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NETWORK INTERACTIONS OF GLOBAL SUPPLY CHAIN MEMBERS

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Abstract. Supply chain structure of global enterprises tend to develop dramatically. These lead to more difficulty for enterprises in managing and building information sharing systems. Thus, it is a necessary for enterprises to limit the scope of the information sharing system by selecting essential partners. The aims of this study are to quantify the cooperation of each supply chain member, and evaluate and visualize their effects in information sharing systems in order to support policy-makers in making their decisions in supply chain management. The network analytical method in network science is applied to indicate the relationship between supply chain members and present a comprehensive supply chain visually. Moreover, Motor Corporation's topology in Japan is used as a representation of global enterprise features to analyze the relationships between supply chain members. The data for Motor Corporation is secondary data which includes the number of suppliers, manufacturers, and dealers, and the interaction among them. Data is collected and verified from reputable websites such as www.marklines.com, or www.statista.com. As a result, this study contributes by applying a new method for not only determining the impact levels of supply chain members but also giving visual descriptions of impact levels on the large-scale information sharing system.

Keywords: information systems, sharing information, supply chain management, network science, network analysis, global enterprises.

JEL Classification: D8, L2, L14.

Introduction

Sharing information plays a key role in organizations and their supply chains, especially global enterprises. Information flow promotes the smooth operation of material and

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financial flows in the supply chain (Topal & Sahin, 2018; Lambert & Cooper, 2000). In network of global enterprises, complex bidirectional information interaction is appeared (Vörösmarty & Dobos, 2019). Bidirectional interaction is identified as the degree of business nodes in which direct communication is implemented to exchange information (Li et al., 2014). In this context, Dvorský et al. (2020) in their case study examined the attitudes of entrepreneurs on the sources of strategic risk in SMEs and Dobrovič et al. (2019) implemented the EFQM model to assess and improve business performance. Based on the movement of the information flow, managers make their decisions in improving productivity (Jiang & Ke, 2019; Bencsik & Juhász, 2020; Pakurár et al., 2019). Besides, they minimize cost or maximize profit for each partner or/and the whole supply chain and increase their competition in the market (Bakacsi et al., 2002; Cai et al., 2020; Lei et al., 2019; Jeong & Hong, 2019; Myšková & Kuběnka, 2019; Onalan & Magda, 2020; Wu et al., 2019; Zhao et al., 2019).

Maskey et al. (2020) consider 15 factors affecting the operation and strategies of information sharing. Among these factors, personal connections and interaction routines are factors influencing both operation and strategy of sharing information (Dvorský et al., 2020; Gallo et al., 2019; Zéman, 2019), which, in turn, positively affect the HRM processes in enterprises (Bilan et al., 2020). At the same time, the level of development of technological and digital infrastructure plays a decisive role in the development of these factors, as they are the determining factors of competitiveness at both the country and company level (Béresné, 2018). Personal connections are the personal relationships formulated basing on trust and cooperation (Cai & Yang, 2014), including advanced forms of knowledge sharing (Mishchuk et al., 2016). Interaction routines are defined as the degree to which business communicate with partners to exchange information in business activities. For example, companies and their partners exchange mutual goals and objectives, or plans (Baranyai et al., 2012; Li et al., 2014).

This study analyzes the complex interaction routines and personal connection in information sharing networks between global enterprises and their supply chains. The aims of study are to determine key members who significantly affect information sharing network and quantify the level of cooperation among partners in supply chain. These results will support managers in a significant way when they make their decisions in building a strategy for information sharing and information sharing operations, as well as supply chain management (Kot et al., 2018). Network analytics in network science is applied to solve these problems. Unlike traditional methods, network analysis mainly focuses on studying the structure of network instead of the attributes of each member in network. This means that the core of network analysis is tight relations among the participants in a system (Giuffre, 2013). Thus, network science, which consists of mathematical functions, is suitable for analyzing the interaction of complex and large networks (Wang, 2014). Moreover, based on Cytoscape software, network science provides a comprehensive visual picture of the effect levels of each member in a large network. Large-scale data is collected on websites of a global company, their branches, and their supply chain in the automotive industry in Japan. The results give a comprehensive evaluation of personal connection. Furthermore, the interaction routines of each member are also compared, to reveal which members affect significantly the sharing of information in a global enterprise and its supply chain.

Seven sections are included in the paper structure. First of all, a literature review discusses the application of network science in previous studies, and reveals differences between this study and previous studies. The next section presents the method, showing the necessary elements to apply network science in a real network. Fourthly, a case in the automotive industry is described through its features of organization, product flows, interaction network, data, and assumptions. The results are analyzed and a visual description is presented in Sections 5 and 6, respectively. The final section is the conclusion.

1. Literature review

Global enterprises are defined as international companies. International companies are a set containing many branches. Their branches spread over many countries. Besides, these branches work under management and control, as well as within the broad policy framework of their parent company. The combination between global enterprises and their supply chain members plays a vital role in fuelling international trade and global industrialization (Popp et al., 2018; Gonda et al., 2020).

"Information sharing (IS)" refers to the activity of exchanging good-quality information or knowledge among partners in supply chain (Li et al., 2006). Sharing information is bidirectional, which means that its moving includes both vertical and horizontal connections in supply chain structure (Shang et al., 2016). Information sharing system plays a key role in the efficiency of supply chain management. Exchanging information enhances collaboration between supply chain partners. Besides, shared information flows reduce uncertainties and complexities by distributing the actual primary information without the need of predicted data (Huo et al., 2014).

Network science describes characteristics of network through the vertices and edges. Vertices refer to nodes, and edges refer to links which connect a node pair. The link number of a node is a degree. The in-degree of a node refers to the number of heads of a node. By contrast, the number of the tails of a node is the out-degree of a node (Barabási, 2016). It is clear from the results of previous studies that network science is an effective method suiting a complex supply chain network (Bier et al., 2020; de Lima Simão et al., 2018; de Camargo Junior et al., 2012; Durda & Ključnikov, 2019). Network analysis is a method belonged to network science field "Network analysis is the study of structure". This means that the content of analysis does not emphasize what the own attributes of each member are. By contrast, the analysis mainly focuses on the relationships among members in network (Giuffre, 2013).

In supply chains, previous studies have mainly applied network science to solving problems relating to the topological characteristics of supply chains, the selection of a suitable network, and the relationships between factors in a supply chain network (Table 1). Firstly, Saglietto et al. (2014) applied network analysis to answer the question "What is supply chain structure?" in a wine industry supply chain. Based on network science, Brintrup et al. (2015) found that the structure of an industry is formed by communities connected by hub

Table 1. Relevant problems for applying network science in previous studies (source: authors' own study)

Authors	Topological characteristics	Selection of a suitable network		Relationship between factors
		Small-world network	Scale-free network	
Chen and Lin (2012)	x	x	x	
Hearnshaw and Wilson (2013)	x		x	
Saglietto et al. (2014)	x			
Zhang (2014)			x	
Brintrup et al. (2015)	x			
Jozwiak et al. (2016)	x			
Nuss et al. (2016)				x
Perera et al. (2017)		x	x	
Liao et al. (2017)		x	x	
Chin and Lee (2018)	x			
Fekete and Hatványi (2018)				x
Ledwoch et al. (2018)				x
Siddique et al. (2018)			x	
Bier et al. (2020)		x	x	
This study				x

firms. Similarly, Jozwiak et al. (2016) and Chin and Lee (2018) established a general set of topological characteristics in real supply chain networks. Next, Perera et al. (2017) and Bier et al. (2020) introduce a comprehensive review of the methodologies. They describe how to build the topology and robustness of supply chain networks, and the suitability of small-world networks and scale-free networks in the complex networks (Chen & Lin, 2012; Hearnshaw & Wilson, 2013; Liao et al., 2017). Zhang (2014) and Siddique et al. (2018) selected scale-free networks based on analysis of the evolution of the logistics distribution network and collaboration patterns in material handling, respectively. Finally, network science is also applied in analyzing and evaluating relationships between factors in the supply chain (Benda-Prokeinová et al., 2017). In particular, Nuss et al. (2016) introduced network structure, including supply chain actors (nodes) and the associations among them. Similarly, Ledwoch et al. (2018) considered the relationship between the network structure and their ability to reduce inventory and re-establish routing. A more complex network structure is proposed Fekete and Hatványi (2018). They applied network science theory to find the cause and show the effect of the relationship between the network element of a logistics network and its behaviors. Therefore, it is clear from the data in Table 1 that in the last five years researchers tend to prioritize the application of network science for selecting a suitable network and evaluating the relationship between factors over determining topological characteristics. Among the selection of a suitable network and the evaluation of relationships, the selection of a suitable network has attracted more attention from researchers than the evaluation of relationships between factors.

This study focuses on the aspect of analyzing relationships between factors using network analysis. However, there are two differences between this study and the studies of (Ledwoch et al., 2018; Nuss et al., 2016). First of all, this study develops a complex information sharing network with large-scale nodes and complex interactions between Tier 1-suppliers, Tier 2-suppliers, the head office of the company, headquarters, manufacturers, dealers, and customers. Secondly, the impacts of members are analyzed, and the critical level of each member in terms of overall networking and information-sharing activities with others is assessed. It also examines the activities of directly related members, such as strategy structure, planning, and operations (Kot et al., 2019). To address these gaps, a large-scale data regarding the interaction between supply chain members is collected. These interactions are formed by the exchanged of information in two ways between members. The impact of each member in a supply chain of the automotive industry is found by applying network-science-based analysis.

2. Method

2.1. Equivalent definition

Definitions of the factors which serve for building and sharing information networks are exchanged equivalently from the definitions of network science based on the previous applications of network science in supply chain management. This includes basic elements, i.e. that nodes represent members in information sharing networks such as the focal company, each supplier, and customers at each tier. The relevant definitions are shown in Table 2.

Table 2. Equivalent definition of information sharing network from network science (source: authors' own study)

Network science	Supply chain
Node	Represents the single products (Clemente et al., 2015), each supply chain member (Hearnshaw & Wilson, 2013; Perera et al., 2018a, 2018b; Zhao, 2012), and contractual relationships such as: purchase relationship, contractual outsourcing relationship, relationship, selling relationship, relationship norms (Saglietto et al., 2014)
Link	Interactions, collaborations or relationships among nodes. For example, interaction among nodes by sharing information, delivering material, or transacting finance (Brintrup et al., 2015; Clemente et al., 2015; Hearnshaw & Wilson, 2013; Perera et al., 2018b; Zhao, 2012)
Path length	Path length or the characteristics path length is the average number of firms that simultaneously exchange information between any two firms selected at random (Hearnshaw & Wilson, 2013)
Neighborhood connectivity	The average connectivity of all neighbors of a firm (Fekete & Hatványi, 2018)
Stress centrality	The number of shortest paths passing through a firm (Hearnshaw & Wilson, 2013)

End of Table 2

Network science	Supply chain
Connectivity	The number of firm's neighbours (Nuss et al., 2016)
Topological coefficients	To measure the extent of sharing information with a firm's neighbors (Brintrup et al., 2015)
Degree distribution	The distribution of the number of relationships across firms in the network (Brintrup et al., 2015)
Clustering coefficient	Measure of the number of firms which are depended on each other indirectly through the connection with the same third party. Besides, clustering coefficient measures the level of interactions within members (Brintrup et al., 2015)
Closeness centrality	Closeness centrality counts the total of the shortest possible lines between a node and all other nodes to measure speed of spreading information among nodes. With high closeness, firms may access the information quickly so they may receive more benefits and proactively avoid issues such as bullwhip effect (Brintrup et al., 2011, 2015)
Betweenness centrality	Betweeness centrality presents the appearance of a node on edges that connect different nodes in the network. With high betweenness centrality, nodes can control the speed of information exchange and play crucial role in controlling the flow of materials and communication in the network (Brintrup et al., 2011, 2015; Clemente et al., 2015; Harvey & O'Neale, 2020)

2.2. Mathematical model

Topological coefficients P_n:

$$P_n = \frac{avg(F(n,m))}{h_n}, \quad (1)$$

h_n – Neighbors, and $F(n,m)$ – all nodes m that share at least one neighbor with n node. Clustering coefficients O_n:

$$O_n = \frac{2e_n}{(h_n(h_n - 1))}, \quad (2)$$

h_n – Number of neighbors of n, and e_n – Number of connected pairs among all neighbors of n.

Closeness centrality $O_c(n)$:

$$O_c(n) = \frac{1}{avg(K(n,m))}, \quad (3)$$

$K(n,m)$ – The length of the shortest path among two nodes n and m.

Betweenness centrality $O_b(n)$:

$$O_b(n) = \sum_{i \neq n \neq j} (\sigma_{ij}(n) / \sigma_{ij}), \quad (4)$$

i, j and n – Nodes in the network, σ_{ij} – Number of shortest paths from i to j, and $\sigma_{ij}(n)$ – Number of shortest paths from i to j that n lies on.

This network is analysed by Cytoscape version 3.7.2. Cytoscape is an open source software platform on https://cytoscape.org/. Cytoscape provides functions for integrating and analyzing data, and visualization for the complex networks.

3. Network features in the automotive industry

3.1. Organizational structure

Motor Corporation, which is a global enterprise, includes a head office in their home country and branches spread over many countries (Figure 1). All these branches have to work within the broad policy framework of their parent company. This means that the headquarters in each different area have to follow their parent company's target and strategies to make their decisions, including decisions regarding production, marketing, operation, and finance.

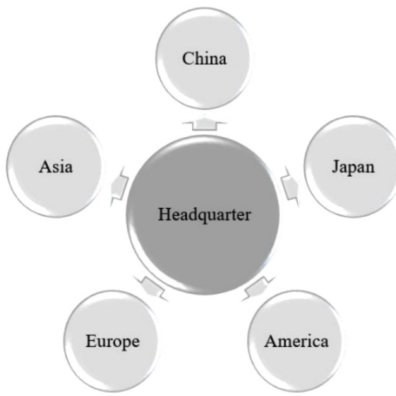

Figure 1. Organizational structure by geographic area

3.2. Interaction

Interaction is identified as the degree of business nodes in which direct communication is implemented in order to exchange information (Figure 2).

In this global enterprise, information exchanges are bidirectional. Some information moving from the parent company to headquarters and supply chains in different countries is considered. At each headquarters, departments exchange information with suppliers and dealers through buying products and receiving orders. Besides, these departments provide all relevant information to manufacturers. Suppliers exchange information with manufacturers when material arrives at facilities and their suppliers about purchasing material. Finally, dealers interact customers and share information to relevant departments at headquarters.

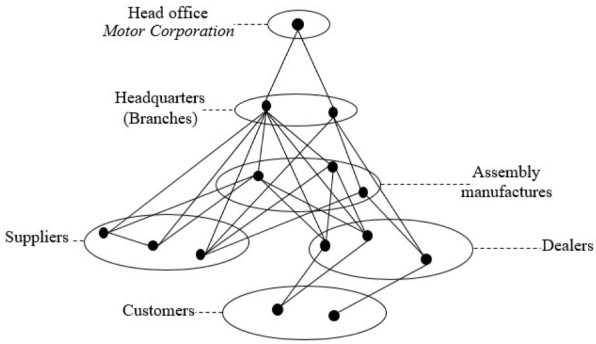

Figure 2. Information sharing network

3.3. Data collection

Data is collected from websites such as www.marklines.com, https://global.toyota, and the website of each supply chain member. They relate to the number of headquarters, assembly manufacturers, suppliers, dealers, and customers and their interaction.

– Headquarters and assembly manufacturers

According to the statistics of headquarters and assembly facilities at Motor Corporation (Table 3), there are 17 headquarters and 60 assembly manufacturers, which appear across 19 countries in 5 regions. Most of factories focus on Japan and America. 20% of the factories focus on the Asian area, Europe accounts for 13.3% of the total number of factories, and 11.7% of factories are in China. The assembly manufacturers assemble parts for 635 final products.

Table 3. Motor Corporation's headquarter and assembly facility statistics (source: authors' own study)

Region	Country	Headquarters	Facility	(%)
America	Mexico	–	3	26.6
	Canada	1	2	
	USA	1	8	
	Brazil	1	2	
	Argentina	1	1	
Asia	Thailand	1	4	20
	Indonesia	1	5	
	India	1	1	
	Philippines	1	1	
	Vietnam	–	1	
Europe	UK	1	1	13.3
	Turkey	–	1	
	Czech Republic	–	1	
	France	–	2	

End of Table 3

Region	Country	Headquarters	Facility	(%)
	Austria	–	1	
	Russia	–	1	
	Portugal	–	1	
China	China	3	7	11.7
Japan	Japan	5	17	28.3
Total	19	17	60	100%

– Suppliers, Dealers and Customers

Following the supplier and dealer statistics of Motor Corporation in five regions, i.e. China, America, Europe, Asia, and Japan (Table 4), there are 482 suppliers who provide semi-finished products to 60 manufacturers to produce their final products, 3291 dealers who sell final products to final customers in local markets, and all customers of 5 regions who consume final products.

Table 4. Supplier and Dealer statistics (source: authors' own study)

Total		Supplier	Dealer	Customer
		482	3291	5 regions
Region	China	86	75 units	All customers in China
	America	117	1531 units (from USA, Canada and Mexico)	All customers in USA, Canada and Mexico
	Europe	43	844 units (from UK, France, Czech Republic, Turkey, Austria, Russia and Portugal)	All customers in UK, France, Czech Republic, Turkey, Austria, Russia and Portugal
	Asia	112	603 units (from Thailand, Indonesia, Philippines, India and Vietnam)	All customers in Thailand, Indonesia, Philippines, India and Vietnam
	Japan	210	238 units	All customers in Japan

4. Results

4.1. Evaluation of overall network structure

In general, the information sharing network forms from 3.850 nodes and 94.937 links which are interactions of a node pair. This network has connections between many different members, and forms a single shape. Besides, there is the appearance of hub nodes where the number of links greatly exceeds the average. However, collaborative activities are fewer between the different firm groups. Specifically, features of the information sharing network are described by simple parameters in Table 5, as follows:

- There are 14.988.512 shortest paths in the information network. The shortest path corresponds to the path with the fewest number of links that connect two nodes.

The shortest edge length is the distance among two nodes.

- The diameter of a network is the largest distance among a couple nodes. Besides, diameter is an indicator for the evaluation of the overall network connectivity. The diameter indicator of network is 6. This value shows that the diameter indicator is low. According to Wang et al. (2014), as more members appear in the network, the diameter becomes smaller. These may indicate that the network is a large network, which has connections between numerous members.
- The value of connected components is 1, which means that all members (nodes) are pairwise and connect together to form a connected component.
- The characteristic path length of a supply chain (2.304) presents the average number of firms that simultaneously exchange information between any two firms selected at random. For instance, information flow passes through 2.304 nodes to move between a node pair.
- The connection of each node to other nodes is non homogeneous, which shows through network heterogeneity (4.216). This leads to the tendency of an information network that contain hub nodes where the number of links greatly exceeds the average
- The clustering coefficient measure of the number of firms which are depended on each other indirectly through the connection with the same third party. Besides, clustering coefficient measures the level of interactions within members. A higher cluster coefficient score means that interactions in this network are expected to be higher (Brintrup et al., 2015). In this network, the cluster coefficient is 0.119. This value is equivalent to a low score. The score indicates that there is less collaborative activity between different firm groups.
- The average connectivity of a node, known as the average number of neighbors, is 49.020 in the network. The network density compared with the edges is 0.013. This value shows that 1.3% of all possible relationships among the firms are present in the information sharing network.

Table 5. The simple parameter value of the network (source: authors' own study)

Parameter	Value
Connected components	1
Network diameter	6
Shortest paths	14988512 (100%)
Characteristic path length	2.304
Avg. number of neighbors	49.020
Network density	0.013
Network centralization	0.807
Network heterogeneity	4.216
Clustering coefficient	0.119

4.2. Evaluating the effect of supply chain members in the network

The impact of a node is evaluated by centrality indicators. These nodal centrality indices capture a node's importance as being close to others (closeness centrality), being the intermediary between others (betweenness centrality), and being directly connected to others. The effect of a node is high when centrality indicators are high (Wang et al., 2011). Closeness centrality counts the total of the shortest possible lines between a node and all other nodes to measure speed of spreading information in the network. Supply chain members with high closeness will get more benefits from the supply chain (Brintrup et al., 2011, 2015). Betweenness centrality measures how often a node is traversed by the shortest paths connecting all pairs of nodes. In other words, the amount of control that this node exerts over the interactions of other nodes is reflected by the betweenness centrality in the network. Nodes with high betweenness centrality act as a communication centrality. If there are problems in sharing information at nodes with high betweenness centrality, information flow will be adversely affected in the overall network (Brintrup et al., 2011, 2015; Clemente et al., 2015; Harvey & O'Neale, 2020; Kovács, 2016). Therefore, based on the value of betweenness centrality, closeness centrality, and direct connection, a company may evaluate the impact of each member on operations on the overall network, the activities of sharing information among its near members, and/or the activities of directly connected members.

Supply chain members who have different centrality indictors, are distributed in three cluster groups in Figure 3. According to Revelle (1979), hierarchical cluster analysis is an algorithm which is used for classifying supply chain members with similar centrality indictors into groups called clusters. Besides, the distance between two clusters is computed based on the length of the straight line from one cluster to another. The distance between two clusters is as known as The Euclidean distance between their centroids or means, as follows (5).

$$D_{ij} = \sqrt{\sum_{e=1}^{n} (z_{ei} - x_{ej})^2} , \quad (5)$$

D_{ij} – Length between members i and j; and z_{ei} – The value of variable Z_e for member j.

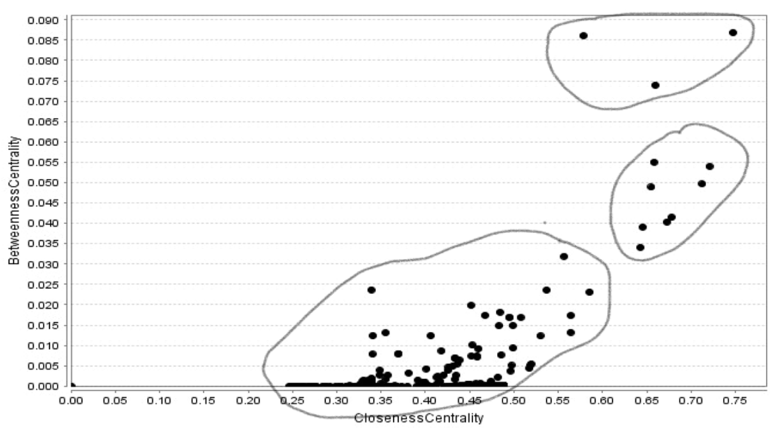

Figure 3. Betweenness centrality and closeness centrality of supply chain members

The result of the cluster analysis shows that cluster 1 contains 3 members who have a wide range of betweenness centrality from 0.074 to 0.087, and closeness centrality from 0.58 to 0.75. Eight supply chain members of cluster 2 have a range of betweenness centrality between 0.0325 to 0.055, and closeness centrality between 0.64 and 0.73. By contrast, the betweenness centrality of members in cluster 3 is always lower than 0.0325. At the same time, their closeness centrality is always under 0.58. This indicates that clusters 1 and 2 have more impact on others in the network than cluster 3. Furthermore, only one of the three members in cluster 1 has both betweenness centrality and closeness centrality higher than the centrality indicators of all members in cluster 2.

Table 6 provides complete information regarding the members of clusters 1 and 2. Cluster 1 and cluster 2 are a set of headquarters and manufacturers coming from Japan, Thailand, United States, and Turkey. Both headquarters and manufacturers are not affiliated with members of the same type. Manufactures (except for manufacturer TuM01) have a direct connection with headquarters, suppliers, and dealers. Manufacturer TuM01 has interaction with the head office of the parent company, suppliers, and dealers.

When compared with other members in clusters 1 and 2, only JaMHZse has the highest value of both closeness centrality (0.747), betweenness centrality (0.087), and the number of connected other members (3,173). This means that JaMHZse is a bridge between the most numerous of the other members in the network. Besides, JaMHZse dramatically affects its directly connected members, and spreads information to other members quickly. By contrast, the betweenness centrality and closeness centrality of other members have a tendency to fluctuate significantly when the number of directly connected members reduces gradually. This indicates that there is a difference between the impact of each member on the overall supply chain network, their information spread, and the direct effect on other members who are connected with them. As an illustration of this, UsaMH and TuM01, who belong to cluster 1, are in the top 3 with high betweenness centrality within all members. The betweenness centrality (0.086) of TuM01 is ranked second, while its closeness centrality (0.578) and the number of connected other members (587) is the lowest in both clusters 1 and 2. Similarly, UsaMH ranks third in betweenness centrality (0.075) but fourth in both closeness centrality (0.660) and number of connections with other members (2,830). From this, it is clear that there is a significant difference in the impact of each member on each aspect of the supply chain network. TuM01 and UsaMH tend to have a greater impact on the connection of many members in the network than the information sharing activities of nearby members, and their direct relationships. By contrast, JaMHZse has a great ability to impact on operations on the overall network, information sharing activities among its near members, and the activities of directly connected members, including building strategies, or operation planning.

A similar analysis is implemented to compare the effect of suppliers and dealers in each group of suppliers and dealers in order to find the key ones. The fact remains that the impact of suppliers and dealers is less overall than the impact of headquarters and manufacturers (Figure 4) in the network. Combined with the results from Table 6, Table 7 summarizes the top 3 of selected members who significantly affect the whole supply chain, the speed of information, or the members connected with them by betweenness centrality, closeness centrality, and the number of direct connections with them. For example, headquarters JaMHZse is a key member who dramatically affects other members in the whole network, and many members connect with JaMHZse directly.

Table 6. The direct connection of members in cluster 1 (source: authors' own study)

Member's information					The information of direct connected members					
Member	Origin	Function	Betweenness centrality	Closeness centrality	Total units	Country	Head office/ Headquarters	Supplier	Manu-facturer	Dealer
JaMHZse	Japan	Headquarters	0.087	0.747	3173	17	1 Head office	161	7	3004
JaMHZse02	Japan	Manufacturer	0.054	0.720	2973	16	1 Head-quarters	63	–	2909
JaMHZse07	Japan	Manufacturer	0.050	0.712	2956	16	1 Head-quarters	65	–	2890
UsaMH	United States	Headquarters	0.075	0.660	2830	15	1 Head office	86	8	2735
ThM	Thailand	Headquarters	0.055	0.658	2815	16	1 Head office	55	4	2755
ThM02	Thailand	Manufacturer	0.049	0.654	2790	16	1 Head-quarters	37	–	2752
UsaMH05	United States	Manufacturer	0.039	0.645	2703	15	1 Head-quarters	46	–	2656
UsaMH03	United States	Manufacturer	0.034	0.642	2680	15	1 Head-quarters	12	–	2667
JaMHZse06	Japan	Manufacturer	0.041	0.678	2647	14	1 Head-quarters	69	–	2577
JaMHZse04	Japan	Manufacturer	0.040	0.672	2634	14	1 Head-quarters	77	–	2556
TuM01	Turkey	Manufacturer	0.086	0.578	587	4	1 Head office	9	–	577

Table 7. Impact summary of key members in network (source: own study)

Member	Origin	Function	Operation activities on the entire supply chain (Betweenness centrality)	Information sharing activities of nearby members (Closeness centrality)	Activities of directly connected individuals
JaMHZse	Japan	Headquarters	x	x	x
UsaMH	United States	Headquarters	x		
JaMHZse02	Japan	Manufacturer		x	x
JaMHZse07	Japan	Manufacturer		x	x
TuM01	Turkey	Manufacturer	x		
75 ChD	China	Dealer	x		x
88 FrD	France	Dealer	x	x	x
T1S482T2S29	Thailand	Supplier	x		
T1S467T2S14	Japan	Supplier		x	x
T1S400	Japan	Supplier	x	x	x
T1S443	Japan	Supplier	x	x	x
T1S391	Japan	Supplier			x
T1S383	Japan	Supplier			x

Note: Members who are highlighted have a dramatic impact on or an important role in connecting and sharing information in the network; 75 ChD means that there are 75 Chinese dealers, 88 FrD that there are 88 French dealers; and x: there is an impact of the member on the factors considered.

4.3. Visual description

The visualization of an information sharing network is regulated by transforming the size and color of the nodes and links (Figure 4). The changing size and color of a node depends on the value of betweenness centrality. Nodes, as known as hub nodes, have a dense connection with others in sharing information. The largest hub nodes are the filled circles with the greatest size and darkest color (blue). Nodes which have fewer connections, are represented by smaller circle sizes and brighter colors, such as orange. Similar, the changing size and color of an edge shows the change in the edge betweenness value. The strongest interaction between a node pair described by the greatest thickness of edges and the darkest color while smaller size and orange color present weaker interaction.

Based on a visual description, decision makers can easily evaluate the effect of each supply chain member in the network, and recognize the level of the relationships between them and other members. For example, if a manufacturer is represented by a big circle, this shows that this manufacture plays a key role in sharing information in the network. Other members who are shown by small circles, only interact with one or some firms in the network.

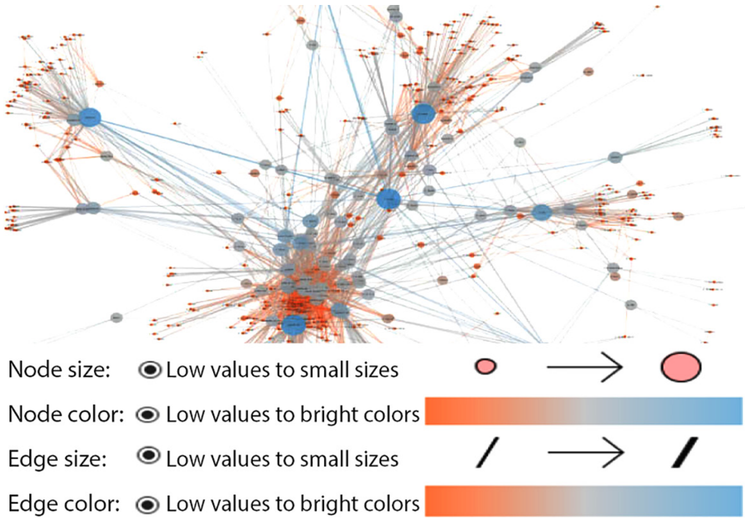

Figure 4. Visual representation of a part of an information network.
Cytoscape software version 3.7.2 is used to form this network

5. Discussion

An information sharing network of global company is introduced as a case study in this study. The network structure contains a set of many firms (3,850 nodes) and interactions (94,937 links) between a node pair. The results show that headquarters (JaMHZse and UsaMH) and manufacturers (JaMHZse02, JaMHZse07, and TuM01) in Japan, Thailand, the United States, and Turkey play the key information coordination centers of the network and the key production centers for products sold in the market. Besides, dealers coming from China and France are the main buyers of products in Motor Corporation. Similarly, five main suppliers coming from Thailand and Japan are mainly supply semi-finished products or materials to assembly manufacturers and other suppliers.

The structure analysis of the entire information sharing network indicates that above headquarters and manufacturers have a tendency to attract more connection than dealers and suppliers. Especially, headquarters (JaMHZse and UsaMH) and manufacturers (JaMHZse02, JaMHZse07, and TuM01) connect almost members in network. Their high centrality indicators evidence their significant influence on the information connection in the overall network. For instance, JaMHZse's betweenness centrality is high (0.087) so it is an important bridge for connecting the operation activities of many firm pairs in the network. Furthermore, JaMHZse has the highest closeness centrality (0.747). This leads to that JaMHZse have the shortest distances to the rest of the network. This ability affects a large number of other members a rapid spread of information. As a result, JaMHZse is critical in the distribution of information in the network, and any disruptions to it would affect the entire network. Thus, the network of Motor Corporation shows low density, but high clustering between headquarters, manufacturers, dealers, and suppliers.

The supply network analysis of Motor Corporation indicates that almost suppliers have connection with headquarters and manufacturers in Japan and the United States, which indicates the suppliers in network seem adapt their requirements such as the quality of materials or information security. For instance, Motor Corporation requires their suppliers get high quality certificates of material or products in specialized manufacturing field. Addition to, the suppliers may access important information quickly to avoid issues and get benefits more when close connecting with these headquarters and manufacturers. For example, suppliers may avoid bullwhip effect thanks to receiving the forecast information from headquarters and manufacturers. Such strict controlling of material/products/semi-finish products creates a fairly high threshold for suppliers, and the given benefits from tight connecting with headquarters and manufacturers bring significant motivation for suppliers. In some case, few capable firms can join the group, and also that makes them powerful in automotive industry.

Conclusions

This study applies network science to the problem of information sharing network in global companies. Members including headquarters, manufacturers, dealers, customers, suppliers, and supplier's suppliers, implement their interaction in the network by exchanging information with others. Unlike previous studies, this study forms a complex information sharing network containing a large-scale and complex data of nodes and links among supply chain members. Besides, this study evaluates the influence of members and assesses the critical information level of each member in terms of overall networking and information-sharing activities with others. Furthermore, the activities of directly related members are also examined, such as strategy structure, planning, and operations. The results show that information sharing network is mainly controlled by some headquarters and manufacturers. Thus, if the information disruption appears at these headquarters and manufacturers, the network will be damaged. The achieved results contribute to a solution in evaluating comprehensive network structures and highlighting key members affecting an information sharing network, as well as giving detail on various aspects affected by key members. These provide significant support for managers in making their decisions and building long-term or short- term strategies. However, there is one limitation which needs to be addressed and overcome in future research. This study evaluates the impact of members only based on the database of interactions among partners. For future research, researchers may invest a master database including products, type of information, or types of relationships for connectivity of firms in network. These would provide deeper and specific measures for different and specific scenarios. Besides, effective solutions are proposed to develop and improve the efficiency of information sharing networks.

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Author contributions

T.D.C.L. and M.P. conceived the study and were responsible for the design and development of the data analysis. J.O. were responsible for data collection and analysis. T.D.C.L was responsible for data interpretation T.D.C.L. and M.P. wrote the first draft of the article.

Disclosure statement

Authors declare that they have no competing financial, professional, or personal interests from other parties.

References

Bakacsi, G., Sándor, T., András, K., & Viktor, I. (2002). Eastern European cluster: Tradition and transition. *Journal of World Business*, *37*(1), 69–80. https://doi.org/10.1016/S1090-9516(01)00075-X

Barabási, A. L. (2016). *Network science*. Cambridge University Press.

Baranyai, Z., Gyuricza, C., & Vasa, L. (2012). Moral hazard problem and cooperation willingness: Some experiences from Hungary. *Actual Problems of Economics*, *138*(12), 301–310. https://www.researchgate.net/publication/288380794_Moral_hazard_problem_and_cooperation_willingness_Some_experiences_from_Hungary

Bencsik, A., & Juhasz, T. (2020). Impacts of informal knowledge sharing (workplace gossip) on organisational trust. *Economics and Sociology*, *13*(1), 249–270. https://doi.org/10.14254/2071-789X.2020/13-1/16

Benda-Prokeinová, R., Dobeš, K., Mura, L., & Buleca, J. (2017). Engel's approach as a tool for estimating consumer behaviour. *E a M: Ekonomie a Management*, *20*(2), 15–29. https://doi.org/10.15240/tul/001/2017-2-002

Béresné, M. B. (2018). Sustainable competitiveness of Hungary – Focusing on the years 2013–2017. *Annals of the University of Oradea Economic Science*, *1*(1), 269–278. https://ideas.repec.org/a/ora/journl/v1y2018i1p269-278.html

Bier, T., Lange, A., & Glock, C. H. (2020). Methods for mitigating disruptions in complex supply chain structures: A systematic literature review. *International Journal of Production Research*, *58*(6), 1835–1856. https://doi.org/10.1080/00207543.2019.1687954

Bilan, Y., Mishchuk, H., Roshchyk, I., & Joshi, O. (2020). Hiring and retaining skilled employees in SMEs: Problems in human resource practices and links with organizational success. *Business: Theory and Practice*, *21*(2), 780–791. https://doi.org/10.3846/btp.2020.12750

Brintrup, A., Kito, T., López, E., New, S., & Reed-Tsochas, F. (2011). *The structure of the Toyota supply network: The emergence of resilience* (CABDyN Working Paper). http://www.cabdyn.ox.ac.uk/complexity_PDFs/Working%20Papers%202011/WorkingPaper_ToyotaRobustness.pdf

Brintrup, A., Wang, Y., & Tiwari, A. (2015). Supply networks as complex systems: A network-science-based characterization. *IEEE Systems Journal, 11*(4), 2170–2181. https://doi.org/10.1109/JSYST.2015.2425137

Cai, K., He, S., & He, Z. (2020). Information sharing under different warranty policies with cost sharing in supply chains. *International Transactions in Operational Research, 27*(3), 1550–1572. https://doi.org/10.1111/itor.12597

Cai, S., & Yang, Z. (2014). The role of the *Guanxi* institution in skill acquisition between firms: A study of Chinese firms. *Journal of Supply Chain Management*, *50*(4), 3–23. https://doi.org/10.1111/jscm.12035

Chen, H. H., & Lin, A. M. (2012). Complex network characteristics and invulnerability simulating analysis of supply chain. *Journal of Networks*, *7*(3), 591–597. http://www.celap.org.cn/attach/0/1301221530221875299.pdf

Chin, K., & Lee, H. (2018). Analysis of the vulnerabilities of the supply chain network of a manufacturing company using the network-science approach: S-Electronics case. In *2018 Portland International Conference on Management of Engineering and Technology (PICMET)* (pp. 1–6). IEEE. https://doi.org/10.23919/PICMET.2018.8481939

Clemente, F., Nasuelli, P. A., & Baggio, R. (2015). Formal network analysis of a food supply chain system: A case study for the Italian agro-food chains. *Journal of Agricultural Informatics*, *6*(4), 1–16. https://doi.org/10.17700/jai.2015.6.4.205

de Camargo Junior, J. B., Neto, M. S., Pires, S. R. I., da Silva, E. M., Vivaldini, M., & Correa, D. A. (2012, March 19–20). The role of logistics services providers in the supply chain management: The social network perspective. In *2ème Congrès TRANSFORMARE* (pp. 34–43). Paris. https://www.transformare.adm.br/anais/Joao-Batista-de-Camargo-Junior-et-al.-The-role-of-logistics-services-providers.pdf

de Lima Simão, M. P., Barbosa, D. H., Barbosa, J. S. K., Leal, G. C. L., Galdamez, E. V. C., & Cotrim, S. L. (2018). Emerging trends and collaborative network patterns on Reverse Logistics. *Independent Journal of Management & Production*, *9*(2), 321–339. https://doi.org/10.14807/ijmp.v9i2.689

Dobrovič, J., Kmeco, L., Gallo, P., & Gallo, Jr., P. (2019). Implications of the model EFQM as a strategic management tool in practice: A case of Slovak Tourism Sector. *Journal of Tourism and Services*, *10*(18), 47–62. https://doi.org/10.29036/jots.v10i18.91

Durda, L., & Ključnikov, A. (2019). Social networks in entrepreneurial startups development. *Economics and Sociology*, *12*(3), 192–208. https://doi.org/10.14254/2071-789X.2019/12-3/13

Dvorský, J., Petráková, Z., Khan, K. A., Formánek, I., & Mikoláš, Z. (2020). Selected aspects of strategic management in the service sector. *Journal of Tourism and Services*, *11*(20), 109–123. https://doi.org/10.29036/jots.v11i20.146

Fekete, I., & Hatványi, T. (2018). Network science in logistics: A new way to flexible adaptation. In Sushil, T. P. Singh, & A. J. Kulkarni (Eds.), *Flexible systems management. Flexibility in resource management* (pp. 57–69). Springer, Singapore. https://doi.org/10.1007/978-981-10-4888-3_4

Gallo, P., Mihalčová, B., Gallo, Jr. P., Čabinová, V., & Tomčíková, Ľ. (2019). Application of the balanced scorecard as a strategic management tool in practice: A case of Slovak Tourism sector. *GeoJournal of Tourism and Geosites*, *24*(1), 19–28. https://doi.org/10.30892/gtg.24102-339

Giuffre, K. (2013). *Communities and networks: Using social network analysis to rethink urban and community studies*. John Wiley & Sons. https://www.wiley.com/en-lt/Communities+and+Networks%3A+Using+Social+Network+Analysis+to+Rethink+Urban+and+Community+Studies-p-9780745654201

Gonda, G., Gorgenyi-Hegyes, E., Nathan, R. J., & Fekete-Farkas, M. (2020). Competitive factors of fashion retail sector with special focus on SMEs. *Economies*, *8*(4), 95. https://doi.org/10.3390/economies8040095

Harvey, E. P., & O'Neale, D. R. (2020). Using network science to quantify economic disruptions in regional input-output networks. In N. Masuda, KI. Goh, T. Jia, J. Yamanoi, & H. Sayama (Eds.), *Springer Proceedings in complexity*: *Vol. 1. Proceedings of NetSci-X 2020: Sixth international winter school and conference on network science* (pp. 259–270). Springer, Cham. https://doi.org/10.1007/978-3-030-38965-9_18

Hearnshaw, E. J., & Wilson, M. M. (2013). A complex network approach to supply chain network theory. *International Journal of Operations & Production Management*, *33*(4), 442–469. https://doi.org/10.1108/01443571311307343

Huo, B., Zhao, X., & Zhou, H. (2014). The effects of competitive environment on supply chain information sharing and performance: an empirical study in China. *Production and Operations Management*, *23*(4), 552–569. https://doi.org/10.1111/poms.12044

Jeong, K., & Hong, J. D. (2019). The impact of information sharing on bullwhip effect reduction in a supply chain. *Journal of Intelligent Manufacturing*, *30*(4), 1739–1751. https://doi.org/10.1007/s10845-017-1354-y

Jiang, Q., & Ke, G. (2019). Information sharing and bullwhip effect in smart destination network system. *Ad Hoc Networks*, *87*, 17–25. https://doi.org/10.1016/j.adhoc.2018.07.006

Jozwiak, A., Milkovics, M., & Lakner, Z. (2016). A network-science support system for food chain safety: A case from Hungarian cattle production. *International Food and Agribusiness Management Review*, *19*(A), 1–26. https://doi.org/10.22004/ag.econ.240694

Kot, S., Haque, A. U., & Kozlovski, E. (2019). Strategic SCM's mediating effect on the sustainable operations: Multinational Perspective. *Organizacija*, *52*(3), 219–235. https://doi.org/10.2478/orga-2019-0014

Kot, S., Onyusheva, I., & Grondys, K. (2018). Supply chain management in SMEs: Evidence from Poland and Kazakhstan. *Engineering Management in Production and Services*, *10*(3), 23–36. https://doi.org/10.2478/emj-2018-0014

Kovács, Z. (2016). Moral hazard in producer organizations – Some experiences of an empirical survey. *Applied Studies in Agribusiness and Commerce*, *10*(4–5), 77–83. https://doi.org/10.19041/APSTRACT/2016/4-5/10

Lambert, D. M., & Cooper, M. C. (2000). Issues in supply chain management. *Industrial Marketing Management*, *29*(1), 65–83. https://doi.org/10.1016/S0019-8501(99)00113-3

Ledwoch, A., Yasarcan, H., & Brintrup, A. (2018). The moderating impact of supply network topology on the effectiveness of risk management. *International Journal of Production Economics*, *197*, 13–26. https://doi.org/10.1016/j.ijpe.2017.12.013

Lei, H., Wang, J., Shao, L., & Yang, H. (2019). Ex post demand information sharing between differentiated suppliers and a common retailer. *International Journal of Production Research*, *58*(3), 703–728. https://doi.org/10.1080/00207543.2019.1600758

Li, G., Lin, Y., Wang, S., & Yan, H. (2006). Enhancing agility by timely sharing of supply information. *Supply Chain Management*, *11*(5), 425–435. https://doi.org/10.1108/13598540610682444

Li, Y., Ye, F., & Sheu, C. (2014). Social capital, information sharing and performance. *International Journal of Operations & Production Management*, *34*(11), 1440–1462. https://doi.org/10.1108/IJOPM-03-2013-0132

Liao, H., Shen, J., Wu, X. T., Chen, B. K., & Zhou, M. (2017). Empirical topological investigation of practical supply chains based on complex networks. *Chinese Physics, B*, *26*(11), 110505. https://doi.org/10.1088/1674-1056/26/11/110505

Maskey, R., Fei, J., & Nguyen, H. O. (2020). Critical factors affecting information sharing in supply chains. *Production Planning & Control*, *31*(7), 557–574. https://doi.org/10.1080/09537287.2019.1660925

Mishchuk, H., Bilan, Y., & Pavlushenko, L. (2016). Knowledge management systems: Issues in enterprise human capital management implementation in transition economy. *Polish Journal of Management Studies*, *14*(1), 163–173.

Myšková, R., & Kuběnka, M. (2019). Information sharing in the context of business cooperation – as a source of competitive advantage. *Journal of International Studies*, *12*(3), 169–182. https://doi.org/10.14254/2071-8330.2019/12-3/14

Nuss, P., Graedel, T. E., Alonso, E., & Carroll, A. (2016). Mapping supply chain risk by network analysis of product platforms. *Sustainable Materials and Technologies*, *10*, 14–22. https://doi.org/10.1016/j.susmat.2016.10.002

Onalan, M. S., & Magda, R. (2020). Intolerance to uncertainty and motivational persistence among Turkish females according to entrepreneurial intention. *Polish Journal of Management Studies*, *21*(2), 285–300. https://doi.org/10.17512/pjms.2020.21.2.20

Pakurár, M., Haddad, H., Popp, J., Khan, T., & Oláh, J. (2019). Supply chain integration, organizational performance and balanced scorecard: An empirical study of the banking sector in Jordan. *Journal of International Studies*, *12*(2), 129–146. https://doi.org/10.14254/2071-8330.2019/12-2/8

Perera, S. S., Bell, M. G., Piraveenan, M., Kasthurirathna, D., & Parhi, M. (2018b). Topological structure of manufacturing industry supply chain networks. *Complexity*, *2018*, 3924361. https://doi.org/10.1155/2018/3924361

Perera, S., Bell, M. G., & Bliemer, M. C. (2017). Network science approach to modelling the topology and robustness of supply chain networks: A review and perspective. *Applied Network Science*, *2*(1), 1–25. https://doi.org/10.1007/s41109-017-0053-0

Perera, S., Bell, M., & Bliemer, M. (2018a). *Network science approach to modelling emergence and topological robustness of supply networks: A review and perspective* (pp. 1–34). arXiv preprint arXiv:1803.09913.

Popp, J., Kiss, A., Oláh, J., Máté, D., Bai, A., & Lakner, Z. (2018). Network analysis for the improvement of food safety in the international honey trade. *Amfiteatru Economic*, *20*(47), 84–98. https://doi.org/10.24818/EA/2018/47/84

Revelle, W. (1979). Hierarchical cluster analysis and the internal structure of tests. *Multivariate Behavioral Research*, *14*(1), 57–74. https://doi.org/10.1207/s15327906mbr1401_4

Saglietto, L., Fulconis, F., Bédé, D., de Almeira Goes, J., & Forradellas, R. (2014). *Wine industry supply chain (WSC) modeling: An Argentina-France comparison* (pp. 1–18).

Shang, W., Ha, A. Y., & Tong, S. (2016). Information sharing in a supply chain with a common retailer. *Management Science*, *62*(1), 245–263. https://doi.org/10.1287/mnsc.2014.2127

Shannon, P., Markiel, A., Ozier, O., Baliga, N. S., Wang, J. T., Ramage, D., Amin, N., Schwikowski, B., & Ideker, T. (2003). *Cytoscape: A software environment for integrated models of biomolecular interaction networks (3.7.2)* [Computer software]. Genome Research. https://cytoscape.org/

Siddique, P. J., Gue, K., & Ayuby, M. S. (2018). The small world of material handling research. In *15th IMHRC Proceedings*. Savannah, Georgia, USA. https://digitalcommons.georgiasouthern.edu/pmhr_2018/31

Topal, B., & Sahin, H. (2018). The influence of information sharing in the supply chain process on business performance: An empirical study. *Studies in Informatics and Control*, *27*, 201–212. https://doi.org/10.24846/v27i2y201808

Vörösmarty, G., & Dobos, I. (2019). The role of personal motivation in sustainable purchasing practices. *Amfiteatru Economic*, *21*(50), 121–136. https://doi.org/10.24818/EA/2019/50/121

Wang, J., Mo, H., & Wang, F. (2014). Evolution of air transport network of China 1930–2012. *Journal of Transport Geography*, *40,* 145–158. https://doi.org/10.1016/j.jtrangeo.2014.02.002

Wang, J., Mo, H., Wang, F., & Jin, F. (2011). Exploring the network structure and nodal centrality of China's air transport network: A complex network approach. *Journal of Transport Geography*, *19*(4), 712–721. https://doi.org/10.1016/j.jtrangeo.2010.08.012

Wang, Y. (2014). *Using network science to disentangle supply networks: A case study in aerospace industry*. http://dspace.lib.cranfield.ac.uk/handle/1826/9322

Wu, J., Wang, H., & Shang, J. (2019). Multi-sourcing and information sharing under competition and supply uncertainty. *European Journal of Operational Research*, *278*(2), 658–671. https://doi.org/10.1016/j.ejor.2019.04.039

Zéman, Z. (2019). The extended functions of strategic controlling in relation to the value creation of sustainable development. *Visegrad Journal on Bioeconomy and Sustainable Development*, *8*(1), 47–52. https://doi.org/10.2478/vjbsd-2019-0009

Zhao, D., Chen, M., & Gong, Y. (2019). Strategic information sharing under revenue-sharing contract: Explicit vs. tacit collusion in retailers. *Computers* & *Industrial Engineering*, *131,* 99–114. https://doi.org/10.1016/j.cie.2019.03.035

Zhang, X. (2014). Analysis for scale-free network characteristics of logistics distribution network. *Journal of Service Science and Management*, *7*(3), 189–195. https://doi.org/10.4236/jssm.2014.73015

Zhao, K. (2012). *A multi-level analysis of information and supply flows in social and business networks* [Dissertation]. The Pennsylvania State University. https://etda.libraries.psu.edu/files/final_submissions/7421