STRUCTURAL CHARACTERISTICS OF HUMANITARIAN SUPPLY NETWORK

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Introduction

In disaster relief operations, The humanitarian supply network (HSN) consists of various actors involved such as donors, aid agencies, NGOs, governments, military, and logistics service providers, and suppliers (Kovács and Spens, 2008), community-based organizations, beneficiaries (Oloruntoba and Gray, 2006), media (Van Wassenhove, 2006). The collection of organizations that deliver humanitarian assistance can be understood as a complex open system, consisting of specialized units that are loosely coupled, socially connected, and highly dependent on external resources (Seybolt, 2009).

These actors differ in local presence, size, and mandate. Typically, no single actor has sufficient resources to respond effectively to a major disaster (Balcik et al., 2010). This difference in organizational structure affects the response times of these organizations (Kovács and Spens, 2009). The effective and efficient distribution of relief goods is a key challenge in disaster management. Typically, humanitarian supply network need to be built, in which various actors with different interests collaborate.

The collaboration occurs when different actors work together to address problems through joint effort, resources, decision-making (Zhao et al., 2012). Through collaboration, organizations negotiate and agree on the goals of their shared efforts and on the amount of contribution each partner must bring to execute the collaboration; in addition, organizations must align their actions to achieve the specified goals (Gulati et al., 2012). Collaboration efforts between actors in humanitarian supply network have been challenged due to characteristics of humanitarian aid environment as it is large, highly complex, differentiate, unstable, and moderate connectivity (Seybolt, 2009). Moreover, extreme demand and supply uncertainty is another obvious barrier to build relationship with other actors in the particular field (Van Wassenhove, 2006). Thereby, collaboration is considered as critical success factor of strategic plan in order to enhance the delivery performance (Pettit and Beresford, 2009). The purpose of this paper is to investigate structural characteristics of humanitarian supply network of disaster relief operations in Khon Kaen province by using social network analysis.

Literature review

Humanitarian Supply networks

The humanitarian supply network can also be called inter-organizational collaboration network (Zhao et al., 2012). Evaluating humanitarian supply network effectiveness is critical for understanding whether networks are effective in meeting the goals of the network as a whole, those of the individual network members and more importantly, the extent to which the needs of the affected people have been met (Ngamassi et al., 2014). Establishing the level of network effectiveness is also important for actors in the network and those whose policies and funding support the network. Ideally an effective humanitarian supply network would enhance the quality of service provided to its beneficiaries; optimize use of resource by reducing redundancies; however at a minimum it should achieve its own goals.

While coordination mechanisms within the domain of commercial supply chain management have been well studied, coordination in humanitarian relief chains is still in early stage (Balcik et al., 2010). Inter-organizational networks are believed to be a way to improve collaboration among humanitarian organizations. Although researchers have devoted a considerable amount of time exploring the influence of network structure on network performance and effectiveness, little work has been done in the humanitarian relief field (Ngamassi et al., 2014). Therefore, it is increasingly important to analyse the network structure of humanitarian supply network.

Social network analysis (SNA)

Social network analysis (SNA) has recently gained acceptance among scholars for its potential to integrate the operations and supply management field with other branches of management science (Autry and Griffis, 2008; Borgatti and Li, 2009a, 2009b; Carter et al., 2007). SNA is an approach for examining the patterns of relationships that arise among interacting entities in supply chain operations. Specifically, SNA provides researchers a descriptive and statistical method to understand how supply network components are positioned, connected, and embedded within the supply network (Bellamy and Basole, 2013).

SNA provides both node- and network-level measures (Wasserman and Faust, 1994). SNA has proven to be a valuable lens and mechanism to compute and analyse salient structural and relational properties in numerous disciplines, including organizational theory and behaviour, strategic management, business studies, sociology, computer science, physics, psychology, joint ventures, interfirm alliances, knowledge transfer, and innovation (Provan et al., 2007). Surprisingly, there is comparatively little work that uses SNA in supply chain management. (Borgatti and Li, 2009b) provide an initial overview of SNA and its potential network mechanisms and properties that can be implemented by SCM researchers.

SNA is both an approach and an analytical method, allows for an in-depth investigation of the structural characteristics and the inherent relationships of such networks that would not be easily understood if investigated by traditional research approaches (Carter et al., 2007; Dempwolf and Lyles, 2012; Hollenbeck and Jamieson, 2015)

A network is made up of nodes and ties that connect these nodes. In a social network, the nodes (i.e., persons or firms) have agency in that they have an ability to make choices. With its computational foundation in graph theory (Cook, 1998; Kirchherr, 1992; Li and Vitanyi, 1991). Social network scholars (Everett and Borgatti, 1999; Freeman, 1978, 1977; Krackhardt, 1990; Marsden, 2002) have developed a range of network metrics at the node-level and network-level to characterize the dynamics inside a social network.

Social network analysis metrics

Node-level metrics

Node-level metrics measure how an individual node is embedded in a network from that individual node's perspective. Identifying the key actors in a social network is one of the primary uses of SNA (Wasserman and Faust, 1994). The concept of centrality is fundamental to node-level network metrics (Borgatti and Li, 2009a; Everett and Borgatti, 1999). Centrality reflects the relative importance of individual nodes in a network. There are different types of centrality metrics and they identify nodes that are important, in different aspects. Most prominent are as follows:

Node-level metrics	Definition	Supply network context	Calculation
Degree centrality	The number of direct ties to a node.	The extent to which the firm influences other firms on their operations or decisions as the firm has more direct contacts with others (Cachon and Lariviere, 2005; Ferguson et al., 2005).	$C_D(n_i) = \sum_j x_{ij} = \sum_j x_{ji}$
Closeness Centrality	Measures how many steps is required to access every	The extent to which a firm can act autonomously and	$C_C(n_i) = \left[\sum_{j=1}^{g} d(n_i, n_j) \right]^{-1}$

	other node from a given node.	navigate freely across the network to access resources in a timely manner (Kim et al., 2011).	
Betweenness Centrality	Measures how often a node lies on the shortest path between all combinations of pairs of other nodes.	The extent to which a firm can affect the interactions among others in the same supply network (Kim et al., 2011).	$C_B(n_i) = \sum_{j<k} \frac{g_{jk}(n_i)}{g_{jk}}$

Table 1: Node-level metrics

Network-level metrics

Social Network Analysis also yields metrics concerning the structure of the overall network, such as network density, network centralization, and network complexity. Network level metrics compute how the overall network ties are organized from the perspective of an observer that has the bird's eye view of the network.

Network topologies

Network topology is the structure of the network as a whole. The network topology can reveal characteristics of the network and behaviours (McCulloh et al., 2013). Moreover, the network topologies characterize the overall structure or configuration of a network. This can help researchers and managers in understanding how supply network function.

Developing supply network topologies will help advance existing theories on supply network structure (Borgatti and Li, 2009c; Kim et al., 2011). Random, small-world, and scale free network topologies are commonly used to represent real life supply network (Nair and Vidal, 2011). The measures can be characterized by values such as clustering coefficient, average shortest path and degree distribution of the network.

Research Methodology

This study focus on the case study of humanitarian supply network in disaster relief operations in Khon Kaen province. The province is divided into 26 districts. The 198 sub-districts and 2,139 villages. The province has local administration organizations comprise of 1 Provincial Administration Organization, City Municipality, Town municipality, Sub-district municipality and Sub-district Administration Organization. Khon Kaen province faces challenges caused by various disasters such as flood, storm, drought, fire, cold spell, forest fire and smoke and infectious disease (KKDPMPO, 2015).

Data source and Network construction

This study utilizes multiple data sources from the qualitative study such as documents and semi-structured interviews to create the structure of humanitarian supply network in disaster relief operations in Khon Kaen province. The related actors in disaster relief operations are assigned as nodes in the network. The links between actors are derived from collaboration relationship. This study used reciprocated collaborative links, meaning that both actors indicated that they collaborated. The collaboration occurs when different actors work together to address problems through joint effort, resources, decision-making (Zhao et al., 2012). The collaboration relationship among actors can be denoted by an inter-organizational collaboration network. In such a collaboration network, a node represents an actors and a link that connects two nodes means that the two actors are collaborators.

Each actor is constructed as a binary adjacency matrix, with cell entries is 1 if there is any relationship between two actors and 0 otherwise. As collaborative relationships are considered to be bi-directional, the humanitarian supply network resulted in an undirected graph (Newman et al., 2001).

Data analysis

In this study, *R programming language* and *igrapg package* which is a library collection for creating and manipulating graphs and analysing networks (Csardi and Nepusz, 2006) is used to visualizing the network, compute node-level metrics and network-level metrics.

<u>Results and Interpretation of results</u>

Real Structure of the humanitarian supply

A network visualization technique is used to depict the humanitarian supply network structure. R programming language and igrapg package is used to visualize the humanitarian supply network. The Reingold-Tilford layout (Reingold and Tilford, 1981) is used to create visually appealing and insightful the humanitarian supply network representation. Fruchterman-Reingold is one of the popular force-directed layout algorithms (Ognyanova, 2015). Force-directed layouts try to get a nice-looking graph where edges are similar in length and cross each other as little as possible. The links act as springs that attract connected nodes closer together. As a result, nodes are evenly distributed through the chart area, and the layout is intuitive in that nodes which share more connections are closer to each other. The real structure of the humanitarian supply is shown in Figure 1. The nodes colours in the network reflect the groups of the actors.

Networks are often most easily viewed using familiar visual forms such as circles (Cherven, 2015). Concentric layouts allow us to take advantage of this. Nodes are arranged in series of concentric circles base on the distance from the focal node. So, nodes with direct connections are arranged in the first circle followed by nodes that are at distance of two nodes away from the centre and so on. By arranging nodes in this concentric fashion, viewers are able to more easily navigate small network structures and see the closeness of relationships to a single node, and to each other. This study is also used the concentric layout approach to visualize the humanitarian supply network. The focal node is placed at the centre of the visualization while nodes k steps away from the focal node are placed on the k^{th} circle.

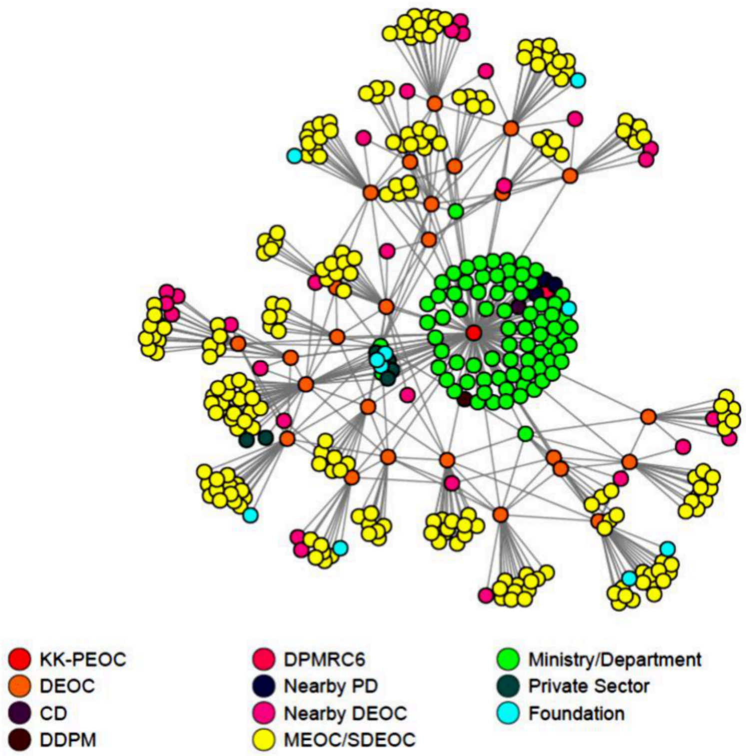

Figure 1: Visualization of humanitarian supply network in disaster relief operations in Khon Kaen province.

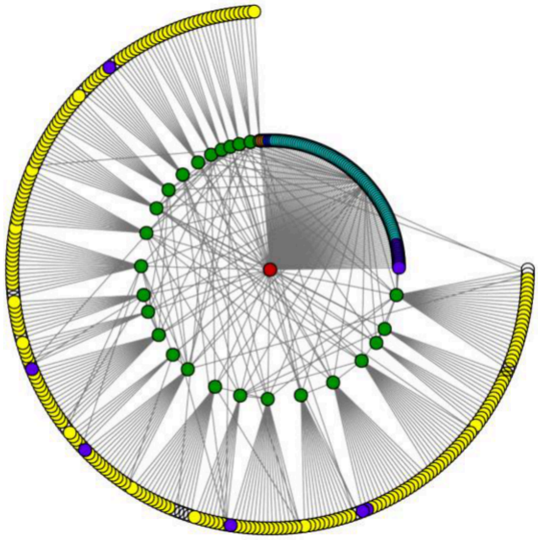

Figure 2: Visualization of humanitarian supply network by using concentric layouts.

Node-level results

The node-level metrics described in previous section include three centrality measures namely degree centrality, closeness centrality, betweenness centrality were calculated for each actors in the humanitarian supply network, the results of which are summarized in Table 1.

Rank	Degree centrality	Closeness centrality	Betweenness centrality
1	KK-PEOC (31.03)	KK-PEOC (59.18)	KK-PEOC (83.50)
2	DD1 (10.34)	DDPM1 (42.94)	DD1 (11.26)
3	DD5 (6.37)	DDPM2 (40.41)	DD5 (9.30)
4	DD15 (6.37)	DDPM3 (40.36)	DD15 (8.77)
5	DD7 (6.10)	DD5 (39.77)	DD7 (7.94)
6	DD12 (6.10)	DD1 (39.35)	DD12 (7.78)
7	DD10 (5.84)	DD16 (39.23)	DD9 (7.69)
8	DD4 (5.57)	DD4 (39.03)	DD4 (7.00)
9	DD16 (5.57)	DD6 (38.95)	DD16 (6.94)
10	DD9 (5.31)	DD12 (38.91)	DD10 (6.69)

Table 1: Node-level metrics results.

From the results, Khon Kaen Provincial Emergency Operation Centre (KK-PEOC) is prominent on all centrality metrics in the humanitarian supply network. The KK-PEOC has the highest degree centrality, closeness centrality, betweenness centrality scores. In term of degree centrality, the role of KK-PEOC is coordinator reconcile differences of network members and align their opinions with the greater supply network goals. In term of closeness centrality, the KK-PEOC acts as navigator who can explore, access, and collect various information with greater autonomy in the supply network. Finally, for closeness centrality, the KK-PEOC is a broker who mediate dealings between network members and turn them into its own advantage.

Network-level results

The results of the application of the network metrics introduced in section 2.6.2 are summarized in Table 2.

Network measures	Values
Number of nodes (actors)	378
Number of links	934
Network diameter	4

Network density	0.01310822
Average degree	1.310822
Average closeness	30.95272
Average betweenness	0.6015784
Degree centralization	0.2972366
Closeness centralization	0.5504267
Betweenness centralization	0.7545068
Clustering coefficient	0.21294
Average shortest path length	3.203949

Table 2: Network-level results

From Table 2 The network density of 0.01310822 mean that the network is sparse, with the number of links between nodes being only a small percentage of possible total number of links if all node were linked to all other nodes. This means that flow through the links will be limited to only those connections that exist, and in this case the number of links is small.

Recall that diameter of a network measures how many steps it takes to walk across the network from one side to another. This measure will assist us in determining how long it will take for nodes on the outer edges of the network to receive information and flows when compared to nodes closer to the center of the network. As a rule of thumb, a diameter less than or equal to 3 has ready access to all organizational resources (McCulloh et al., 2013). From the results, the network diameter is 4. This means it takes 4 steps to reach from one side of the network to the other. This value is a little larger than rule of thumb. This can show significant distance from one end of the organization to the other. Hence, it takes longer for information to travel to the outer parts of the network. Managers might be able to develop relationships between distant ends of an organization to reduce the diameter and thus increase the ability of agents to access organizational resources.

The average degree, betweenness, closeness centrality for nodes are determined provide a piece of the overall puzzle that reflects the network characteristics. The average degree centrality is a measure of network density which is a measure of the number of links present compared to the total number of links possible. The average closeness centrality measures the average length of geodesics within the network. Finally, Average betweenness centrality is the average number of nodes per geodesic. From the results, average degree and average betweenness are relatively low. The average closeness centrality

Regarding average betweenness, the supply network shows relatively low score (0.6015784), indicating that this network needs a smaller number of channels to get things done (Kim et al., 2011). Therefore, this supply network appears as more efficient, for instance, in managing such issues as supply disruptions because communications at the network level can be comparatively faster and more organized. However, the supply network shows the high average closeness score (30.95272). This implies that the actors in the supply network are more readily reachable from each other, indicating that information can travel faster across the network (Kim et al., 2011).

The centralization measures for the humanitarian supply network are between those for the star and ring networks, which are the two extremes in centralization. The degree centralization is 0.2972366, which indicates that there are very few nodes that are high in degree centrality when compared to the other nodes in the network. Betweenness centralization is 0.7545068, indicating that there is one node that acts as a boundary spanner or gatekeeper controlling access to all other nodes in the network. Closeness centralization is 0.5504267, again indicating that there is evidence of few dominant node: there is few nodes that is only one step away from every other node.

Network topologies

From the results, the humanitarian supply network has low clustering coefficient (0.21294) and medium average shortest path length (3.203949). The distribution of the number of connections per actor, or degree distribution, is widely used as a primary summary of the topology of complex networks.

A result, shown in Figure 3 and 4, reveals that degree distributions of the humanitarian supply network are not random but rather follow a power-law distribution.

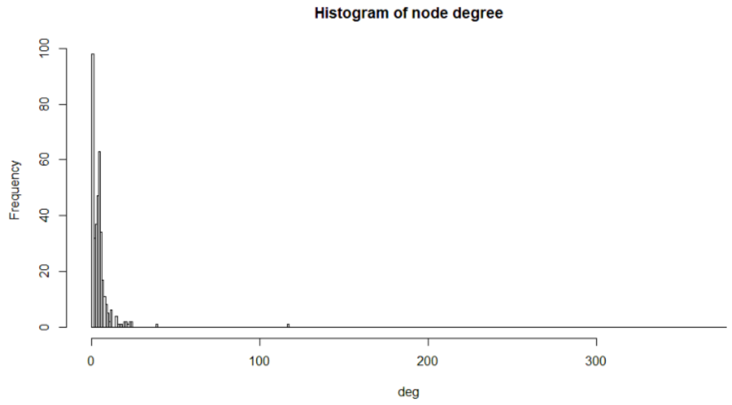

Figure 3: Histogram of node degree

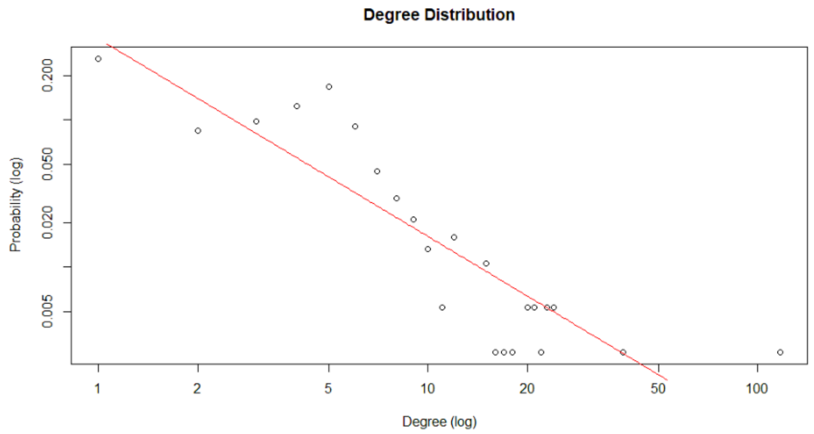

Figure 4: Fitting the degree distributions

A power law (PL), also known as a scaling law, is the form taken by a remarkable number of phenomena in the natural, social, and engineered systems. It is a relation of the type $Y=kX^{\alpha}$, where Y and X are variables of interest, α is called the power law exponent, and k is a typically unremarkable constant. A power-law implies that small occurrences are extremely common, whereas large instances are extremely rare. In other words, the humanitarian supply network is comprised of few actors with many and a majority of actors with only a few links, respectively.

A network whose distribution of connections among the nodes that follows a power law is known as a "scale-free" network (Barabási and Albert, 1999). The degree distribution of the humanitarian network follows a power law. This characteristic imply that the humanitarian network is a scale-free networks. The scale-free networks is more promising to represents efficient supply network and very resilient against random disturbances (Hearnshaw and Wilson, 2013).

Conclusions

We apply social network analysis to real supply network data derived from the key legal document governing disaster management in Thailand, Disaster Prevention and Mitigation Act, B. E. 2550 and related government documents. We use different social network analysis metrics at the node- or firm-level. The metrics are linked to specific roles in the humanitarian supply network and their implication performance. The humanitarian supply network consists of 378 actors and 934 links. Khon Kaen Provincial Emergency Operation Centre (KK-PEOC) is prominent on all centrality metrics in the humanitarian supply network. The degree distribution of the humanitarian network follows a power law. This characteristic imply that the humanitarian network is a scale-free networks.

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