. Conceptual AHP model

3. Results and discussions

3.1. Content analysis: Stakeholders' workgroups

A comprehensive content analysis was carried out to indicate the workgroups of stakeholders during emergency conditions. The Army Corps, security services, NGOs, the National Guard, municipal organizations, and other related organizations have their application and task by different types of intervention. All of these organizations are concerned about how the total system and the society perform during and after natural and manmade disruptive events. Based on the legal documents and the instructions of the municipal emergency management center, task-based workgroups should be established and formed to be functional during disasters.

Accordingly, the first task-based workgroup should be the committee of hazards and threat monitoring. The principal tasks of this committee correspond to the principles of risk assessment in threat analysis, vulnerability assessment, consequence analysis, and even attacker or hazard analysis (Al Mannai, 2008). The second task-based workgroup is the committee of households and public participation. Different NGOs and organizations are involved normally during training for disaster management. However, the main collaborator for this reason in Iran is a public participants' organization, which is the Basij. Other NGOs and workgroups, such as Community Emergency Response Teams (CERTs), collaborate with the political and security deputy of Iran's Interior Ministry. The committee of learning, training, and information is the third workgroup that controls the educational frameworks related to disaster management for institutes, companies, agencies, and households. The committee of rescue and relief and the committee of health and medical care are two important workgroups related to the response period. The committee of transportation and lifelines; the committee of supplying fuel, oil, and petroleum; the committee of logistics; and the committee of communication and telecommunications are four important supplying workgroups during response and recovery time. The committee of insurance, recovery, rehabilitation, and reconstruction is a workgroup that especially functions during recovery, and it should be governed by credit and housing organizations, such as the Central Bank of Iran, Central Insurance of Iran, Housing Foundation of Islamic Revolution, the Ministry of Roads and Urban Development. Other organizations and ministries in the field of infrastructure also provide services as members of this workgroup. The other important field is providing a secure situation during response time. Thus, two workgroups were indicated with a general scope and a specific scope. The committee of safety and security focuses on the general scope of security, which is monitored and led by the political and security deputy of Iran's Interior Ministry, the police, the National Guard, the Army Corps, and the Intelligence Ministry of Iran. The specialized and technical committee is the committee of nuclear, biological, chemical, and radiological (NBCR) threats, which is handled by the National Guard, Iran's Ministry of Defense, the police's Special Guard, and the Intelligence Ministry of Iran. The content analysis of literature for indicating the workgroups as stakeholders of disaster management is stated in **Table 3**.

3.2. Content analysis: Main divisions and sub-divisions for disaster management intervention (effective factors)

Using the incident command system (ICS) model seems to warrant the success of emergency operation centers (EOCs) during disaster time. Thus, implementing the organizational structure

Table 3. Content analysis of literature for indicating the workgroup committees in disaster management

Workgroup number	Workgroup committees	Members									
		(Jalali Farahani, 2012)	(Abhari, 2011)	(Setaareh et al., 2011)	(Movahedinia, 2009)	(Givchchi and Jamshidi, 2011)	(Tavakoli, 2012)	(Tavakoli and Razmi, 2013)	(Alamdaari, 2010)	(Eskandari, 2013)	(Azadehdel et al., 2012)
1	<u>Committee of hazards and threat monitoring</u> Crisis Management Organization of Interior Ministry of Iran, Municipal Emergency Management Centre, Iran Ministry of Roads and Urban Development, Iran Ministry of Agriculture Jihad, National Guard, Intelligence Ministry of Iran, regional water companies, environment organizations, passive defense organizations	✓	✓	P	✓	×	✓	P	P	✓	P
2	<u>Committee of households and public participation</u> Political and security deputy of Iran Interior Ministry, public participants' organizations	P	P	×	O	×	✓	✓	✓	O	✓
3	<u>Committee of learning, training, and information</u> Iran Broadcasting, Iranian Islamic Development Organization, Iran Ministry of Islamic Culture and Guidance, Islamic Culture & Communication Organization of Iran	P	×	O	✓	✓	P	P	✓	P	✓
4	<u>Committee of rescue and relief</u> Red Crescent, Red Cross, fire departments, Iran Ministry of Health and Medical Education, National Guard, Army Corps	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5	<u>Committee of communication and telecommunications</u> Iran Ministry of Communication and Information Technology	O	×	O	P	✓	O	×	P	P	✓
6	<u>Committee of health and medical care</u> Red Crescent, Red Cross, fire departments, Iran Ministry of Health and Medical Education, National Guard, Army Corps	P	P	O	×	P	P	✓	✓	P	✓
7	<u>Committee of transportation and lifelines</u> Iran Ministry of Roads and Urban Development, Iran Ministry of Communication and Information Technology, Iran Ministry of Energy, Ministry Oil and Petroleum	×	P	✓	O	✓	O	×	×	✓	✓
8	<u>Committee of safety and security</u> Political and security deputy of Iran Interior Ministry, police, National Guard, Army Corps, Intelligence Ministry of Iran	P	P	O	P	P	P	P	P	×	P
9	<u>Committee for supplying fuel, oil, and petroleum</u> Iran Ministry of Industry, Mine, and Trade; Iran Ministry of Energy; NIOPDC; NIGC	O	×	×	✓	✓	O	O	P	P	O

Table 3. (Continued)

Workgroup number	Workgroup committees										
	Members	(Jalali Farahani, 2012)	(Abhari, 2011)	(Setaareh et al., 2011)	(Movahedinia, 2009)	(Givhechi and Jamshidi, 2011)	(Tavakoli, 2012)	(Tavakoli and Razmi, 2013)	(Alamdaari, 2010)	(Eskandari, 2013)	(Azadhel et al., 2012)
10	Committee of insurance, recovery, rehabilitation, and reconstruction										
	Central Bank of Iran; Central Insurance of Iran; Housing Foundation of Islamic Revolution; Iran Ministry of Roads and Urban Development; National Guard; Army Corps; Iran Ministry of Energy; Iran Ministry of Industry, Mine, and Trade	✓	✓	×	✓	✓	✓	P	✓	✓	✓
11	Committee of logistics										
	National Guard; Army Corps; Red Crescent; municipals; Iran Ministry of Industry, Mine, and Trade; Iran Ministry of Cooperatives, Labour, and Social Welfare	P	P	×	×	O	✓	✓	✓	P	✓
12	Committee of nuclear, biological, chemical, radiological (NBCR) threats										
	National Guard, Iran Ministry of Defence, police's Special Guard, Intelligence Ministry of Iran	✓	✓	×	✓	P	×	×	O	✓	✓

of ICS as the core of disaster management intervention makes it the best policy under concurrent engineering. ICS is primarily a command-and-control system delineating job responsibilities and organizational structure for managing day-to-day operations for all types of emergency incidents (Jamieson, 2005). Consequently, all types of disaster management intervention also should be categorized under the divisions of the ICS model. ICS helps to ensure the safety of responders and stakeholders, supports in achieving tactical objectives, and provides efficient use of resources. The operations and the planning divisions are the most important divisions during emergencies. However, planning helps teams to be prepared and trained for the response period. During response time, the intervention regarding the operations divisions is more highlighted. **Figure 7** illustrates the graphical content analysis of the literature on the main divisions for disaster management intervention. The other important division is the logistics division, which is supervised by logistics coordinators. However, this research did not consider the staff under each division. The logistics division provides all resources and support for the response operation, including procurement, delivery arrangements, and deployment of resources. The logistics division is responsible for providing support to the operations division. Finally, the last division is the finance division. The finance division is responsible for all accounting and financial aspects of the disaster and any other administrative requirements.

The operational response is overseen by functions or branches activated to deal with the emer-

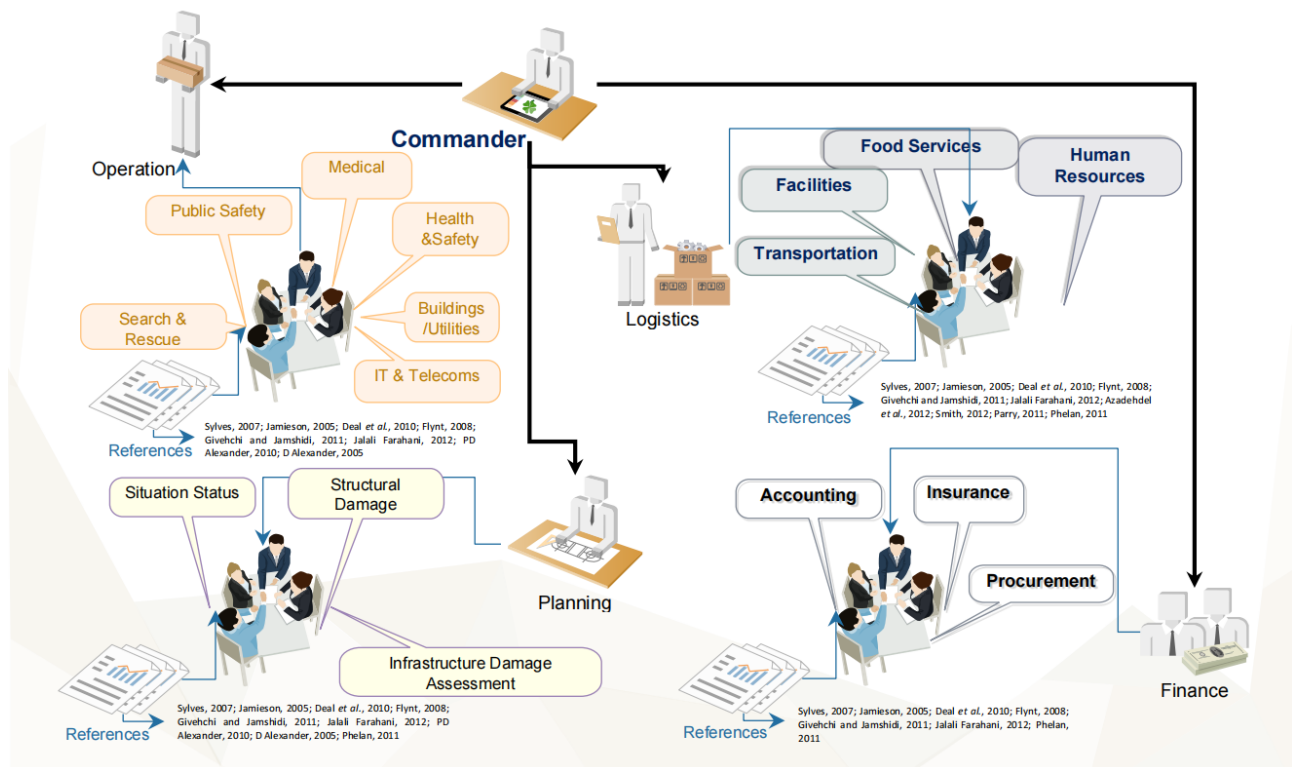


Figure 7. Graphical content analysis of main intervention for disaster management

gency. The operations division is responsible for coordinating all operations in support of emergency responses and the implementation of action plans. The response teams are the main member of this division. These teams try to reduce the immediate hazard and to establish controlling actions and the restoration of normal conditions. The functional sub-divisions under operations are public safety, medical, IT/telecommunications, health & safety, buildings & utilities, and search & rescue. These sub-divisions cluster the interventional actions, as shown in **Figure 8**, which were extracted from literature.

Although planning is a critical task during the pre-disaster time, the situation status sub-division under the planning division during response time plays an effective role in feeding all service providers and stakeholders by providing correct and comprehensive information (de Silva, 2001; Alexander, 2002; 2005). Damage assessment of general assets and infrastructures are the responsibility of other sub-divisions of the planning division, which are carried out by sub-divisions such as inspection, damage estimation, documentation, repair or replace, and planning for business continuity (Davison, 2014; Parry, 2011; Setaareh et al., 2011; Schafer et al., 2008; Alexander, 2005; Pearce, 2003). **Figure 9** illustrates the clusters of sub-divisions for the planning division.

In the aftermath of natural disasters, efficient emergency logistics plays a vital role in providing a quick response to urgent relief needs. Locating and providing water and food, sheltering, locating alternative sites, and maintaining operational facilities are the main preliminary intervention (Sheu, 2007; Caunhye et al., 2012; Kovács and Spens, 2007; Zhou et al., 2011; Alexander, 2010; Lindell et al., 2006; Davison, 2014; Jalali Farahani, 2012; Pearce, 2003). Transportation, access roads, and path selection are fundamental problems in emergency logistics management (Lindell et al., 2006; Yuan and Wang, 2009; Caunhye et al., 2012; Siegel, 1985). Managing volunteers and CERT groups

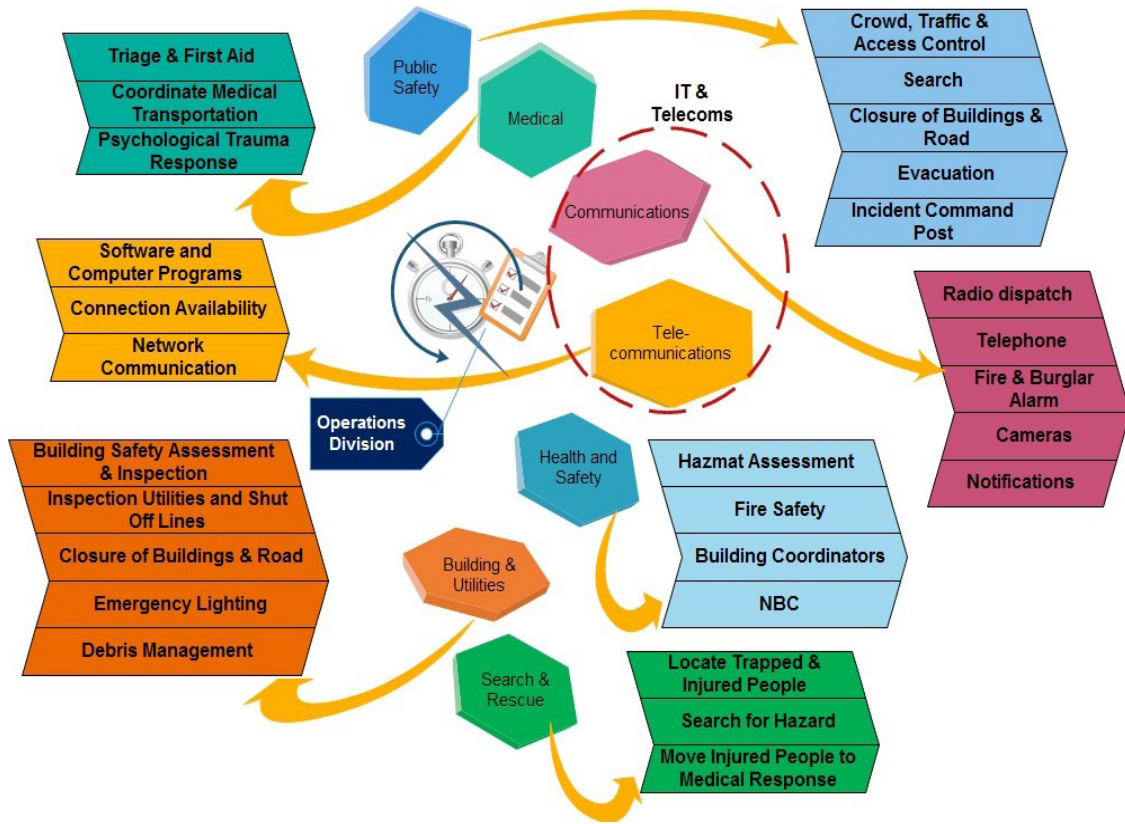


Figure 8. Interventional sub-divisions under the operations division

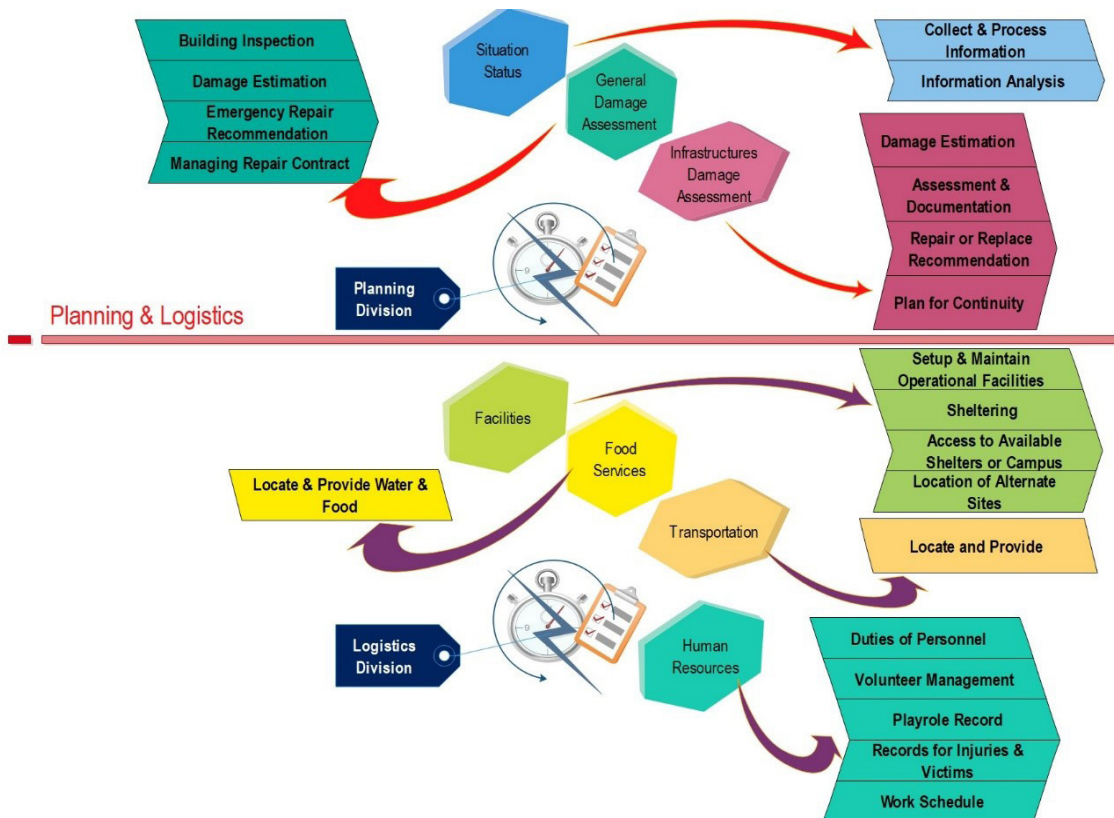


Figure 9. Interventional sub-divisions under the planning and logistics divisions

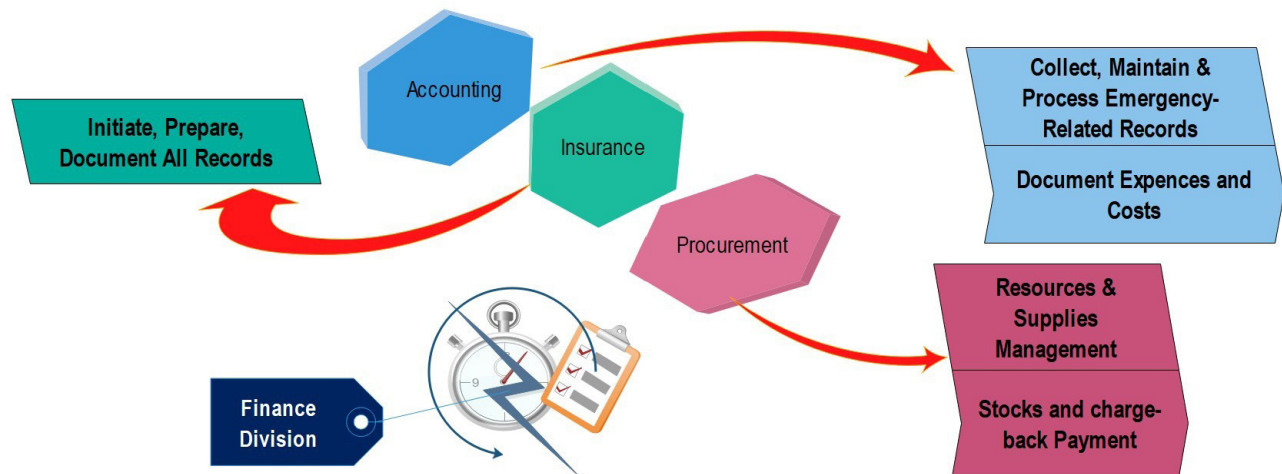


Figure 10. Interventional sub-divisions under the finance division

and scheduling and assigning roles, tasks, and personnel’s duties are the other important intervention according to roles’ assessments (Siegel, 1985; Lindell et al., 2006; Alexander, 2010; Jalali Farahani, 2012). Figure 9 illustrates the intervention under the logistics domain.

The other important intervention is financial. The financial domain covers accounting, insurance, and procurement sub-divisions. Collecting, maintaining, and processing emergency-related records, as well as documenting expenses and costs, form the accounting sub-division. The other important duty of this division is in terms of insurance to support the refugees and victims. The insurance sub-division should initiate, prepare, and document all records to support the rehabilitation and reconstruction of the damaged areas following the recovery period. Having insurance has sometimes been identified as a mitigation strategy, and it is also important to increase hazard insurance awareness among households and other stakeholders. Managing resources, including stock checking and auditing and supplying materials, are other types of intervention under the finance division (Parry, 2011; Lindell et al., 2006; Alexander, 2010; Canton, 2007; Arnold et al., 2005; Farazmand, 2001; Jamieson, 2005; Eskandari, 2013; Azadehdel et al., 2012; Alamdaari, 2010). **Figure 10** illustrates the graphical content analysis of the intervention under the financial domain.

3.3. Cross-functional intervention network: Literature-based model of interaction between workgroups and divisions

After indicating the workgroups and divisions of the emergency management intervention by analyzing the content of governmental rules and literature, it was very critical to develop a model for the interactive process of information between these divisions and workgroups. The workgroups with more critical tasks and duties normally should have a greater share of output information, as they need the information to handle situations appropriately. Otherwise, the workgroups with operational tasks should have a greater share of input information. The preliminary weighted model based on current documents was developed among workgroups and sub-divisions under each division. **Figures 11–14** illustrate the process of information in ICS divisions. Figure 11 illustrates the interaction of the workgroups (which are represented with their numbers) with the sub-divisional intervention. For instance, Workgroups 3, 4, and 10—which are the committee of learning, training, and information; the committee of rescue and relief; and the committee of insurance, recovery, rehabilitation, and reconstruction—have the greatest interactions in the operations division’s

information process. These interactions include the input and output of data.

Based on the available documents and bills, the committee of hazards and threat monitoring and the committee of communication and telecommunications have the greatest share of information in the planning division.

In the logistics division, most of the workgroups are engaged with the process of information. This division provides all services and vital materials and facilities for emergency management

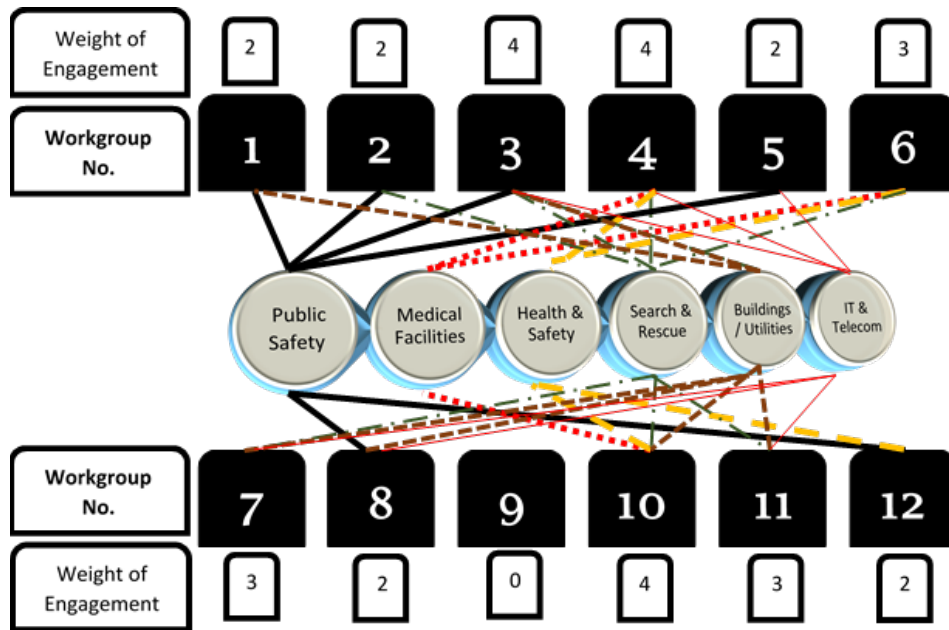


Figure 11. Process of information in the operations division

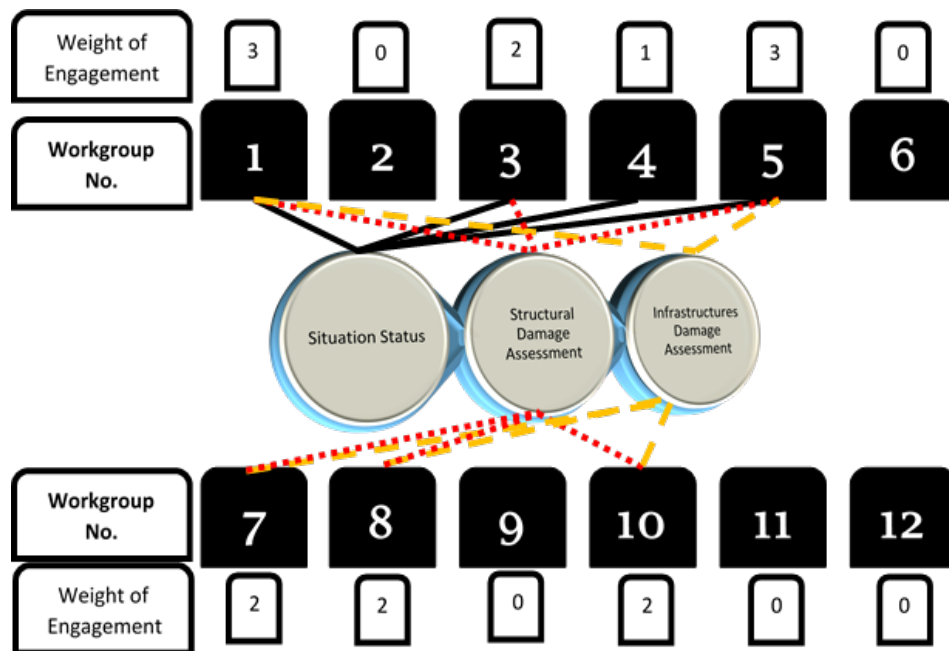


Figure 12. Process of information in the planning division

stakeholders. Figure 13 shows the process of information in the logistics division.

The final division is the finance division. This division provides the financial flow for all divisions in the ICS model. Thus, the engagement of all workgroups is clear in Figure 14. However, Workgroups 10 and 11, which are the committee of logistics and committee of insurance, recovery, rehabilitation, and reconstruction, have the greatest weight of engagement. The reason is that the committee of logistics needs to highly interact with the finance division to provide better facilities and services.

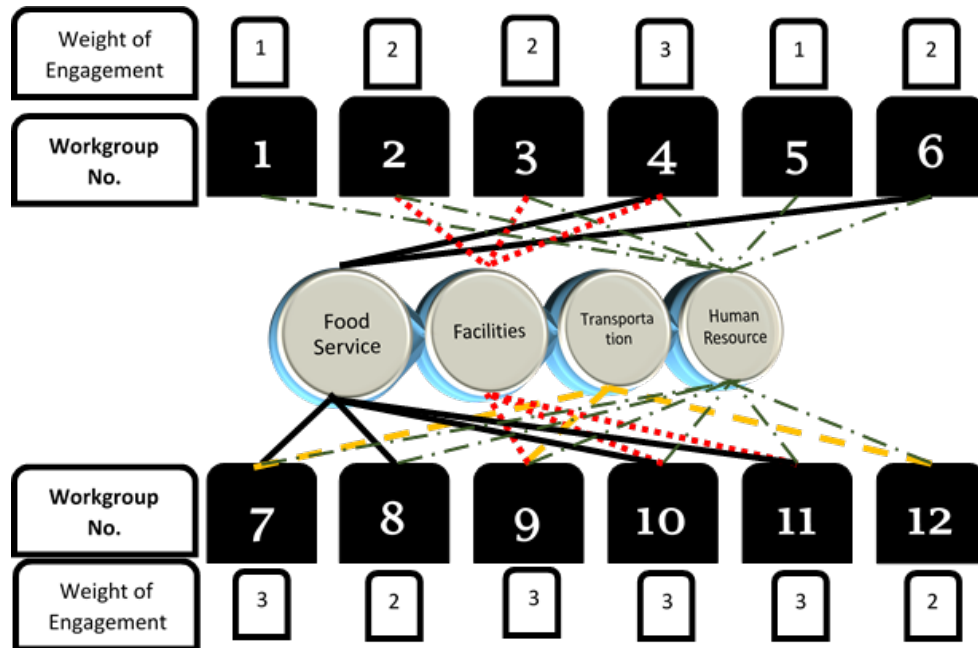


Figure 13. Process of information in the logistics division

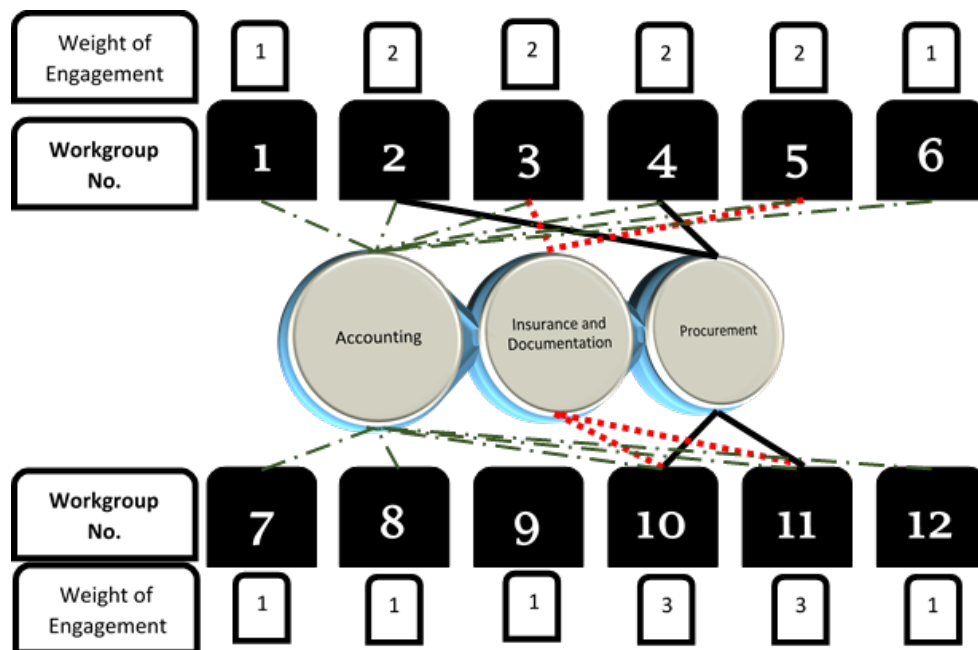


Figure 14. Process of information in the finance division

4. Concurrent engineering model among stakeholders' workgroups

To develop the final weighted CE model, it is necessary to determine the bandwidth of the received and transmitted data for the stakeholders and the central server. Moreover, the share values of information as a weight of each division and its sub-divisions represent the considered occupied space in the data center for that division. The weights of divisions and sub-divisions help designers and experts to design the space of entities for each division and its sub-divisions in the data center appropriately. Thus, in the first step, the weight of each division was determined from the structured interviews, as shown in **Figure 15**.

Figure 15 illustrates that the operations division achieved the highest weight of information interchange during the response to disasters, as the operations division had the highest engagement by using six sub-divisions. The planning and logistics divisions achieved similar values of 0.217 and 0.209. The least value of information interchange was for the finance division. This is because of its limited number of sub-divisions and engaged workgroups, as most of the communication with this division is single-way communication. The records showed that this division often uses information rather than producing and transmitting data to other divisions. The weights of information interchange among sub-divisions are also indicated in Figure 15. The results of the interviews should support the literature-based model of interaction between workgroups and divisions, which was extracted from the literature in the previous section. The most weighted sub-division is the search and rescue subdivision, which has connections to seven workgroups based on the literature-based model of interaction between workgroups and divisions. This confirmed the result of the

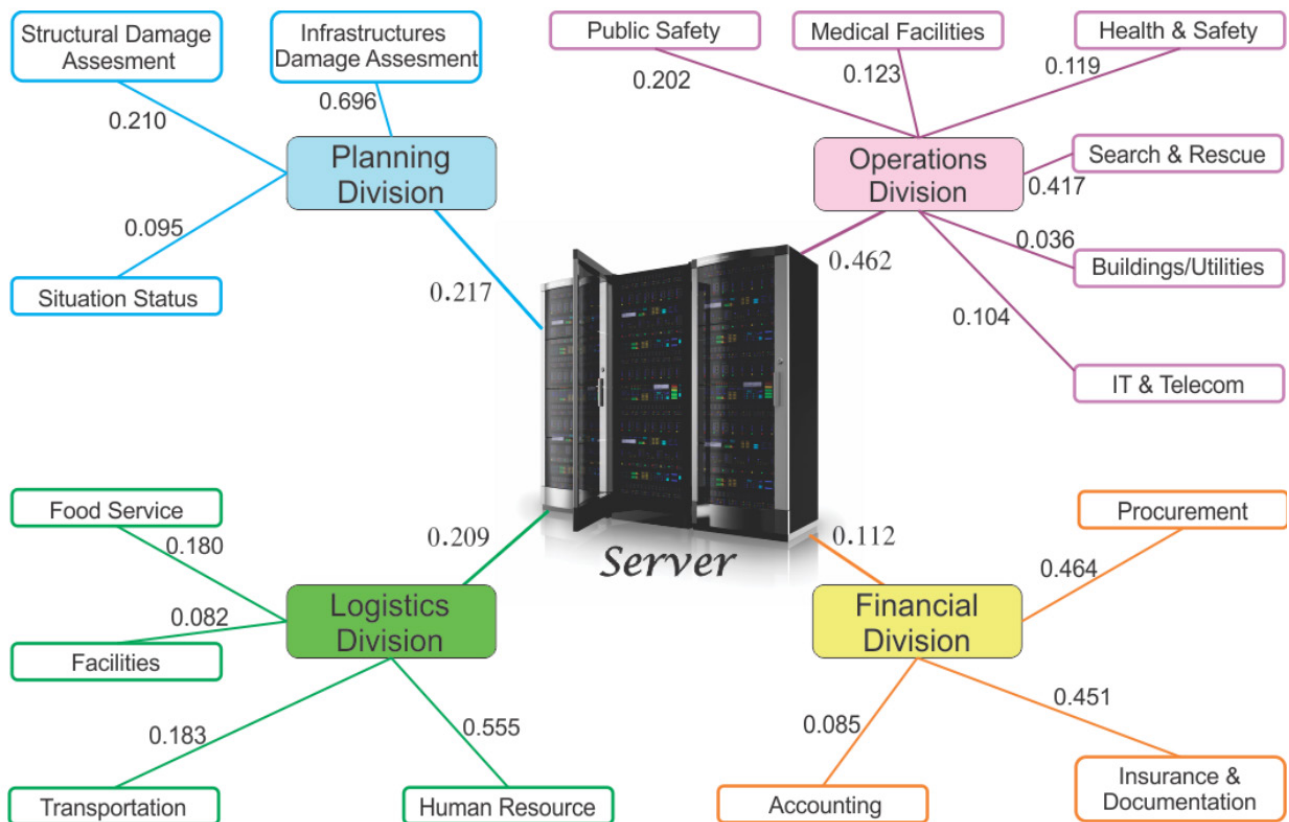


Figure 15. Result of weighting procedure for main divisions and their sub-divisions

structured interviews, as the search and rescue sub-division achieved the highest weight among the sub-divisions. The human resources sub-division from the logistics division, infrastructure damage assessment sub-division from the planning division, and the procurement sub-division from the finance division achieved the highest weights from the interviews. This result supported the result of content analysis extracted from literature in the previous section.

In the next step, the concurrent engineering model among stakeholders' workgroups was developed by using the AHP method. The interaction of workgroups with each sub-division was assessed from the structured interviews. Then, pairwise comparisons between workgroups under each sub-division were carried out by using the qualitative transposing system, which was presented in Table 2. The relative preference in the amount of input and output information was compared concerning each sub-division. The share value of exchanging information for workgroups was synthesized under the hierarchy of divisions and sub-divisions of emergency management intervention (Figure 16). Figure 17 illustrates the weighted model of CE among stakeholders' workgroups for exchanging information. The inconsistency of judgment in the AHP model was less than 0.09 in all stages of comparison, which was at an appropriate level of judgment.

It is clear from Figure 17 that the committee of logistics (Workgroup 11) and the committee of rescue and relief (Workgroup 4) achieved the widest bandwidth of information flow in the CE model. The existence of divisions and sub-divisions with the same intervention is the main reason for this fact. The committee of NBCR (Workgroup 10) followed closely the two foremost committees in the CE model. Since the committee of learning, training, and information (Workgroup 3) is more dependent on its own mass media networks, it achieved the least bandwidth of information flow in this CE model.

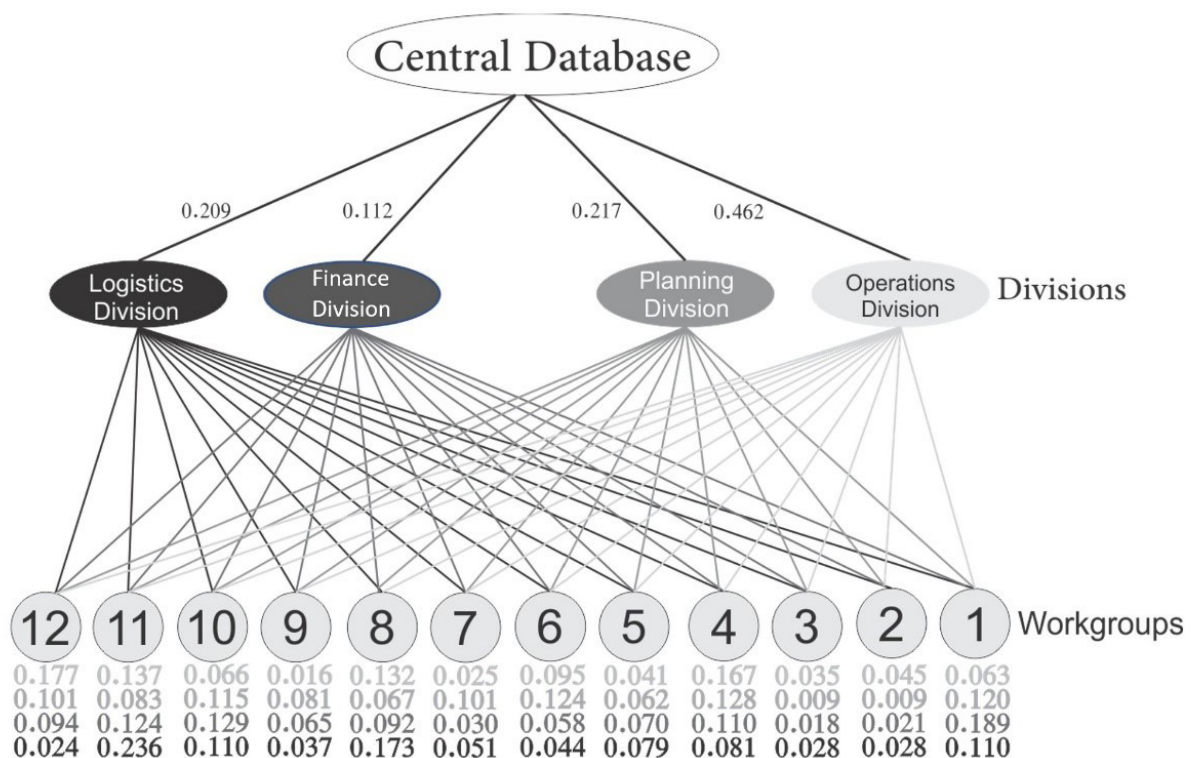


Figure 16. Relative share value of exchanging information for each workgroup under overall divisions and sub-divisions by the AHP method

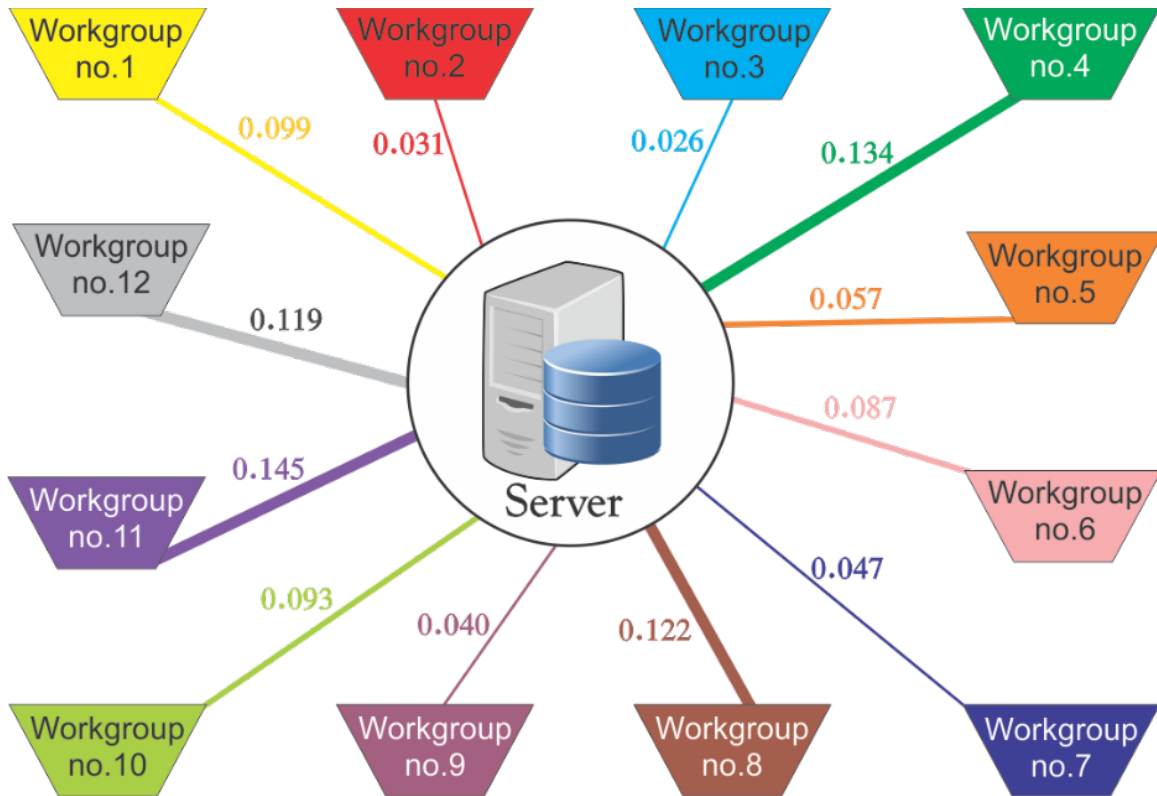


Figure 17. Weighted model of CE among stakeholders' workgroups for exchanging information

5. Conclusion

Resilience is an important character to promote livable and safe places. It helps to balance environmental and development issues. Thus, resilience strategies help policymakers to provide flexible and multi-layered systems to deal with the forces of nature. Concurrent engineering (CE) is a production management philosophy that originated from the manufacturing industry, which enhances recovery effort in the concept of resilience. This research found that CE is a viable concept to be implemented in emergency management. Previous literature showed that CE has been applied by industries to achieve a collaborative teamwork environment and to change the traditional method of working. The main aim of this research was to develop an integrated model for the flow of information as the main asset in emergency management by using concurrent engineering philosophy. This model can help stakeholders to provide a better collaborative teamwork environment during disasters based on their duties, tasks, or achievements. The results of this paper contributed to the applicable clustering of emergency management intervention and related workgroups, including all organizations and stakeholders during response time. The final model and the relative share value of exchanging information among each workgroup can help database designers and decision-makers to allocate enough space and routes for exchanging data and information, especially during a disaster.

This research introduced 12 workgroups, which have a more distinguished and distinct boundary from each other. However, the organizations that participate in these workgroups could be reiterative in some cases. The intervention is also divided into main and sub-division categories following the

incident command system (ICS) model. The integrated model showed a huge amount of exchanged data by three main committees, which were the committees of logistics, rescue and relief, and NBCR. Thus, it is very important to provide fast and easy access to the database for the participants of these workgroups, with the committee of logistics as the team to support, repair, and maintain the data center and infrastructures for this collaborative network. Moreover, the operations division also needs the greatest room for saving and transforming data.

Finally, it should be mentioned that the main contribution of this model is the performance of data sharing as a helpful collaborative tool during the hardest and the most crowded time of a disaster. Thus, the performance of this model will be enhanced by good training of all stakeholders and engaged organizations to clarify their duties and tasks. It is important to indicate the needs of each workgroup and to unify different participants in each committee by implementing an appropriate organizational structure, in addition to skillfully protecting the whole system of the database and its infrastructures.

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