A Framework Based on Social Network Analysis (SNA) to Evaluate Facilities and Alternative Network Designs for Closed Loop Supply Chains

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ABSTRACT

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A Framework Based on Social Network Analysis (SNA) to Evaluate Facilities and Alternative Network Designs for Closed Loop Supply Chains

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A supply chain is a network of suppliers, production, or manufacturing facilities, retailers, and transportation channels which are structured to acquire supplies, produce new products, and distribute the finished products to retailers and customers. Closed Loop Supply Chain (CLSC) networks incorporate the flow of the returned, used, or recycled products from the customers through the retailers to the manufacturing, recycling, or refurbishing facilities to support managing the full lifecycle of the products.

Social Network Analysis (SNA) has been developed to identify and analyze the patterns in social networks. SNA is used as a theoretical framework for better understanding of social networks by characterizing the structure of a network in terms of nodes and links. SNA is applied to various types of networks including telecommunication networks, protein interaction networks, animal disease epidemics, and customer interaction and analysis.

Although SNA is a powerful method to study networks in many areas, it has not been comprehensively applied to supply chain networks. Likewise, there is no application and interpretation of SNA metrics in CLSCs.

In this study, SNA metrics are introduced and interpreted for components in CLSC networks and forward and reverse logistic activities. Correspondingly, a decision

making tool is developed based on selected SNA metrics for comparing alternative network designs in terms of network reliability and balance of the flows.

DEDICATION

To My parents Ashraf and Abbas.

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CHAPTER 1: INTRODUCTION

US companies alone are responsible for almost 7.6 billion tons of solid waste (Mclellan, 2017). In order to cut back on these wastes, Closed Loop Supply Chains (CLSC) have been used in many big companies such as Apple, Walmart, Amazon, Dell, etc. US companies spend up to $100 billion annually on reverse logistic activities involved in the product return process (Ghadge et al., 2016a). Similarly, it has been one of the interesting academic research subjects within the green supply chain. The design and mathematical modeling of CLSC networks have been investigated in facility location-allocation problems in recent studies.

In real world, mathematical models for big sized problems result in many optimal and near-optimal solutions which are almost identical in terms of the quality. One of the main challenges in supply chain network design is to evaluate all optimal and near optimal solutions and select one. To overcome this challenge, this study focuses on developing a new decision making tool to evaluate alternative network designs. We use a CLSC mathematical model as a case study; however, the proposed methodology and metrics can be applied to the design of any supply chain network.

For this purpose, some of the popular metrics in social network analysis (SNA) are selected and proposed for application in the design of CLSC networks. Although social network analysis (SNA) is used as the powerful method to study relationship patterns within many types of networks, applying SNA to supply chain networks has remained a gap (Caldwell, 2018) since all reviewed papers have failed to practically apply SNA metrics to supply chain networks and interpret the results. Moreover, no research on considering SNA in the more complex supply chain networks such as CLSC networks exists in the literature.

Accordingly, the present study attempts to introduce and interpret SNA metrics in the context of CLSC network design for the first time. Furthermore, the proposed metrics are applied to evaluate alternative network designs based on optimal and near optimal solutions.

The study is structured as follows. The literature review of CLSC and SNA metrics is presented in chapter 2. In Chapter 3, application of ANA metrics in CLSC is presented. In chapter 4, the evaluation of alternative network designs based on SNA metrics is discussed. The conclusions and future work are discussed in chapter 5.

CHAPTER 2: LITERATURE REVIEW

In this chapter a review of the existing literature on two topics of Closed Loop Supply Chains (CLSC) and Social Network Analysis (SNA) is presented. In the first section, Sustainable Supply Chain Management (SSCM) and Green supply chain management (GSCM) are discussed. Then, a summary of the studied areas in GSCM including green procurement, green manufacturing, and green logistics will be provided. Closed Loop Supply chain (CLSC) is the main focus area of our study as the main subcategory of green logistics literature. The CLSC network design will be discussed, and a review of the recent studies on CLSC modeling will be presented in section 2.5.7.

A review of the common SNA metrics is provided in the next section. The literature on the application of SNA metrics in supply chain networks will then be discussed. Finally, the summary of the findings and the gaps identified in the reviewed studies are presented in the conclusions section.

According to Seuring (2013), Sustainable Supply Chain Management (SSCM) is defined as the management of the supply chain while considering sustainability factors. The SSCM approach incorporates economic, social, and environmental sustainability criteria in the supply chain

Green supply chains generally strike a balance between environmental and economic aspects. The GSCM has focused on the development and implementation of green supply chain management (GCSM) systems, increasing from 191 to 308 by the end of 2010. Seuring (2013) conducted an extensive literature review of both the SCM and the GSCM and came to the conclusion that the number of publication areas in both areas has increased significantly. The GCCM has focused on the development and implementation of green supply chain management (GCSM) systems, increasing from 191 to 308 by the end of 2010. Table 2-1 shows the Supply Chain Management (SCM) and GSCM according to Sulistio and Rini (2015).

Table 2-1. SCM and Green SCM adopted from Sulistio and Rini (2015)

Characteristics	GSCM	Traditional SCM
Objective and values	Economic and ecological	Economic
Ecological optimization	Low ecological impact	High ecological impact
Supplier selection criteria	Ecological aspect (and price) Long-term relationship	Price switching suppliers quickly Short-term relationship
Cost pressure and price	Low cost pressure / High price	High cost pressure
Speed and flexibility	Low	High

Traditional and green supply chain can be compared based on the two following aspects.

Objective**:** In the traditional supply chains, objective functions such as cost/benefits, responsiveness, and flexibility are typically considered. In green supply chains, a trade-off between environmental and economic aspects is usually made.

Structure**:** Traditional supply chains usually have a forward flow that delivers products to customers and a backward flow to customers. However, a green supply chain is usually a cyclical network that creates added value by integrating product lifecycle stages forwards and backwards with material and information flows (Elbounjimi et al., 2014). The forward flow involves the transportation of products from the upstream suppliers to the downstream customers. The reverse flow involves the transportation of returned products from the customer to the upstream supply chain, for the purpose of recycling or reusing (Sundari and Vijayalakshmi, 2016).

Green supply chain management (GSCM) has been studied in three categories of green procurement, green manufacturing, and green logistics.

2.1. Green Procurement

Focusing on the green factors that affect the relationship between suppliers and manufacturers is an essential step towards a greener supply chain. In this respect, green procurement models can be divided into two main categories: green suppliers and green producers. This is because two of the main sources of carbon emissions are those for which the producer is responsible for the carbon contained in the raw materials supplied and whose emissions depend on factors such as the distance travelled, the quality of the raw material and the quantity of supply (Abdallah et al., 2010).

2.2. Green Manufacturing

Saving Energy and reducing pollution are considered as two main objectives of green manufacturing (Atlas & Florida, 1998). For this purpose, many methods are used to reduce the generation or use of hazardous materials in different supply chain processes. Green manufacturing can be applied to the production planning, recycling, and product design (Atlas and Florida, 1998).

2.3. Green Logistics and CLSC

All aspects of traditional logistics including transportation, warehousing, and inventory management are implied in green logistics while environmental aspects are added in the supply chain as well. There is no major difference between green logistics and GSCM according to the literature. In green logistics, CLSC is becoming an extremely interesting topic in both academia and industry. Researchers have shown an increased interest in CLSC since companies can cover economic and environmental dimensions of sustainability by closing their loop (Guide and Van Wassenhove, 2009; Neto et al., 2010). In the green logistics, CLSC offers an efficient sustainable process where the products are recovered through sustainable practices including recycling and remanufacturing in order to decrease environmental degradation (Neto et al., 2010).

Companies have started to adopt CLSCs to reduce waste and create value since the last few decades (Bajwa, 2018). CLSC makes environmentally friendly impacts even if the economic factor is the main drive for the companies.

A CLSC consists of forward and reverses logistics. In forward logistics the manufacturer delivers the product to the customers, and the returned products are sent back from customers to the refurbishing centers in reverse logistics as shown in **Error! Reference source not found.** (Özceylan and Paksoy, 2013).

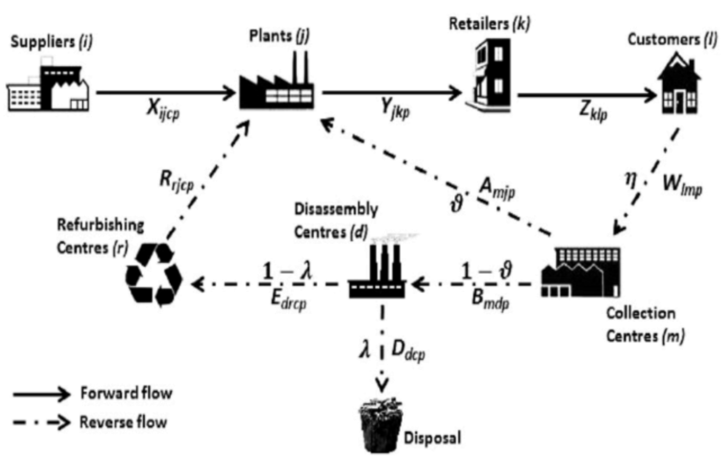

Figure 2-1. CLSC network design, adopted from Özceylan and Paksoy (2013)

The integration of forward and reverse flows in CLSCs results in greater efficiency of the entire supply chain (Pazhani, 2016). CLSC network design is discussed in the next section.

2.4. Closed Loop Supply Chain (CLSC) Network Design

Network design problems are well-known types of problems to be implied in making decision in the companies (Aravendan and Panneerselvam, 2016; Pati et al., 2013). The environmental aspects of the supply chain are influenced by the choice of equipment, transport and inventory during the three decision phases, including design, planning and management (Dekker et al., 2012). In the decision-making phase of the network design, the first step is to consider the facility locations and the required capacity as a first step (Melo et al., 2009). Therefore, facility location problems are considered as a vital part of the supply chain network design.

The literature dedicated to CLSC network design is composed of forward network design (traditional supply chain design) and reverse network design. A Classification of problems in forward and reverse logistics is presented in .

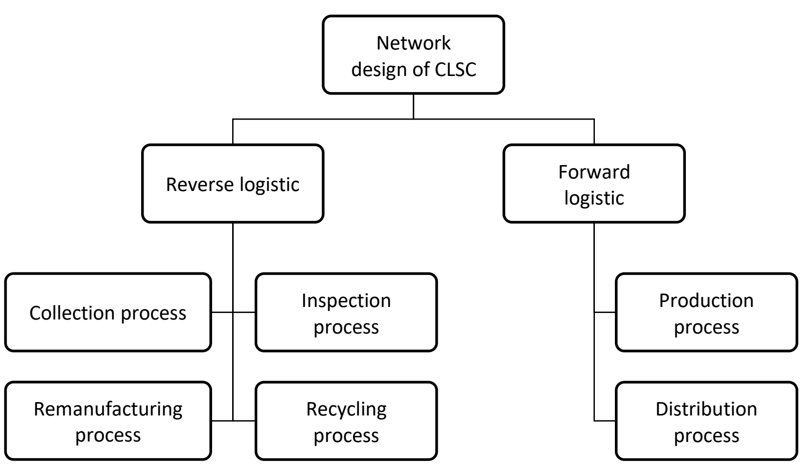

Figure 2-2. Problems in CLSC network design

2.4.1. Forward Logistic Network Design

In the forward logistics network design or traditional supply chain problems, the main concern is the structure of a supply chain network from suppliers to customers (Pishvaee et al., 2009). In design of traditional supply chain network, decisions are made on the facility locations, and required capacity of facilities, as well as tactical decisions regarding the flow between the facilities, transportation mode, and inventory (Farahani et al., 2014). Forward network design is a popular area in the supply chain aiming at distributing products from manufacturers to customers. This definition has been extended by presenting the reverse logistic network design. Dealing with reverse logistics is more complex than having only forward logistics in traditional supply chains. The reason is that quality and quantity of returned products are influenced by many uncertainties and risks. Therefore, developing reverse logistic processes requires understanding of new processes which are quite different from the processes in forward logistics (Srivastava, 2007).

2.4.2. Reverse Logistic Network Design

In the reverse logistic network design the distribution of the returned products for reprocessing (i.e. recycling, reusing, or remanufacturing) are discussed (Jayaraman et al., 2003).

The reverse logistics is the collection of unused or defective products, their sorting and inspection and the transport of the collected products from the treated waste to reuse and disposal centers. It is considered environmentally friendly because it offers the possibility of obtaining a product from waste or recycled materials (R. Dekker et al., 2012). US firms spend up to $100 billion annually on reverse logistic activities involved in the product return process (Ghadge et al., 2016b). Different types of product return in reverse logistics including end-of-use, end-of-life, and commercial are discussed in the following sections (Amin and Zhang, 2012; Guide and Van Wassenhove, 2009).

2.4.2.1. End-of-use Products.

When a functioning product is replaced by a technological upgrade, the majority of end-use products are remanufactured and reused. Replacing components and reprocessing used parts to convert old products into new ones creates value for the used products. Moreover, it may be possible to manufacture enough parts and components to achieve cost effective reprocessing (Amin and Zhang, 2012) .

2.4.2.2. End-of-life Products

End of life returns usually happen when the products become technologically obsolete or no longer have any value for the current user. Parts recovering and recycling are more appropriate in the end of life returns.

2.4.2.3. Commercial Products

Commercial returns are products that are returned by customers within a certain period of time (e.g. 30 days after buying). Returned products are often need to be lightly repaired. Commercial returns are usually in barely used condition and should be returned to the market rapidly (Amin & Zhang, 2012; Guide & Van Wassenhove, 2009)

Three main processes or stages of collection, inspection, and reprocessing are involved in design of reverse logistic in CLSC networks.

2.4.2.4. Collection Process

The collection process is the first recovery step in reveres logistic for returned products (Pati et al., 2013). Fleischmann et al. (2000) defined this process as the process of moving used products to the place where the rendering process is performed on them (Fleischmann et al., 2000a).

2.4.2.5. Inspection Process

Products are first inspected and based on the recycling process, outcome, they are offered for re-use, resale, or re-distribution (Fleischmann et al., 2000; Pati et al., 2013).

2.4.2.6. Recycling Process

The recycling process involves collecting returned products and parts from customers and storing these and potentially usable parts. This includes dismantling and some kind of reprocessing, and the chemical and physical properties of the material can be completely altered during the recycling process (Pui-Yan Ho and Choi, 2012). If a product is not accepted for the separation process or cannot meet the expected quality needed by the market, it is sent to the disposal centers (Fleischmann et al., 2000b).

2.4.2.7. Remanufacture / Refurbish

The returned products are conveyed to remanufacturers in order to be modified to an acceptable level of quality in the supply chain. This process includes disassembling, assembling, as well as refurbishing operations (Sasikumar and Kannan, 2008).

2.5. Modeling of CLSC Network Design

In this section, the common features of CLSC models are discussed. Furthermore, the literature review on two approaches on CLSC modeling including separated forward-reverse logistics and integrated forward-reverse logistics will be provided. Integrated forward-reverse logistics is selected to be reviewed in more details.

Generally, facilities and flows of products are presented by nodes and links in the CLSC networks. Facility location problems are the main focus of CLSC network design studies (Ghadge et al., 2016b). Demand modeling, planning horizon, network structure, flow assumption, and objective function are among the features which are needed to be considered in the modeling of the CLSC networks (Akçalı et al. 2009).

2.5.1. Demand Modeling

Modeling and solution approaches are affected by considering demand as stochastic or deterministic in the model.

2.5.2. Planning Horizon

The two main types of models with respect to planning horizon are single-period and multi-period. The parameters in single-period models are static and used for one-time decision making. Multi-period models are adapted to accommodate changes in parameters such as demand and costs in dynamic models.

2.5.3. Network Structure

The network structure can be characterized by various factors such as type and number of facilities as well as capacity restrictions on the opened facilities.

2.5.4. Flow Assumption

Networks are designed based on single or multi product flows of material in the supply chain.

2.5.5. Objective Function

Single or multiple objective functions can be used in models to incorporate ecological, economic, or social factors in supply chain design.

Network design models for CLSC networks can be classified into separated forward and reverse logistics, and integrated forward-reverse logistics models. Fleischmann et al. (2000) called into the question of whether to consider the reverse and forward logistics in one integrated distribution channel or two separate distribution channels when modeling CLSC networks. Despite the fact that in many studies forward and reverse logistic are considered separately in the network design for simplicity, it has been claimed that integrated forward-reverse logistics is the better option in terms of cost (Lee et al., 2013). Pishvaee et al. (2009), Khajavi et al. (2011), Lee et al., (2013), Ponce-Cueto and Muelas (2015), De Rosa et al. (2014), El-Sayed et al. (2010), Ghadge et al., (2016b), and Kang et al. (2017) proposed different types of integrated forward-reverse logistics CLSC networks. When designing integrated forward-reverse logistics networks, having hybrid processing facilities is more advantageous than isolated distribution and collection centers. Hybrid processing facilities offer the same functionality of traditional distribution centers used in forward logistics with the added benefit of collecting the returned products. The use of hybrid facilities reduces the cost and environmental footprint owing to sharing the required infrastructure and material handling equipment (Pishvaee et al., 2009).

2.5.6. Integrated Forward and Reverse Logistics in CLSC Modeling

A detailed discussion of the literature on integrated forward and reverse logistics in CLSC modeling is provided in the following.

Pishvaee et al. (2009) developed a stochastic model for integrated forward-reverse logistics. Figure 2-3 shows the structure of a network for a single-period and a single product. The network consists of production-recovery centers, hybrid distribution-collection centers, disposal centers, as well as customer zones. Since stochastic demand is the source of uncertainty in this network, the facility location and allocation problem was solved for all production centers, hybrid facilities, and disposal centers utilizing a scenario-based stochastic approach. A small sized problem was solved as case study.

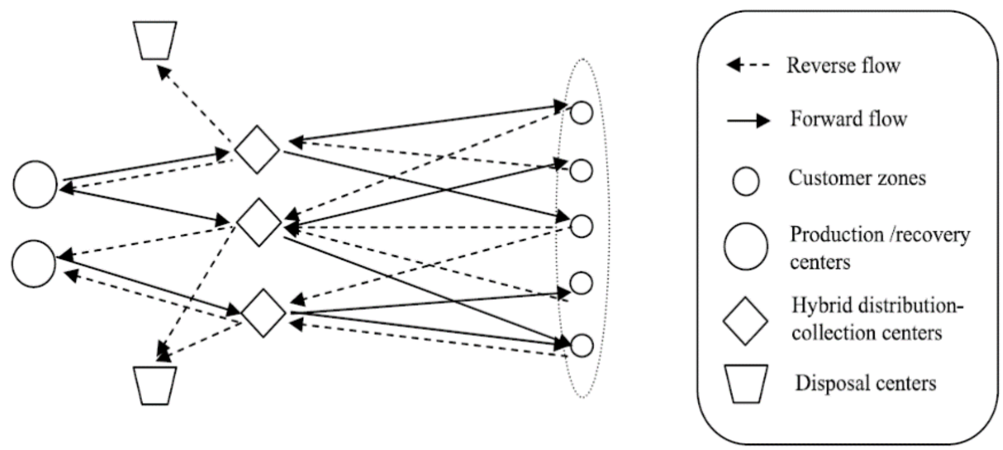

Figure 2-3. Integrated forward-reverse logistics network, adopted from Pishvaee et al. (2009)

El-Sayed et al. (2010) provided a stochastic model for integrated forward-reverse logistics. The network includes suppliers, facilities, distributors, customers, disassembly centers, and disposal and redistribution centers as shown in Figure 2-4. The facility location and allocation problem is solved to maximize profit by considering a multi-period planning horizon and multiple products. This study considered both stochastic and deterministic demand in each of the customer zones. A small size problem was provided as the case study. In order to solve the problem, stochastic mixed integer linear programming (SMILP) was applied, and the effect of the demand and the returning rate were explored in their research.

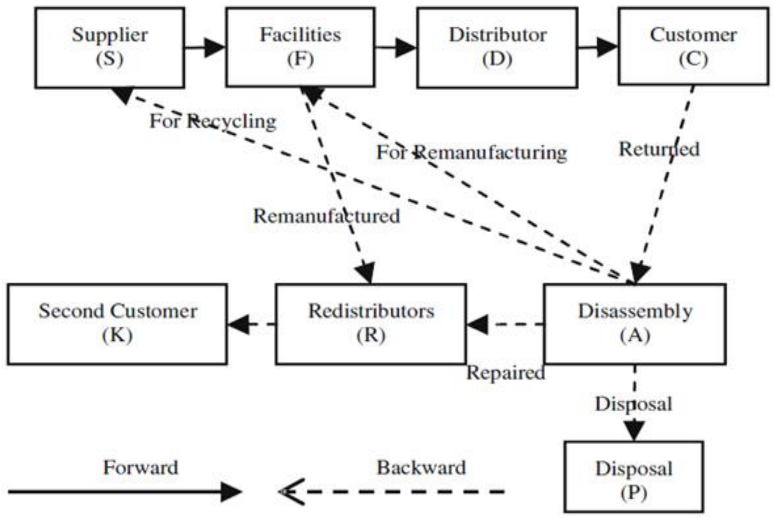

Figure 2-4. Integrated forward-reversed logistics, adopted from El-Sayed et al. (2010)

Khajavi et al. (2011) proposed a capacitated multi-stage logistics network with integrated forward-reverse logistics. The main distinguishing point of their work lies in the handling of forward and reverse logistics simultaneously and including multiple conflicting objectives of minimizing the total cost and maximizing responsiveness in their model. As shown in Figure 2-5, distribution centers work as distribution centers in forward logistics and collecting centers in reverse logistics. In forward logistics, distribution-collection centers are used to transfer new products to each customer zone and collect the returned products in reverse logistics. Returned products are shipped from distribution-collection centers to recovery or production centers. A small sized problem was solved as a case study.

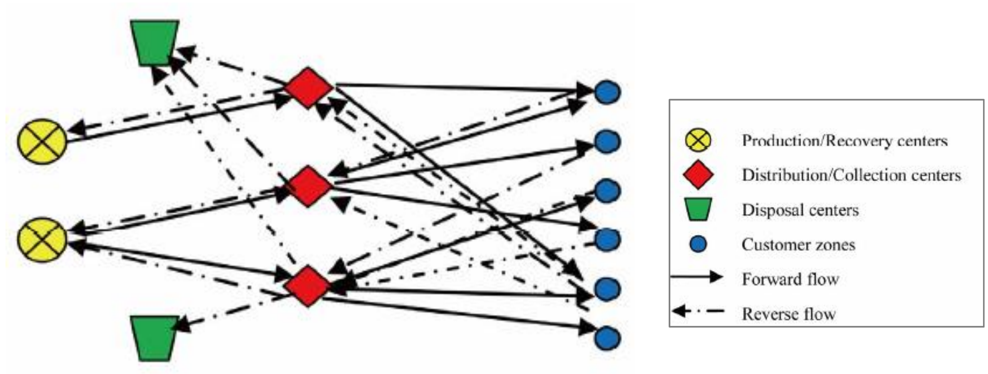

Figure 2-5. Integrated forward- reverse logistics network, adopted from Khajavi et al. (2011)

Lee et al. (2013) proposed a model with integrated forward-reverse logistics. The network includes a combination of collection centers, hybrid facilities, and warehouses as shown in Figure 2-6. Hybrid facilities were defined as warehouse-distribution centers to support both reverse and forward logistics in the supply chain simultaneously (Lee et al., 2013). Multiple planning horizons were considered in the model. The strength of the proposed model is the objective function which simultaneously minimizes cost and maximizes time efficiency of the network.

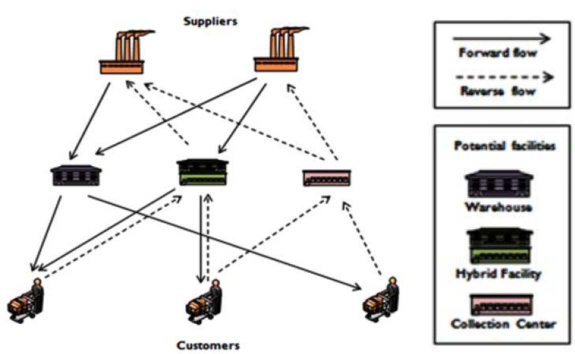

Figure 2-6. Integrated forward- reverse logistics network structure, adopted from Lee et al. (2013)

As part of their study, the total cost of the network with and without hybrid facilities were compared. The results showed that with different return rates, the cost of a supply chain network with hybrid facilities was lower than the cost of a network without them. Consequently, they concluded that integrated forward-reverse logistics network is a more cost-efficient approach. Average percentage of savings earned by using hybrid facilities was 1.33%. De Rosa et al. (2013) introduced a robust deterministic model for integrated forward-reverse networks with the aim of optimizing both transportation and investment costs. The structure of their bi-directional network including production-recycling facilities, delivering depots, collecting depots, hybrid depots, and customer zones is shown in Figure 2-7.

The dynamic facility location problem was solved for the multi-period horizon and multiproduct when demand and supply were uncertain. Scenario-based description method was applied to generate more flexible and robust solutions for robust deterministic sustainable capacitated facility location problem (RSuCFLP) under uncertain demand and supply. Six different scenarios of a small sized capacitated facility location problem were explored and ranked based on deviation from the optimal solution. Furthermore, changing demand and supplies for these scenarios were compared.

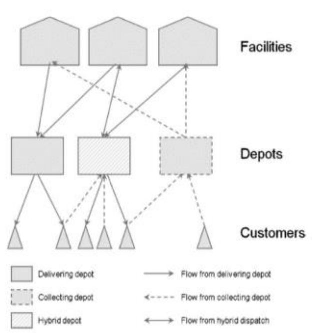

Figure 2-7. Bi-directional network structure adopted from De Rosa et al. (2013)

Ponce-Cueto and Molenat Muelas (2015) presented a mathematical model for integrated forward-reverse logistics for commercial goods. Decision making is on the locations of the warehouses. The other supply chain echelons were factories, retailers, disposal centers, and disassembly centers. A disassembly center works as a collection center for both none-recovered and recovered products. Also, it is a gate to send end-of-life products to disposal centers in which products are disassembled or recycled. The objective function included the estimated transportation and warehousing costs including commercial and technical maintenance costs.

Ghadge et al., (2016a) provided a facility location model in the CLSC to facilitate managerial decision making when the objective is to optimize the distribution center locations. The two questions of whether increasing the product returns affects the location of the facilities, and how to minimize the cost of transportation in forward-reverse logistics were answered in this study. Center of gravity (COG) was applied to find the potential locations for distribution centers. Then, a Mixed Integer Linear Programming (MILP) model is solved for one and two hubs to find the optimal facility locations minimizing transportation and material handling costs. This study covered all supply chain sustainability features in three dimensions of environmental, economic, and social. The proposed network consisted of collection-distribution centers (CDCs), manufacturers, and retailers as shown in Figure 2-8.

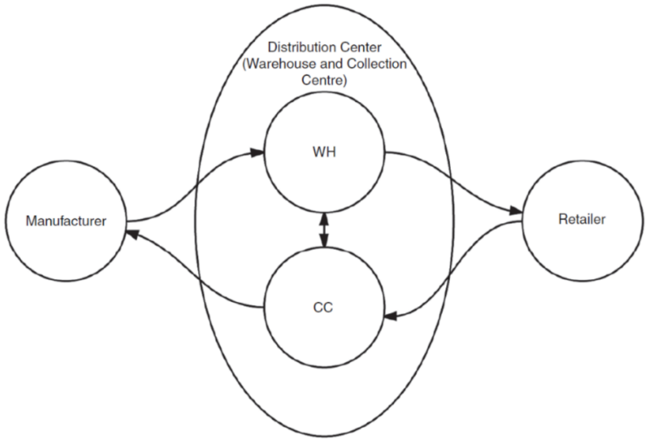

Figure 2-8. Supply chain network design adopted from Ghadge et al. (2016)

Kang et al. (2017) modeled a CLSC with both forward and reverses logistics in an integrated network. A real case was studied in Chinese beer Industry on the recycling process of bottles as a part of waste management to reduce cost and increase economic efficiency. Optimal facility locations were found under uncertain factors including return rate and return product disposal rate. Fuzzy random variables for the return rate were considered in the proposed model which was solved using global-local-neighbor particle swarm optimization (glnPSo) heuristic algorithm.

The objective of the model is to reduce the economic and environmental costs of the green supply chain. The proposed network including factories, retailers, collection-distribution centers (CDCs), and disposal centers is shown in Figure 2-9.

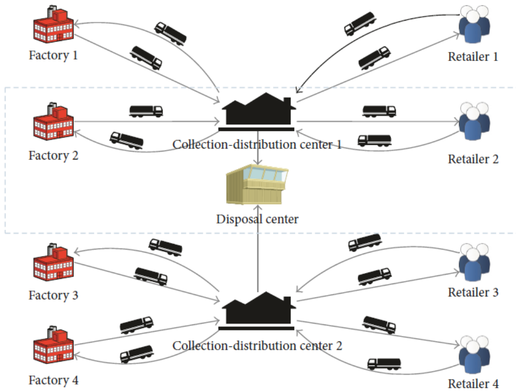

Figure 2-9. Closed-loop supply chain (CLSC) adopted from Kang et al. (2017)

2.5.7. The Summary of Reviewed Models

The summary of the reviewed models with integrated forward-reverse logistics is presented in Table 2-2 and Table 2-3. A Comparison of the models in terms of the supply chain configuration, decision variables, and main features of the model are presented in Table 2-2. Other factors such as size, model type, solution method, number of variables, and runtime are compared in Table 2-3.

Table 2-2. Comparison of the CLSC network design models (I)

V: Decision variable
E: Fixed location of centers
S: Stochastic
D: Deterministic
P: Predefined rate
F: Fuzzy rate
NR: Not reported in model
#: Number of facilities

		Supply chain network components							Models features														
		configuration of the integrated reverse -forward logistic network							Variables			Enviro. Factor	Demand	Return rate				Disposal rate	# of products		Period		
Year	References	Production/ recovery centers	Hybrid facility	Separated collection centers	Disassembly centers	Disposal centers	Retailer/Customer zones	Warehouses	Transportation amount	Facility capacity	Location-Allocation	Carbon emission	Stochastic/Deterministic	Percent of demand	Random	Fuzzy	Interval	Predefined/ Fuzzy	One product	Multi products	One period	Multi period	Facility capacity
2009	Pishvaee et al.	#5,V	#10,V			#3,V	#15,E		*		*		S	*				P	*		*		*
2010	El-Sayed et al.	#3,V			#3,V	#3,V	#4,V	#3,V	*		*		S	*						*		*	*
2011	Khajavi et al.	#3,V	#5,V			#3,E	#4,E		*		*		D	*				P	*		*		*
2011	Lee et al.	#2,E	#3,V	#3,V			#5,E	#3,V	*		*		D	*					*			*	*
2013	Rosa et al.	#6,E	#12,V	#12,V			#100,E	#12,V	*	*	*		D				*			*		*	*
2015	Ponce-Cueto & Muelas	#NR,E			#NR,E	#No,E	#NR,E	#No,V	*		*		D							*		*	
2016	Ghadge et al.	#3,E	#5,V				#3,E		*		*		D		*				*		*		
2017	Kang et al.	#4,E	#NR,V			#1,E	#30,E		*		*	*	D			*		F	*		*		*

Table 2-3. Comparison of the CLSC network design models (II)

Year	References	Objectives			Model Type	Problem(s)	Solver/Constraints	Constraints	Variables		Runtime
		Time	Cost	Sale					Bin.	Int.	
2009	Pishvaee et al.		*		MILP,SMILP	Location-allocation / Transportation quantity	Lingo, 1.6 GHz 1 GB RAM	11	3	5	NA
2010	El-Sayed et al.		*	*	SMILP	Location-allocation / Production quantity/ Transportation quantity	Mosel, 1.37 GHz 512 MB RAM	43	2	5	NA
2011	Khajavi et al.	*	*		MIP	Location-allocation / Transportation quantity	Lingo, 2.5 GHz	15	3	8	NA
2011	Lee et al.		*		MINLP	Location-allocation	GAMS, 2.0 GHz 3 GB RAM	8	3	2	NA
2013	Rosa et al.		*		MIP,SuCFLP MIP,RSuCFLP	Location-allocation with capacity adjustment	CPLEX, 1.6 GHz 4 GB RAM Scenario-based approach	32	6	5	2 18-103 min
2015	Ponce-Cueto & Muelas		*		MILP	Location-allocation	CPLEX, 1.65 GHz 3 GB RAM	4	2	4	< 1 min
2016	Ghadge et al.		*		MILP,COG	Location-allocation	Custom C++ solver	7	10	2	NA
2017	Kang et al.		*		MILP	Location-allocation	Heuristic Pgln PSO	8	2	2	< 1 min

2.6. Social Network Analysis (SNA)

A network is a set of nodes connected by links, while the links are representing the relationship between two nodes (Brass et al., 2004). In social networks, the nodes can be people or firms (Kim et al., 2011), and links represent the type of relationship between the connected nodes (Landherr et al. , 2010).

Social network analysis (SNA) is the process to investigate the patterns of links in the network, which is driven by graph theory (Y. Kim et al., 2011). Moreover, it is a way to explore and map the interaction between nodes. There has been a growth in the application of social network analysis in various field of studies including trade relationship networks (Mueller et al., 2007), disease epidemic networks (Candeloro et al., 2016), and telecommunication networks (Al-Shehri et al., 2017).

A taxonomy of SNA metrics is presented in Figure 2-10. SNA metrics are classified into three categories of node-level, network-level, and node and network level metrics. In the first category, some of the common metrics of SNA which are used for node level analysis are presented. These metrics which are applied to evaluate each node are strength centrality, eigenvector, reducing factor (R), betweenness, and closeness. In the second category, the metrics that are applied in the network-level analysis are presented. These metrics are used to explain the properties and features of the network as a whole. Heterogeneity and symmetry are the network level metrics discussed in this category. In the third category, degree centrality which is a common metric applied in both node and network level analysis is discussed.

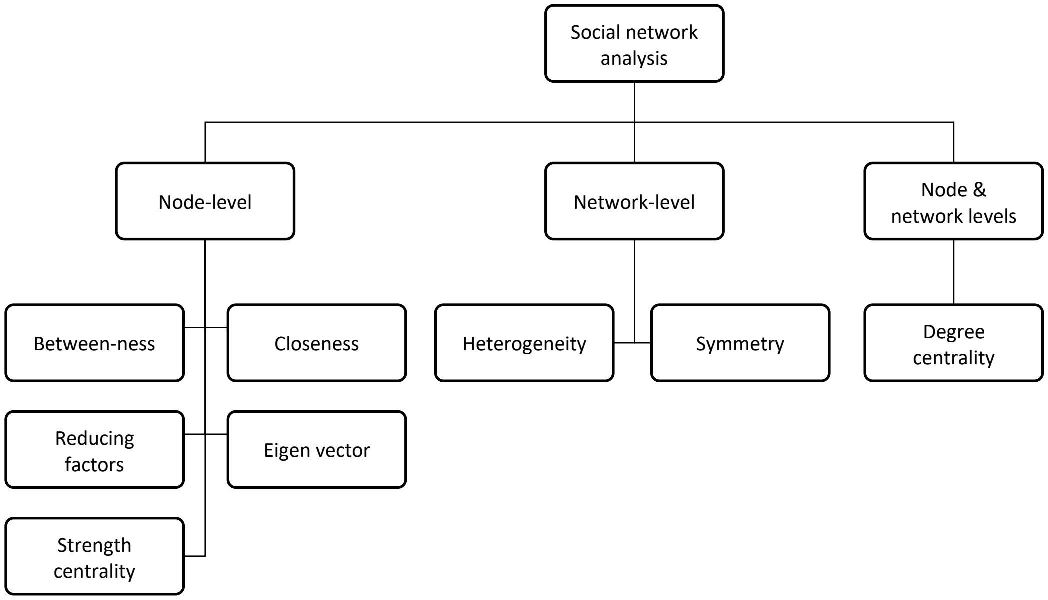

Figure 2-10. SNA metrics taxonomy

2.6.1. Degree Centrality

Centrality is one of the well-known metrics in the evaluation of robustness in the social networks (Borgatti, 2005a). One of the challenges in SNA is to identify the key person as the most central one in social networks. Centrality is used for evaluating a person's interactions with others in the network (Landherr et al., 2010). In the context of node level centrality, Borgatti (2005) defined degree centrality as "the number of links incident upon a node". Easy interpretability of degree centrality metric is the reason for its common application in SNA (Candeloro et al., 2016). According to Wei et al. (2011), three types of in, out and total degree centrality can be calculated. In-degree centrality is the number of received links from other nodes to a given node. Out-degree centrality is the number of nodes that a given node points to. And, total degree which is the number of nodes that both a given node points to and receives from.

A node with the highest node level degree centrality is considered as the most central node in the network. The most central node can be used as a major distribution channel of the flow in the network. When a node represents a person in the social network, the node with the highest degree centrality is considered a central point of communication and likely a main source of information in the network (Opsahl et al., 2010). Having no connection to other nodes or zero degree centrality indicates an isolated node in terms of communications with other nodes, and it is commonly considered a weakness (Freeman, 1978).

Network level degree centrality is a metric to demonstrate how the centrality values are distributed in a network. If a single node has high degree centrality while the majority of the nodes in the network have low degree centrality, the network level degree centrality would be higher than the case with equally distributed degree centrality values (Wei et al., 2011). High network-level degree centrality is not desirable because it reduces the resilience or robustness of the network. The robustness is defined as the ability of a network to withstand the removal of nodes and links from the network (Sydney et al., 2008). In other words, robustness represents the ability of a system to remain functional and withstand the changes despite failure conditions (Thai and Pardalos, 2012). Alternatively, the terms of resilience and robustness are frequently used interchangeably in the literature (Al-Shehri et al., 2017).

2.6.2. Strength Centrality

Strength centrality or weighted degree centrality is used as a node level SNA metric in weighted networks. For this purpose, instead of counting the number of neighbors for a node, sum of the link weights are used (Wei et al., 2011).

2.6.3. Reducing Factor (R)

Candeloro et al. (2016) proposed a new weighted centrality measure referred to as weighted strength centrality (WSC). Similar to strength centrality, this measure is applicable to weighted networks. Strength centrality reflects the sum of the weights on the links connected to a node, however, it lacks the information related to the number of links or how the weights are distributed among them. This can be an issue in networks where the distribution of the weight (flow) is important.

Candeloro et al. (2016) discussed an animal movement network in which the nodes are administrative units (areas) and links are animal movements between them. In a disease spread situation, equal number of animals being dispatched from one area to the surrounding areas would have different outcomes compared to when the majority of the animals are dispatched to one area. Equal weight distribution has been discussed as a desired feature in other networks such as computer networks (Hu et al., 2012) and power distribution networks in the literature (Baloch, 2013).

To incorporate the effect of the weight distribution, a tuning parameter referred to as the reducing (R) factor is calculated and multiplied by the strength centrality metric. When the weights on all edges connected to a node are equal, R would be equal to one. Any deviation from the uniform (equal) weight distribution, would decrease R.

Therefore, low R value indicates significant departure from equal or uniform distribution of weights for a node. Although Candeloro et al. (2016) used reducing factor as a multiplier to calculate weighted strength centrality, we use it as a standalone measure of the weight distribution in this study. Weighted strength centrality is the product of strength and degree centrality by reducing factor which is a complex metric without an intuitive interpretation in the context of supply chain networks.

2.6.4. Closeness

Node level closeness centrality reflects the closeness of a node to others in the network (Abbasi and Altmann, 2011). Freeman (1978) defined the closeness as sum of the graph-theoretic distances of a node from other nodes. More precisely, closeness centrality is calculated based on the average distance between a given node and all other nodes in the network. High closeness centrality for a node indicates that the node is close to the rest of nodes in the network and benefits from accessing resources (Iyer et al., 2013).

2.6.5. Betweenness

Betweenness measures a node’s potential in controlling the communications or flow of information in a network (Abbasi and Altmann, 2011; Wei et al., 2011). It is defined as the number of shortest paths crossing a given node over the total number of shortest paths in the network (Abbasi and Altmann, 2011).

2.6.6. Eigenvector

A node is considered more central when it is connected to nodes with higher centrality. More precisely, the centrality of a node depends on both the number of its adjacent nodes (R. Dekker et al., 2012) and their centrality values (Ruhnau, 2000). Eigenvector centrality can be applied to measure the "power" of each node in a social network (Liu and Lu, 2010).

2.6.7. Heterogeneity

Heterogeneity is a measure reflecting the variability in the node degrees in networks and has been defined in different ways in the literature (Jacob et al., 2017). In the context of social networks, heterogeneity is defined as the variance of node degrees (Snijders, 1981).

2.6.8. Symmetry

A. H. Dekker and Colbert (2005) defined Symmetry as a measure to predict the robustness of a network. Symmetry of a network is defined as the ratio between distinct number of eigenvalues of the network adjacency matrix and network diameter. The network diameter is the longest shortest path between a pair of nodes in the network (A. H. Dekker, 2005). This metric is not commonly used and discussed in other papers.

2.6.9. Applying of SNA Metrics in the Supply Chain

Although social network analysis (SNA) is used as a powerful method to study relationship patterns within a network in various research areas, its application in Supply Chain Management (SCM) has remained a unexplored (Caldwell, 2018). Galaskiewicz (2011), Mueller et al. (2007), and Pishvaee et al. (2009) pointed out the importance of SNA as well as its potential role in SCM research, however, none of them explained how SNA metrics should be applied and clearly interpreted in supply chain networks. The literature review did not identify any studies on the application of SNA metrics to supply chain networks.

Kim et al. (2011) addressed and interpreted SNA metrics for the specific case of supply networks rather than a supply chain network. A supply network is a network with inter-connected companies mainly involving procurement and delivery of products and services (Harland et al., 2001). However, a supply chain network is a network consists of suppliers, manufacturers, retailers, where the products are manufactured and delivered through the transportation channels to the customers (Borland, 2009). The key insights from studies discussing the SNA theory in SCM are summarized in Table 2-4.

Table 2-4. Studies on SNA theory in SCM

Study	Findings	Identified gaps
Mueller et al. (2007)	– Mentioned the potential of using SNA metrics in supply chains. – Provided a theoretical review of the network diagram and network attributes to be considered in SCM – Degree centrality, closeness, and betweenness were discussed	– No measurement of the metrics in SCM – Lack of interpretation of the SNA metrics in the context of supply chain networks
Borgatti and Li (2009)	– Discussed the typology of the links in SNA by considering companies as nodes – Provided a theoretical review of centrality metrics in supply networks (firms-supplier) – Betweenness, degree centrality, and closeness were discussed in the context of supply networks.	– No measurement of the metrics in the supply networks – Lack of interpretation of SNA in the context of supply chain networks
Galaskiewicz (2011)	– Presented their understanding of relevant social network theories to SCM problems.	– Although a general idea of the possibility of application of SNA to SCM was discussed, the objective and application of the metrics are missing. – No specific SNA metrics were discussed.
Kim et al. (2011)	– Discussed the application of SNA metrics to two areas in supply networks including materials flow and contractual relationships. – Interpreted the degree centrality, closeness, and betweenness in supply networks (firms-supplier). – Discussed both node and network level SNA metrics.	– Lack of interpretation of SNA metrics in supply chain networks. – No measurement of the metrics in a supply chain network.

2.7. Conclusions

The literature on sustainable supply chain management (SSCM) was reviewed in the first section of this chapter with an emphasis on Closed Loop Supply Chain (CLSC) network design. Some of the recently published papers in the modeling of CLSC network design were reviewed. The literature has identified CLSC as one of a major area of interest within the green supply chain because it provides both economic and environmental aspects of sustainability in the supply chain CLSC network design and modeling integrated forward-reverse logistics in CLSC have been discussed in facility location-allocation problems in recent studies. In the reviewed models, cost was the main focus in the objective function; however, time and profit were also considered in two of the reviewed models. Mixed integer linear programming (MILP) is the most popular math modeling method for integrated reverse-forward logistics. These studies, however, involved small size problems with less than 13 facilities and up to 12 potential locations.

The literature on SNA was provided in the second section of the chapter and commonly used SNA metrics in analyzing social networks were addressed. Furthermore, the literature on SNA theory in supply chain networks was discussed. There are relatively few studies focusing on this topic and all of them failed to practically apply and measure SNA metrics in supply chain networks. Moreover, no study applying SNA to more complex supply chain networks such as CLSC was identified in the literature.

The literature review concludes that there is a gap in the application of SNA metrics in the CLSC network design. The application of SNA metrics to CLSC networks can result in the development of performance metrics to analyze and evaluate alternative CLSC network designs.

CHAPTER 3: THE APPLICATION OF SNA METRICS IN CLOSED LOOP SUPPLY CHAINS[i]

3.1. Introduction

In today's competitive environment companies work in a continuously changing environment and therefore, quick response which typically involves a thorough analysis of the situation and re-design based on the available information is the key to survive (Chandra & Grabis, 2016). The dynamics of the changes require the companies to apply new approaches to quickly adapt to the changes and be able to compete.

Supply chain network design problems are perceived as important decision-making problems in the supply chain management (SCM) owing to their notable role in the strategic planning process (Aravendan & Panneerselvam, 2016; Pati et al., 2013). Supply chain network design problems deal with the facilities as the main entities and the flow of products and supplies between them. Common problems to be addressed in supply chain network design problems are the choice of facility locations, allocation of products or customers, transportation, inventory management, and capacity planning (Chandra & Grabis, 2016). Performance management has a key role in the success of organizations through setting objectives, evaluating performance, and composing appropriate action plans. There are various performance metrics for supply chains with respect to order planning, suppliers, service and satisfaction, and cost (Gunasekaran et al., 2004). However, the existing supply chain metrics are not still sufficient to address the

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[i] This is an original Author's manuscript of an article in preparation to be submitted to Decision Support Systems journal

complexity of supply chain networks (Abu-Suleiman et al., 2004), and there is still a great deal of confusion in theory and practice of performance evaluation of supply chains (Bourne et al., 2018). The literature review conducted in this study indicates that no performance metric to monitor and evaluate the network characteristics of the supply chain networks including the facilities and relationships between them exists. Analyzing different types of facilities and their relationships with other facilities in supply chain networks leads to a deeper understanding of the network nature of supply chains and identifying potential issues disrupting the flows of supplies, information, and services in the network. Such metrics can serve as a novel tool set to enhance the quality and speed of managerial decision making and improve the responsiveness to changes.

Social Network Analysis (SNA) is a powerful method to study the relationship patterns within networks of various types including social networks, telecommunication, and epidemic diseases (Borgatti, 2005a; Candeloro et al., 2016; Landherr et al., 2010). However, the application of SNA metrics to supply chain networks has remained unexplored in the literature (Caldwell, 2018). Although Galaskiewicz (2011), Mueller et al. (2007), and Pishvaee et al. (2009) highlighted the importance of SNA as well as its potential role in supply chain management research, none of them described how SNA metrics can be applied and clearly interpreted in supply chain networks.

The objective of this research is to provide a new decision-making tool to evaluate the performance of the individual components of supply chain networks by applying selected node level SNA metrics. The supply chain network components being discussed are manufacturers, distribution centers, retailers, and remanufacturers. SNA metrics including degree centrality, strength centrality, and reducing factor are applied and interpreted on different types of facilities in supply chain networks and more specifically in closed loop supply chain networks (CLSC).

To our best knowledge, the proposed approach in this research is the first instance of the application of the aforementioned SNA metrics to supply chain network evaluation and the results are expected to improve operational and tactical level performance in the supply chain.

The aforementioned metrics are presented as an SNA based performance evaluation framework which helps the decision makers to understand the strengths and weaknesses of an existing supply chain network. The proposed framework can also be used to assess the performance of proposed supply chain network designs before the implementation and strategically plan the resources to improve performance and flexibility. The SNAinSCM R package is developed to calculate and visualize SNA metrics on supply chain networks which is available on GitHub (AkbarGhanadian, 2020/2020a)

In this study, the relevant literature on supply chain networks and social network analysis is presented in3.2. The proposed research methodology is discussed in section 3.3. The empirical results from the application of the proposed framework on a case study are provided in section 3.4 and academic and managerial conclusions are summarized in section 3.5.

3.2. Literature Review

3.2.1. Closed Loop Supply Chain Network Design

Closed loop supply chains (CLSC) are becoming a trending topic in both academia and industry. Researchers have shown increased interest in CLSCs since companies have started considering economic and environmental dimension of sustainability in their supply chains (Guide and Van Wassenhove, 2009; Neto et al., 2010). CLSCs offer efficient sustainable processes in which the products are recovered using sustainable practices including recycling and remanufacturing in order to decrease environmental degradation while improving the profitability (Neto et al., 2010).

The operations in CLSC networks can be divided to forward and reverse logistics. Forward logistics networks which involve the same activities as traditional supply chains are directed networks to deliver product from suppliers to customers, including manufacturers, distribution centers as well as retailers or customers (Pishvaee et al., 2009). In the reverse logistics network, the distribution of the returned products for reprocessing (i.e. recycling, reusing, or remanufacturing) are discussed (Jayaraman et al., 2003). The reverse logistics is the collection of unused or defective products, their sorting and inspection and the transport of the collected products from the treated waste to reuse and disposal centers. It is considered environmentally friendly because it offers the possibility of obtaining a product from waste or recycled materials (Dekker et al., 2012). US firms spend up to $100 billion annually on reverse logistics activities involved in the product return procedure (Ghadge et al., 2016b). Management of returned products affects the operational requirements in remanufacturing and recycling processes and can lead to profitability of the companies (Guide & Wassenhove, 2001). Although CLSCs are more complex compared to the conventional supply chains, they are adopted by many leading companies with large supply chains such as Dell, Walmart, and Apple to improve their recycling efforts.

There are two approaches in CLSC network design modeling: Separated forward and reverse logistics, and integrated forward-reverse logistics. Fleischmann et al. (2000) called into the question of whether to consider the reverse and forward logistics in one integrated distribution channel or two separate distribution channels in CLSC network models. Despite the fact that in many studies forward and reverse logistics are used separately in their network design, it has been displayed that the integrated forward-reverse logistics is the more promising option in terms of cost compared to the separated design (Lee et al., 2013).

Network design models for CLSC networks can be classified into separated forward and reverse logistics, and integrated forward-reverse logistics models. Fleischmann et al. (2000) called into the question of whether to consider the reverse and forward logistics in one integrated distribution channel or two separate distribution channels when modeling CLSC networks. Despite the fact that in many studies forward and reverse logistic are considered separately in the network design for simplicity, it has been claimed that integrated forward-reverse logistics is the better option in terms of cost (Lee et al., 2013). Pishvaee et al. (2009), Khajavi et al. (2011), Lee et al., (2013), Ponce-Cueto & Muelas (2015), De Rosa et al. (2014), El-Sayed et al. (2010), Ghadge et al., (2016b), and Kang et al. (2017) proposed different types of integrated forward-reverse logistics CLSC networks. When designing integrated forward-reverse logistics networks, having hybrid processing facilities is more advantageous than isolated distribution and collection centers. Hybrid processing facilities offer the same functionality of traditional distribution centers used in forward logistics with the added benefit of collecting the returned products. The use of hybrid facilities reduces the cost and environmental footprint owing to sharing the required infrastructure and material handling equipment (Pishvaee et al., 2009).

3.2.2. Social Network Analysis and Metrics

A network is composed of a set of nodes connected by links, with the links representing the existence of a relationship between the connected nodes (Brass et al., 2004). In social networks, the nodes are typically people or firms (Kim et al., 2011), while links represent the type of relationship between the connected nodes (Landherr et al., 2010).

Social network analysis (SNA) is the process of investigating the patterns of links in a network based on the graph theory (Y. Kim et al., 2011). Moreover, it is a way to explore and map the interaction between the nodes. There has been a growth in the application of social network analysis in many fields of study including trade relationship networks (Mueller et al., 2007), disease epidemic networks (Candeloro et al., 2016), and telecommunication networks (Al-Shehri et al., 2017). Although social network analysis (SNA) has been used to study relationship patterns in networks in many disciplines, its application to supply chain networks has remained unexplored.

Several research studies have discussed the application of SNA metrics to supply networks rather than supply chain networks. A supply network is a two side network consisting of supplier and buyer, while supply chain networks include diverse components such as suppliers, production or manufacturing facilities, retailers or customers, and transportation channels to deliver the products to the customers (Santoso et al., 2005; Kim et al., 2011). Borgatti and Li (2009) performed a theoretical review of centrality metrics including betweenness, degree centrality, and closeness SNA metrics in supply networks. Kim et al. (2011) applied and interpreted node and network level degree centrality, closeness, and betweenness SNA metrics in a firm-supplier supply network scenario. Mueller et al. (2007) mentioned the potential application of SNA metrics including degree centrality, closeness, and betweenness SNA metrics to supply chains. However, both studies (i.e. Kim et al. 2011 and Mueller et al. 2007) failed to provide any measurement and interpretation of the SNA metric values in the context of supply chains or networks. Galaskiewicz (2011) presented their understanding of relevant social network theories to supply chains. Although a general idea of the possibility of application of SNA to supply chain networks was discussed, the objective, application, and interpretation of the metrics were missing.

The literature review concluded that no study has practically applied, measured, and interpreted SNA metrics in supply chain networks. Moreover, there is no evidence on the application of SNA metrics to more complex supply chain networks such as CLSC in the literature.

In this research, node-level SNA metrics including degree centrality (in and out), strength centrality (in and out), and Reducing factors ($R_{disperse}$ and R_{absorb}) are measured and interpreted for all types of facilities in forward and reverse logistics in CLSC networks. The node-level analysis is provided for Manufacturer-Distribution Center (M-DC), Distribution Centers-Retailer (DC-Re), Retailers-Distribution Centers (Re-DC), and Distribution Centers-Remanufacturer (DC-RM) relationships in the network. The collection of the aforementioned SNA metrics forms a new decision-making tool to evaluate the components of CLSC networks to aid in CLSC network design.

3.2.2.1. Degree Centrality

Centrality is a commonly used metric to evaluate the robustness of social networks (Borgatti, 2005a). One of the challenges in SNA is to identify the key person (also referred to as the most central person) in social networks. Centrality is a measure for a person's interactions with others in the network (Landherr et al., 2010).

Borgatti (2005) defined node level degree centrality as "the number of links incident upon a node". Easy interpretability of degree centrality metric is the main reason for its extensive application in SNA (Candeloro et al., 2016). Wei et al. (2011) discussed in-degree and out-degree centrality in directed graphs. In-degree centrality is the number of links a given node receives from other nodes in the network. Out-degree centrality reflects the number of nodes that a given node points to. Total degree can therefore be defined as the number of nodes that a given node both points to and receives from.

The node with the highest node level degree centrality is considered the most central node in the network. In social networks, the node with the highest degree centrality is considered a central point of communication and likely a major source of information in the network (Opsahl et al., 2010). Having no connection to other nodes or zero degree centrality indicates an isolated node in terms of communications which is typically considered a weakness (Freeman, 1978). In supply chain networks, the most central node can be strategically used as a major distribution channel for the flow in the network.

3.2.2.2. Strength Centrality

Strength centrality also referred to as weighted degree centrality is the extension of degree centrality where the weight of links are used in analyzing weighted networks (Barrat et al., 2004). The weighted adjacency matrix is used is used to calculate the strength centrality for each node. In a weighted adjacency matrix, an element is equal to zero if there is no link between the nodes corresponding with the row and column of the element, otherwise it is set to the weight of the link between the nodes (Opsahl et al., 2010). Strength centrality reflects the sum of the link weights connecting a given node to its neighbors (Wei et al., 2011). Strength centrality is interpreted differently for each type of networks. Barrat et al. (2004) interpreted the strength centrality as the total traffic handled by each airport in the world-wide airport network. In a scientific collaboration network, strength centrality reflects the total number of publications of the scientist associated with each node. The literature review did not find any evidence of the application of strength centrality to supply networks or supply chain networks.

3.2.2.3. Reducing Factor (R)

Candeloro et al. (2016) proposed a new weighted centrality measure referred to as weighted strength centrality (WSC). Similar to strength centrality, this measure is applicable to weighted networks. Strength centrality reflects the sum of the weights on the links connected to a node, however, it lacks the information related to the number of links or how the weights are distributed among them. This can be an issue in networks where the distribution of the weight (flow) is important.

Candeloro et al. (2016) discussed an animal movement network in which the nodes are administrative units (areas) and links are animal movements between them. In a disease spread situation, equal number of animals being dispatched from one area to the surrounding areas would have different outcomes compared to when the majority of the animals are dispatched to one area. Equal weight distribution has been discussed as a desired feature in other networks such as computer networks (Hu et al., 2012) and power distribution networks in the literature (Baloch, 2013).

To incorporate the effect of the weight distribution, a tuning parameter referred to as the reducing (R) factor is calculated and multiplied by the strength centrality metric. When the weights on all edges connected to a node are equal, R would be equal to one. Any deviation from the uniform (equal) weight distribution, would decrease R. Therefore, low R value indicates significant departure from equal or uniform distribution of weights for a node. Although Candeloro et al. (2016) used reducing factor as a multiplier to calculate weighted strength centrality, we use it as a standalone measure of the weight distribution in this study. Weighted strength centrality is the product of strength and degree centrality by reducing factor which is a complex metric without an intuitive interpretation in the context of supply chain networks.

3.3. Research Methodology

3.3.1. Framework for Interpreting SNA Metric in CLSC

In the network representation of a supply chain network, different types of facilities are characterized as the nodes while the weight of the links (w_{ij}) represent the quantity of products transferred between nodes or facilities denoted by i and j .Two types of networks including binary and weighted networks are commonly used in social network analysis. A binary network is represented by an adjacency matrix A having as many rows and columns as the number of nodes in the network as shown in Equation (1). The value of the elements corresponding to the present links are equal to one. In supply chain networks, elements equal to one in the adjacency matrix suggest the presence of a relationship between two facilities based on the transferred products.

$$A_{ij} = \begin{cases} a_{ij} = 1 & \text{if } i \text{ and } j \text{ are conected} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

In weighted networks, the weight of a link connecting two nodes reflects the intensity or frequency of the relationship between them. In a weighted adjacency matrix, the elements are defined as shown in Equation (2). The elements in the adjacency matrix in this case represent the volume (number, weight, or value) of the transferred products between the corresponding facilities. The two SNA metrics of strength centrality and reducing factor discussed in this research are based on the weighted adjacency matrix.

$$A_{ij} = \begin{Bmatrix} w_{ij} & if\ i\ and\ j\ are\ conected \\ 0 & otherwise \end{Bmatrix} \tag{2}$$

In this research, node-level SNA metrics including degree centrality (in and out), strength centrality (in and out), and Reducing factor ($R_{disperse}$ and R_{absorb}) are applied to all types of facilities in forward and reverse logistics. The node-level analysis is provided for Manufacturer-Distribution Center (M-DC), Distribution Center-Retailer (DC-Re), Retailer-Distribution Center (Re-DC), and Distribution Center-Remanufacturer (DC-RM) relationships in CLSC networks. It is worth mentioning that the calculation and interpretation procedure proposed in this research is applicable to traditional supply chains which only involve the forward logistics.

3.3.1.1. Node- Level Degree Centrality

Degree centrality is the simplest centrality metric in social network analysis (SNA) and determines the number of direct contacts of a node (Landherr et al., 2010). At the node-level, degree centrality C_D is the count of the neighbors for a node in the network. Assuming an adjacency matrix A with elements a_{ij} = 1 when there is an edge from node i to j and 0 otherwise, in and out degree centrality are calculated as follows.

Out-degree centrality $$C_{D-out}(x) = \sum_{j=1}^{N} a_{xj} \tag{3}$$

In-degree centrality $$C_{D-in}(x) = \sum_{i=1}^{N} a_{ix} \tag{4}$$

The degree centrality metric represents the number of relations with other facilities for a given facility in a supply network. A high in or out degree centrality reflects high transactional intensity or related risks for the facility the node represents (Kim et al., 2011).

In the CLSC networks, out-degree centrality is applicable to the facilities from which the products are sent out, while in-degree centrality is measured for the receiving facilities. Hence, in-degree centrality is defined and measured for distribution centers and retailers in the forward logistics. Distribution centers are supplied by manufacturers while retailers are supplied by the distribution centers. Although high in-degree centrality means managing more relationships, having high in-degree centrality for distribution centers and retailers in forward logistics can be advantageous. High in-degree centrality results in the diversity in suppliers which improves the flexibility and resilience in case of disruptions and unexpected events (Costantino & Pellegrino, 2010).

In-degree centrality is considered for distribution centers and remanufacturing facilities in reverse logistics. High in-degree centrality in reverse logistics means receiving returned products from more sources. This is challenging for distribution centers since the facility needs to collect, process, store, and ship the returned products. For remanufacturing facilities, high in-degree centrality implies a neither negative nor positive interpretation because their objective is to have enough capacity and infrastructure to process returned products rather than having relationships with more distribution centers.

Out-degree centrality is considered for manufacturers and distribution centers in forward logistics. High out-degree centrality means serving more facilities which implies more challenges in ensuring on-time delivery, order processing, responding to changes in demand, and transportation planning. On the other hand, having high out-degree centrality in forward logistics is indicative of being a common supplier with the capability of multi allocations as a manufacturer or distribution center, and lower risk of excess or obsolete inventory because of more relationships with other facilities. However, high out-degree centrality combined with low in-degree centrality in distribution centers is a potential risk in forward logistics which will be discussed in section 3.4.3. Out-degree centrality in reverse logistics is measured for retailers and distribution centers. Retailers and distribution centers with high out-degree centrality have the benefit of more relations with more processing facilities for the returned products. Similar to the case of forward logistics, greater out-degree centrality in reverse logistics is indicative of being a common supplier capable of supporting multiple retailers while such facilities need to be supervised and monitored carefully to ensure they perform optimally in the supply chain. In case of disruptions in the operation of such facilities, multiple retailers and remanufacturing facilities would be affected.

3.3.1.2. Node-Level Strength Centrality

As discussed previously, a weighted adjacency matrix is employed in computation of node level strength centrality. Equation (4) shows the strength centrality for a node based on the weight W_{ij} associated with the edge connecting nodes i and j.

$$S_i = \sum_{j}^{N} W_{ij} \tag{5}$$

In social networks, the link weights can represent the volume of interactions between nodes, geographic distance, or the travel time between them (Wei et al., 2011).

Strength centrality is the sum of the weights of the links assigned to a node. This is identical to the degree centrality in binary networks if each link is assumed to have a weight of 1. However, the interpretation of these two measures are totally different. Strength centrality reflects the total level of involvement of a node in the network (Opsahl et al., 2010) while degree centrality indicates the number of relationships for a node (Y. Kim et al., 2011). In-degree and out-degree strength centrality can be calculated as follows:

Out-degree strength centrality
$$S_{D-out}(x) = \sum_{j=1}^{N} W_{ij} \tag{6}$$

In-degree strength centrality
$$S_{D-in}(x) = \sum_{i=1}^{N} W_{ij} \tag{7}$$

In CLSC networks, strength centrality is defined for both the origin and destination facilities that interact with one another. The out-degree strength centrality is defined for the origin facility (aka. supplier) and in-degree strength centrality is discussed for the destination facility.

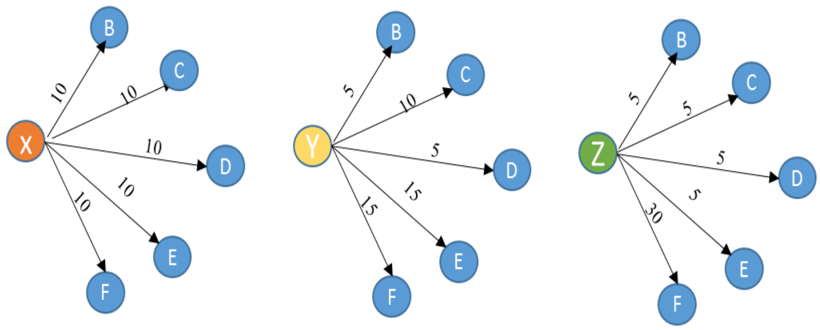
In-degree strength centrality is considered for distribution centers and retailers in forward logistics. High in-degree strength centrality for distribution centers is typically caused by high demand from retailers and reflects more challenges in managing the flow of incoming products, higher investment on storage and transportation infrastructure, equipment, and staff. Dealing with high volumes of products frames the distribution centers as critical facilities in terms of involvement in the supply chain. Retailers with high in-degree strength centrality (i.e. high demand) are considered critical due to their notable role in the sales and therefore profitability of the supply chain. High in-degree centrality indicates greater demand for that retailer. Such retailers and the distribution centers supporting them form crucial distribution channels in the supply chain and are required to be monitored carefully since disruptions in their operation impacts many customers.

In-degree strength centrality is considered for distribution centers and remanufacturers in the reverse logistics. High in-degree strength centrality for distribution centers means receiving a higher volume of returned products which involves more effort to manage the returns and ship them to the remanufacturing or recycling centers and requires higher investment in storage infrastructure, equipment, and staff. Distribution centers with high in-degree strength centrality are also key components in delivering the majority of the returned products to remanufacturing facilities and reverse logistics. As a remanufacturer, high in-degree strength centrality implies challenges in terms of capacity and infrastructure to process the returned products. Since remanufactures perform activities such as disassembly, cleaning, inspection, repair, and sorting that may not occur in the manufacturing process, they typically require more resources and investment compared to manufacturing facilities with similar in-degree centrality. Also, high in-degree strength centrality for a remanufacturer increases the risks associated with availability, timing, and quality of the remanufacturing process.

Out-degree strength centrality in forward logistics is deliberated for manufacturers and distribution centers. Facilities with high out-degree strength centrality have the high in-degree strength centrality too. Therefore, all discussions provided for high in-degree strength centrality are also applicable to high out-degree strength centrality. Facilities with high out-degree strength centrality are considered critical and expected to face more challenges in order management and on-time delivery, monitoring and responding to changes in demand, as well as transportation. Out-degree strength centrality in reverse logistics is measured for retailers and distribution centers. Retailers with high out-degree strength centrality have to deal with higher volumes of returned products from customers which requires more investment in return logistics and transportation. Distribution centers with high out-degree strength centrality face challenges in handling the logistics of the returned products and transportation to remanufacturing or recycling facilities.

3.3.1.3. Reducing Factor(R)

Reducing factor is a metric proposed by Candeloro et al. (2016) and is applied to weighted networks to compare the weight distribution between nodes having identical degree and strength centrality. Three scenarios are presented in Figure 3-1 to illustrate the significance of the reducing factor metric. Although the nodes in all three scenarios have the same degree and strength centrality, their reducing factors are different.



X: strength centrality=50, degree centrality=4, R-factor = 1.0

Y: strength centrality=50, degree centrality=4, R-factor = 0.76

Z: strength centrality=50, degree centrality=4, R-factor = 0.60

Figure 3-1. Example of different distribution of weights in three networks

The area under the cumulative function of percentage weight distribution is denoted by AUC_{Fx}, and the area under the uniformly distributed percentage weight is denoted by AUC_{max}. R is the ratio between (AUC_{Fx}) and (AUC_{max}) as shown in Equation (8).

$$R = \frac{AUC_{Fx}}{AUC_{max}} \tag{8}$$

Reducing factor is equal to one when the weights are uniformly distributed among all edges connected to a node while deviation from the uniform distribution results in lower values. It is critical to sort the weights in ascending order prior to calculating the cumulative weight. The cumulative distribution of percentage weight (Fw) is used for calculating reducing factor for the three networks in Figure 3-1 Deviation from uniform weight distribution decreases the area under the cumulative percentage weight function AUCFx as shown in Figure 3-2.

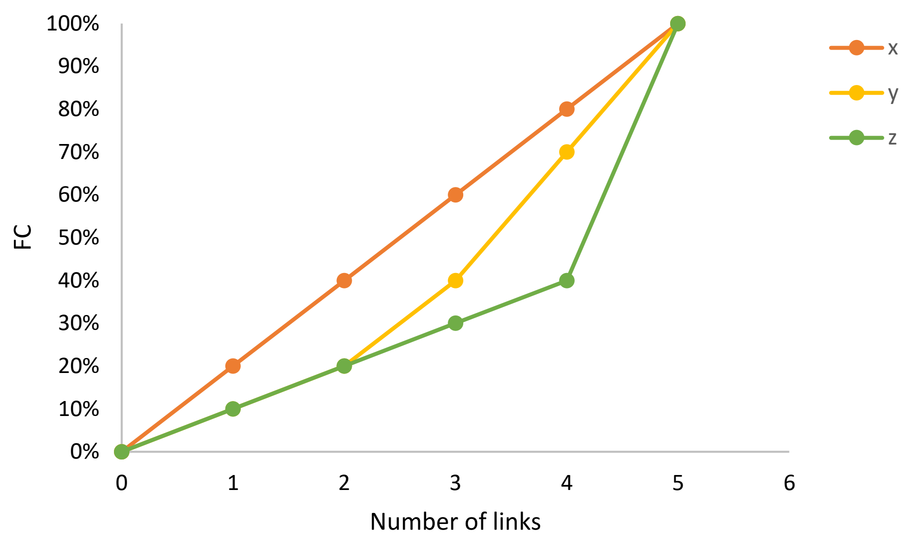


Figure 3-2. Cumulative percentage weight distribution for nodes X, Y and Z

We propose two types of R factor referred to as absorbed and dispersed R factor for each node in a CLSC network. For facilities receiving flow, the absorbed R factor (R_{absorb}) can be defined as a measure indicating how balanced the flows of the incoming products are. Comparatively, the dispersed R factor ($R_{disperse}$) is defined for facilities sending products to measure the uniformness of the distribution of the products sent. Low reducing R factor indicates significant deviation from uniformly distributed product flows for a node while a close to one value shows a well-balanced flow. The degree centrality needs to be greater than one for a node to be able to calculate R_{absorb} or $R_{disperse}$. This is due to the fact that a facility must be connected to two or more facilities in order to have a valid R factor.

Balanced allocation of customers to distribution centers not only decreases the frequency of backorders and late deliveries, but also increases utilization rate and order fill rate in distribution centers (Zhou et al., 2002). The Goal of balanced allocation problems is to design supply chain network in such a way that the best balance of transportation cost and customer services are provided. In this type of problems, avoiding underutilization and overcrowding of distribution centers is performed by balancing the customers' allocation to distribution centers. In the case of establishment of new distribution center which involve high level of risk according to huge start up investment as well as unpredictable demand, applying balance allocation is practical. Zhou et al. (2002) discussed the balanced allocation problem which is drawing from an optimal assignment flows between distribution centers and customers. The product flows are required to be 'equitable' as possible where same amount of workload has been dedicated to each distribution centers. Balancing the flows assigned to all components in the supply chain networks can benefit the inventory management efforts throughout the supply chain but including that as an objective or constraint in an optimization model excessively complicates the solution process. R factor can be used as a simple metric to evaluate the balance of incoming and outgoing flow on various components of supply chain networks. Since R factor indicates the departure from equal or uniform distribution of flows or weights, facilities with high R factor have well balanced flows of products which results in better utilization of transportation, loading, and shipping infrastructure which reduces the transportation costs and simplifies planning. Unbalanced flows increase the complexity of logistics and planning as well as investment in transportation infrastructure.

3.3.2. The Case Study Model

CLSC networks can have separate or integrated forward and reverse logistics. A CLSC network design problem with integrated forward-reverse logistics is used as a case study in this paper. Integrated forward-reverse logistics allows the use of hybrid facilities in the network which lowers the cost and environmental footprint of the network as a result of sharing the infrastructure and material handling equipment (Pishvaee et al., 2009). Figure 3-3 shows the structure of the CLSC network in the case study.

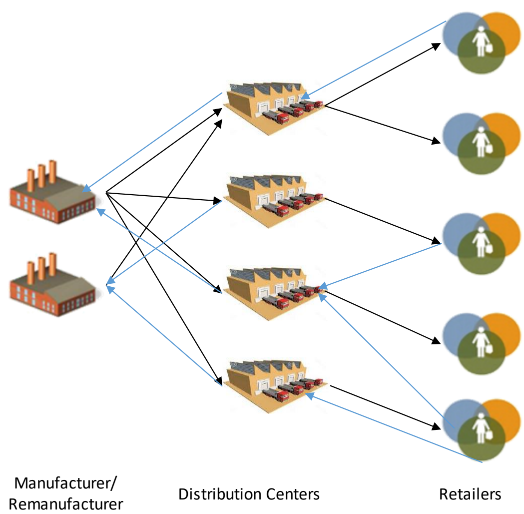


Figure 3-3. The CLSC network with integrated forward-reverse logistics used as case study

The CLSC network design problem in the case study consists of 5 manufacturing facilities, 50 retailers, and 10 distribution centers. 3 out of 5 manufacturing facilities are capable of both manufacturing and remanufacturing. The distribution centers are hybrid facilities that can send and receive supplies and returns to/from the manufacturing facilities and retailers. Each retailer is assumed to receive supplies from only one distribution center. The distribution centers can be potentially located at any of 118 selected Walmart store locations in the state of Ohio (Holmes, 2011), while the manufacturing facility and retailer locations are considered to be fixed. The demand for each retailer is considered to be constant and known. The return rate from each retailer is 10% of the demand. Manufacturing and remanufacturing capacities for each manufacturer are 1,100,000 and 200,000 respectively.

The shortest network distances between the existing facilities and the candidate locations were calculated using the road network data for the state of Ohio (*OpenStreetMap*, 2013). PostgreSQL (PostgreSQL contributors, 2020), PostGIS (Refractions Research et al. 2001) and PgRouting (pgRouting contributors, 2020) were used to perform the required spatial analysis.

3.3.2.1. Model Assumptions and Formulation

- The network consists of 118 Nodes, with 5 manufacturing facilities, 50 retailers, and 10 hybrid facilities as distribution centers.
- 3 out of 5 manufacturing facilities are capable of both manufacturing and remanufacturing.
- Distribution centers can send and receive supplies and returns to/from any manufacturing facility and retailer, but each retailer can only work with one distribution center.

- Distribution centers can be located at any of the 118 nodes on the network.
- Manufacturer and retailer locations are fixed.
- The demand for each retailer is predefined and constant.
- The return rate is considered 10% of the demand for each retailer.
- Manufacturing capacity for each manufacturer is set to 1,100,000 units.
- Remanufacturing capacity is set to 200,000 units.

The mathematical model for the problem is presented below.

The objective function minimizes the total transportation cost.

$$Min\left(\sum_{i\in I}\sum_{j\in J} d_{ij}\left(X_{ij}+P_{ji}\right)+\sum_{j\in J}\sum_{k\in K} d_{jk}\left(U_{jk}+Q_{kj}\right)\right) \tag{9}$$

The first constraint ensures that demand for each retailer is satisfied.

$$\sum_{j} U_{ij} = d_k \qquad \forall\, k \in K \tag{10}$$

The next constraint ensures that all returned products from customers are collected.

$$\sum_{j} Q_{kj} = r_k \,.\, d_k \qquad \forall\, k \in K \tag{11}$$

The next three constraints balance the forward and reverse flows between manufacturers, distribution centers, and retailers.

$$\sum_{i \in I} X_{ij} = \sum_{k \in K} U_{ijk} \qquad \forall\, j \in J \tag{12}$$

$$\sum_{k \in K} Q_{kj} = \sum_{i \in I} P_{ji} \qquad \forall\, j \in J \tag{13}$$

$$\sum_{j \in J} P_{ij} = \sum_{j \in J} X_{ij} \qquad \forall\, i \in I \tag{14}$$

The next constraint ensures the number of opened distribution centers is 10.

$$\sum_{j \in J} Y_j = 10 \qquad \forall j \in J \tag{15}$$

The next two constraints ensure that only opened distribution centers are allocated to retailers or manufacturers.

$$\sum_{i \in I} X_{ij} \le M \times Y_j \qquad \forall\, j \in J \tag{16}$$

$$\sum_{k \epsilon K} Q_{kj} \le M \times Y_j \qquad \forall\, j \in J \tag{17}$$

This constraint ensures each retailer is served by only one distribution center.

$$\sum_{j \in J} Z_{jk} = 1 \qquad \forall k \in K \tag{18}$$

This constrain ensures the retailers are served by open distribution center.

$$Y_{jk} \le Y_j \quad \forall j \in J \quad and \quad \forall k \in K \tag{19}$$

This constraint ensures retailers are served with the specific distribution centers from which the product is shipped.

$$U_{jk} \le M \times Y_{jk} \quad \forall j \in J \quad and \quad \forall k \in K \tag{20}$$

Next constraints set the capacity limitation for manufacturing and remanufacturing centers.

$$\sum_{j \in J} X_{ij} \le CapM_i \quad \forall i \in I \tag{21}$$

$$\sum_{j \in J} P_{ji} \le CapRM_i \quad \forall i \in I \tag{22}$$

Next are the binary, non-negativity, and big M value constraints.

$$Y_j, Y_{jk} \in \{0,1\} \quad \forall j \in J, k \in K \tag{23}$$

$$X_{ij},\ U_{jk}, Q_{kj},\ P_{ji} \ge 0 \quad i \in I, j \in J, k \in K \tag{24}$$

$$M = 2{,}000{,}000 \tag{25}$$

3.3.2.2. Indices, Parameters, and Decision Variables

Table 3-1. Indices, decision variables, and parameters of the proposed model

Indices	i	known position of the production/recovery centers, $i \in I$
	j	Alterative position for *DCs*, $j \in J$
	k	Known position at the retailers, k $\in K$
Variables	X_{ij}	Quantity of products shipped from production center *i* to *DCj*
	U_{jk}	Quantity of products shipped from *DCj* to retailer k
	Q_{kj}	Quantity of products shipped from retailer *k* to *DCj*
	P_{ji}	Quantity of products shipped from *DCj* to recovery center *i*
	Y_j	Binary variable for opened *DCs*
	Y_{jk}	Binary variable for served retailer *k* by *DCj*
Parameters	d_k	demand of retailer *k*
	$CapM_i$	Capacity of manufacturer *i*
	$CapRM_i$	Capacity of remanufacturer *i*
	r_k	Return rate of products from retailer *k*
	$C_{ij} = C_{jk} = 1$	Cost of shipping per unit distance
	$d_{ij} = d_{ji}$	Distance between manufacture *i* and *DCj*
	$d_{kj} = d_{jk}$	Distance between *DCj* and retailer *k*
	J	Set of the indices for potential *DCs*
	I	Set of the manufacturer indices
	K	Set of the retailer indices

The mathematical model was solved in CPLEX to find the optimal network design that minimizes the total transportation cost. The solution includes the locations of the distribution centers, as well as the allocation in forward and reverse logistics between the manufacturing/remanufacturing facilities, distribution centers, and retailers. The optimal forward and reverse logistics networks are visualized in Figure 3-4. The thickness of the edges are proportional to the number of products transferred between the facilities. The detailed results from the model are provided in the appendix.

In the next step, the discussed SNA metrics are applied to the optimal network design and the results are analyzed.

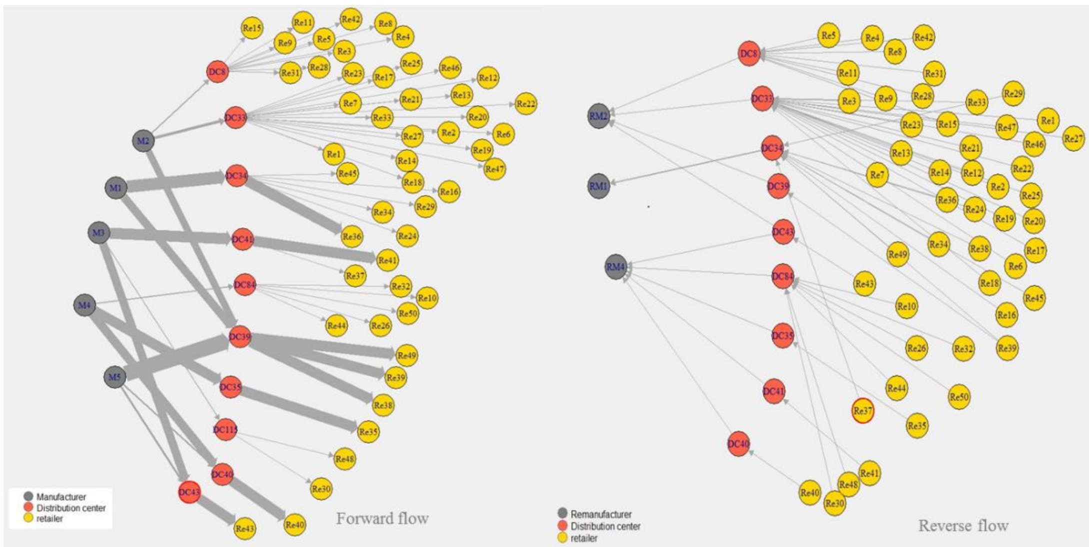


Figure 3-4. The optimal forward and reverse logistics networks

3.4. Results

SNA metrics including degree centrality, strength centrality, and reducing factor were implemented in the developed SNAinSCM R package to analyze the weighted adjacency matrices for the optimal network design depicted in Figure 3-4. The package can be installed in Rstudio using following script:

```
install.packages("SNAinSCM")
devtools::install_github("Saraghanadian/SNAinSCM")
```

Figure 3-5. "SNAinSCM" R package installation script box

This R package is developed to be used easily on any supply chain network design solutions. The weighted assignment matrix which can be extracted from the supply chain network design solutions is the input of the method used in the package. In Figure 3-4, the lines indicate the relation of facilities in the optimal solution based on the optimal weighted assignment matrix in forward and reverse logistics. The thickness of each line is proportional to the volume of transferred products in the optimal weighted matrix. The SNA metrics and their interpretation for all facilities will be discussed in forward and reverse logistics.

3.4.1. Application of SNA Metrics in Forward Logistic of CLSC

3.4.1.1. Manufacturers

The out-degree centrality, out-degree strength centrality, and $R_{disperse}$ for manufacturers in forward logistics are presented in Table 3-2.

Table 3-2. Forward logistics SNA metrics for manufacturers

Manufacturer	Out-degree centrality	out-degree Strenght centrality	R disperse
1	2	1100000	0.90
2	3	615794	1
3	3	1100000	0.68
4	3	1100000	0.68
5	3	1100000	0.52

Table 3-2 summarizes the out-degree centrality metric for all 5 manufacturers in the network. Results show that manufacturers 2, 3, 4, and 5 serve 3 distribution centers each which is the highest out-degree centrality for the manufacturers. High out-degree centrality is indicative of being a common supplier with the capability of supporting multiple distribution centers.

In supply chain networks, out-degree strength centrality for manufacturers is a metric showing the level of involvement of the manufacturers in the network based on the flow of products sent to other facilities such as distribution centers. The manufacturer with the highest out-degree centrality is considered the most central manufacturer in terms of involvement and volume of shipped products in the network. Table 3-2 indicates that manufacturers 1, 3, 4, and 5 have equally high strength centrality utilizing their maximum manufacturing capacity which is 110,000 in the network. It is important to note that manufacturer 2 has some redundant capacity to supply in case of disruptions in the operation of other manufacturers. In supply chain networks, $R_{disperse}$ reflects the balance of flow to other facilities. If a manufacturer supplying to more than one distribution center has $R_{disperse}$ of 1.0, it distributes equal volumes of products to all distribution centers it is supplying which is a positive point. Table 3-2 indicates that Manufacturer 2 has an $R_{disperse}$ equal to 1.0 while manufacturer 5 with $R_{disperse}$ equal to 0.52 has the worst balance of flow among all manufacturers.

3.4.1.2. Distribution Centers

The out-degree centrality, out-degree strength centrality, and $R_{disperse}$ for distribution centers in forward logistics are presented in Table 3-3.

Table 3-3. Forward logistics SNA metric for distribution centers

Distribution Center	In-degree centrality	In-degree Strenght centrality	$R_{disperse}$	Out-degree centrality	out-degree Strenght centrality	$R_{disperse}$
8	1	70176	NA	10	70176	0.78
33	1	160684	NA	19	160684	0.75
34	1	656348	NA	6	656348	0.28
35	1	569499	NA	1	569499	NA
39	3	1708497	0.81	3	1708497	1.00
40	2	569499	0.65	1	569499	NA
41	1	598845	NA	2	598845	0.55
43	2	569499	0.73	1	569499	NA
84	1	47681	NA	5	47681	0.57
115	1	65066	NA	2	65066	1.00

In the supply chain networks, in-degree centrality for distribution centers is a metric reflecting the number of relationships with manufacturers. Table 3-3 indicates that distribution number 39 with in-degree centrality of 3 is the most central among all distribution centers. Furthermore, six distribution centers (i.e. 8, 33, 34, 35, 41, and 84) are supplied by only one manufacturer which can be a potential risk in case of disruptions in the operation of the manufacturers.

In the supply chain networks, in-degree strength centrality for distribution centers reflects the level of involvement of distribution centers in the network based on the volume of received products from manufacturers. Table 3-3 shows in-degree strength centrality metric for distribution centers. Similar to in-degree centrality, distribution center 39 has the highest in-degree strength centrality equal to 1,708,497 units. The strength centrality for distribution center 39 constitutes 34% of total products supplied to all distribution centers, while distribution centers 8, 84, and 115 receive a very small portion of the total supplied products from manufacturers (less than 2%). This situation makes distribution center 39 a critical distribution center in terms of the level of involvement in manufacturer-distribution relationship which needs to be taken into consideration when planning resources, staff, and contingencies.

In the supply chain networks, R_{absorb} for distribution centers indicates the balance of the received products flows from the manufacturers. In Table 3-3, R_{absorb} for distribution centers 8, 33, 34, 35, 41, 84, and 115 is not reported since R factor is not applicable to distribution centers with in-degree centrality less than 2 because commenting on even distribution of flows would be irrelevant for a node with a single relationship. Distribution center 39 has the highest R_{absorb} of 0.81 which is a positive factor. Distribution centers 43 and 40 have lower R-absorb values, which is not concerning due to the fact that they have relatively lower in-degree centrality values.

Table 3-3 indicates that distribution center 33 is the most central distribution center with 19 relationships with retailers. Distribution centers with high out-degree centrality are sensitive facilities because many retailers would be affected in case of disruptions in their operation (19 retailers are affected in case distribution center 33 is disrupted).

In the supply chain networks, out-degree strength centrality for distribution centers reflects their level of involvement in the network in terms of the volume of products sent to retailers. Bar charts in Table 3-3 indicate that distribution center 39 supplies the highest volume of products (1,708,497 units) to the retailers which accounts for 34% of the total retailers' demand. Distribution center 39 is a sensitive distribution center from the distribution center-retailer relationship perspective which calls for continuous monitoring and performance evaluation.

Distribution centers 39 and 115 have $R_{disperse}$ values equal to 1.0 suggesting a perfectly balanced of products supplied to the retailers (see Table 3-3). $R_{disperse}$ for distribution centers 35, 40, and 43 with out-degree centrality values of 1 is not reported in Table 3-3 since an out-degree centrality of at least 2 is required to comment on the distribution of the flows. Distribution center 34 has the lowest $R_{disperse}$ value among all distribution centers.

3.4.1.3. Retailers

SNA metrics including in-degree centrality, in-degree strength centrality, and R_{absorb} are reported for distribution center-retailer relationships are reported in forward logistics.

All in-degree centrality values for retailers are one since the model being discussed as the case study is a single allocation model (i.e. each retailer cannot be assigned to more than one distribution center). In multi-allocation models, this measure can have values other than one. In-degree strength centrality for retailers is the same as their demand which is dictated by the input parameters of the model. The retailers with high in-degree strength centrality (i.e. high demand) are considered critical due to their notable role in the total revenue. Also, high variability in retailer in-degree centrality is typically a challenge since high-demand facilities are over utilized and sensitive while low-demand facilities are often underutilized. R_{absorb} cannot be reported for any of the retailers since their in-degree centrality values are equal to one, however, this metric can be reported in multi-allocation models.

3.4.2. *Application of SNA Metrics in Reverse Logistics*

3.4.2.1. Remanufacturers

Manufacturing facilities are referred to as remanufacturers when processing the returned products. Three metrics of in-degree centrality, in-degree strength centrality, and R_{absorb} are discussed for remanufacturers.

Table 3-4. SNA metrics for Remanufacturers

Remanufacturer	In-degree centrality	In-degree Strenght centrality	R absorb
1	1	200000	NA
2	4	101603	0.70
4	5	200000	0.74

In reverse logistics, high in-degree centrality for remanufacturers implies more relationships with distribution centers. Receiving returned products from a higher number of distribution centers is typically a challenge. As shown in Table 3-4, remanufacturer 2 has the highest number of relationships (5) with distribution centers.

High in-degree strength centrality typically requires higher investment on infrastructure for processing the returned products. Although recycled or remanufactured material and products can often be used in the manufacturing process, the economy of recycling highly depends on the industry and costs associated with recycling. Table 3-4 indicates that remanufacturers 2 and 4 have the highest in-degree strength centrality in reverse logistics. These two remanufacturers utilize their maximum remanufacturing capacity which is 200,000 units.

Table 3-4 indicates that remanufacturers 2 and 4 have R_{absorb} values of 0.70 and 0.74 respectively which indicate reasonably balanced flows of returned products from the distribution centers. A well balanced flow of returned products is typically less expensive to ship using the same transportation system that ships the products to the distribution centers. A poorly balanced flow may require extra investment on the reverse logistics. Remanufacturer 1 receives returned products from one distribution center, and therefore does not have the R_{absorb} value reported.

3.4.2.2. Distribution Center

The three SNA metrics of out-degree centrality, out-degree *strength* centrality, and R_{absorb} are reported for distribution centers involved in Distribution Center-Remanufacturer (DC-RM) relationship while in-degree centrality, in-degree *strength* centrality, and $R_{dsiperse}$ are reported for distribution centers in Retailer-Distribution Center (Re-DC) relationship in reverse logistics.

Table 3-5. SNA metrics for distribution centers in reverse logistics (RE-DC, DC-RM)

Distribution center	In-degree centrality	In-degree Strenght centrality	R absorb	Out-degree centrality	Out-degree Strenght centrality	Rdisperse
8	10	7021	0.78	1	7021	NA
33	19	16081	0.75	1	16081	NA
34	10	200000	0.39	1	200000	NA
35	1	56950	NA	1	56950	NA
39	1	39422	NA	1	39422	NA
40	1	56950	NA	1	56950	NA
41	1	56950	NA	1	56950	NA
43	1	56950	NA	2	56950	0.81
84	7	11279	0.58	1	11279	NA

High in-degree centrality for distribution centers in Re-DC relationship in the reverse logistics indicates more relationships with the retailers. Table 3-5 indicates that distribution center 33 has the highest number of relationships with retailers, which is equal to 19. Distribution center 8 and 34 have the second highest in-degree centrality. Although high in-degree centrality highlights the significance of distribution centers in reverse logistics, such distribution centers are susceptible to more challenges in on-time delivery, order processing, responding to demand changes, and transportation planning.

In-degree strength centrality for distribution centers in Re-DC relationship in the reverse logistics network indicates their level of involvement in the network based on the volume of the products received from the retailers. According to Table 3-5 distribution center 34 has the highest in-degree strength centrality in reverse logistics. This means that distribution center 34 receives the highest volume of products from retailers which accounts for 39% of the total products returned to all distribution centers. In this network, distribution centers 8, 33, and 84 receive the lowest volume of retuned products from retailers (less than 2% of the total returned products). High in-degree strength centrality for distribution center 34 results in more challenges in managing the flow of incoming products. Given the fact that this distribution center also has the highest involvement with respect to out-degree strength centrality in the forward logistics network, decision makers should consider higher investment on storage and transportation infrastructure, equipment, and staff in this distribution center.

High out-degree centrality for distribution centers in DC-RM relationship in reverse logistics network indicate higher number of relationships with remanufacturers.

Distribution centers with greater out-degree centrality have the benefit of more relations with remanufacturers. Table 3-5 indicates that distribution center 43 has the highest number of links to remanufacturers which is equal to 2, while other distribution centers are connected to one remanufacturer. Table 3-5 suggests that distribution center 34 returns the highest volume of products to remanufacturers which accounts for 42% of the total returned products. Processing high volume of products increases the transportation, packaging, sorting, loading, and unloading operations and the costs associated with them. This renders the distribution center 34 critical from the DC-RM relationship perspective and in need of continuous monitoring and performance evaluation.

R_{absorb} for distribution centers 35, 39, 40, 41, and 43 cannot be reported since they have in-degree centrality values equal to one. Distribution center 8 has the most balanced incoming flow with R_{absorb} value equal to 0.78. $R_{disperse}$ is only reported for distribution center 43 which has the out-degree greater than 1, and it is equal to 0.81. The high value of $R_{disperse}$ indicates the balance of outgoing flow from distribution center 43 to remanufactures.

3.4.2.3. Retailers

Out-degree centrality, out-degree strength centrality, and $R_{disperse}$ are SNA metrics applicable to retailers in the reverse logistics network.

Out-degree centrality for all retailers are 1.0 due to the single allocation assumption in the case study which means all retailers send the returned products to only one distribution center. However, in multi allocation models, out-degree centrality for retailers can take values greater than 1. In case of multi allocation, high out-degree centrality is indicative of being a common retailer with the capability of shipping returned products to multiple distribution centers.

Out-degree strength centrality for retailers is equal to their demand multiplied by the return rate in this case study. In a real world scenario, out-degree strength centrality reflects the actual volume of the returned products from each retailer. In cases where returned products indicate defects or quality issues, retailers with high out-degree centrality are areas of concern that need to be planned for. Finally, $R_{disperse}$ is not applicable to nodes with in-degrees centrality less than two as discussed earlier. In multi-allocation models, a well-balanced flow of returned products can be easier to manage using the same transportation system used to deliver the products to the distribution centers.

3.4.3. Key Facilities based on the SNA Metrics

In this section, high risk facilities in the network based on the discussed SNA metrics are identified and recommendations are provided to mitigate the risks associated with these facilities. Risk is defined as the unreliability and uncertainty associated with resources which can cause interruptions and other negative consequence in a supply chain (O. Tang & Nurmaya Musa, 2011). Since in real world, facilities are not always available, it is required to plan for disruptions caused by unavailability in the design of supply chain networks (Jabbarzadeh et al., 2018).

3.4.3.1. Manufacturers

Manufacturers 3, 4, and 5 are critical in the network. Each of these three manufacturers serve three distribution centers which is the highest out-degree centrality in the network while having high strength centrality equal to their maximum manufacturing capacity. High out-degree and strength centrality increase the risk of machines' availability and planned performance and results in challenges in on-time product delivery Furthermore, manufacturer 4 requires additional investment in monitoring and resource management due to its remanufacturing functions in in addition to its criticality in forward logistics. On the other hand, planning the manufacturing facilities to operate at their maximum capacity for extended periods of time is challenging. A highly structured capacity planning and production scheduling approach is required to make the most efficient use of the available production capacity. A constantly high utilization rate severely limits the production flexibility for the critical manufacturers which is a significant disadvantage. Manufacturing flexibility is the capability of the manufacturing system to deal with changes (Gupta & Goyal, 1989). Depending on the type of changes being considered, manufacturing flexibility can be interpreted as machine flexibility, process flexibility, product flexibility, routing flexibility, volume flexibility, expansion flexibility, or operation flexibility (Parker & Wirth, 1999). Manufacturer 5 with $R_{disperse}$ equal to 0.52 has the most unbalanced of allocation flow among all manufacturers. This manufacturer requires higher level of actions to reduce workload, and facing with emergency in shipment, also needs higher level of investment in transportation infrastructure because of complicated transportation planning.

3.4.3.2. Distribution Centers

29 out of 50 retailers (58%) in the network are being supplied by distribution centers 8 and 33. Having the highest out-degree centrality among all distribution centers combined with the lowest in-degree centrality renders these two distribution centers as potential sources of risks in the forward logistics operations. Supplying to the majority of the retailers in the network while receiving from only one manufacturer can be seen as a major point of failure in the network. Furthermore, distribution centers 8, 33, and 34 receive 76% of the returned products from most of the retailers in the network and send them to manufacturers 1 and 2 to be remanufactured. Their significant role in reverse logistics, exposes these distribution centers to more challenges in on-time delivery, order processing, responding to changes in demand, and transportation planning. Hence, the distribution centers identified as critical, are major sources of risk due to the excessive levels of challenges in warehouse replenishment, transportation planning, scheduling and capacity planning (Hartmut and Christoph, 2002). Such activities which are considered mid-term (i.e. performed on weekly or monthly basis) or short-term (i.e. performed on daily basis) planning activities, require more involvement and leadership from the managers for these critical facilities.

Distribution centers 39 and 34 with the highest in-degree and out-degree strength centrality respectively are key facilities in the forward and reverse logistics. Distribution center 39 receives the highest volume of products which accounts for 34% of total flow of products in forward logistics, and distribution center 34 receives the highest volume of returned products equal to 39% of the total returned products in revers logistics. Given their level of involvement in the network, these two facilities are identified as critical distribution centers which significantly affect factors including transit time, lead time to retailers, and transporation methods in the network. Such circumstances, require higher investment on infrustructure as well as transportation management, operations planning and scheduling, and warehouse management.

Distribution centers 41 and 84 with $R_{disperse}$ values of 0.55 and 0.57 respectively, have the most unbalanced outgoing flows among all distribution centers in forward logistics while distribution centers 34 and 84 with R_{absorb} values of 0.55 and 0.57 respectively, receive the most unbalanced flows from the retailers in reverse logistics. These distribution centers face challenges in utilization of transportation, loading, and shipping infrastructure. Finally, distribution center 34 deals with the highest volume of products in both forward and reverse logistics while receiving the most unbalanced flows from retailers in reverse logistics. The critical distribution centers discussed in this section need further observation and special provisions in supply chain management to operate properly in both forward and reverse logistics.

3.4.3.3. Retailers

Retailers 35, 36, 38, 39, 40, 41, 43, and 49 have the highest in-degree strength centrality among all retailers in the network. The retailers with high in-degree strength centrality are critical retailers due to their notable role in the total revenue and profitability of the network. Such facilities are considered major sources of risk in forward logistics because they are receiving from only one supplier which is the result of the single allocation assumption in the case study. Out-degree strength centrality for all these eight retailers in reverse logistics is equal to their demand multiplied by the return rate in this case study. As it is mentioned in 3.4.2.3, in a real world scenario, out-degree strength centrality reflects the actual volume of the returned products from each retailer. In cases where returned products indicate defects or quality issues, retailers with high out-degree centrality are areas of risk that need to be planned for.

3.4.3.4. Remanufacturers

Remanufacturer 4 has the highest in-degree centrality and in-degree strength centrality which makes it a critical remanufacturer in reverse logistics. Performing the remanufacturing activities including recycling and reprocessing combined with high involvement in the forward logistics, highlights manufacturer/ remanufacturer 4 as a critical facility which can negatively affect the manufacturing and remanufacturing time and cost. The increase in cycle time and cost are caused by the increase in maintenance, setup, calibration, packaging, loading and unloading operations, and number of staff involved in them. Also, such critical facilities suffer from low manufacturing and remanufacturing flexibility which can be a source of risk in the supply chain.

3.5. Discussion

3.5.1. Academic and Managerial Contributions

This manuscript presents the first framework to apply SNA metrics to closed-loop supply chain networks. The proposed SNA based framework can help with understanding the strengths and weaknesses of existing supply chain networks, and comparing supply chain network design alternatives before the implementation and strategically planning the resources to improve flexibility and performance.

The flexibility of a supply chain network is defined as the ability of the network to adapt to new conditions when exposed to internal or external uncertainty (Winkler, 2009). Resilience is the property of a supply chain network that allows it to react to unexpected events and recover to the original state while maintaining continuity of the operations (Ponomarov & Holcomb, 2009). Improving flexibility, enhances the supply chain resilience(C. Tang & Tomlin, 2008). Identifying the sources of risk and uncertainty is of the first step to improve the supply chain resilience. Identifying the pinch points which are referred to the facilities whose disruptions has a substantial effect on the rest of network is a pre-requisite to improving the supply chain resilience (Christopher & Peck, 2004). In general, facilities are assets vulnerable to failure. The interpretation of the results from the proposed SNA metrics enable mangers to identify the critical facilities in the network which are more likely to cause disruption or their failure have a significant effect on the network. The case study is the location-allocation problem for CLSC network including 5 manufacturers, 50 retailers, and 10 distribution centers, and 3 remanufactures. The potential locations for the facilities are chosen from 118 Walmart store locations in the state of Ohio (Holmes, 2011) and the real road network distances are calculated using data from OpenStreetMap project (OpenStreetMap, 2013). The model is solved in CPLEX and the result are stored in excel sheets for further analysis in R. In this study, high risk facilities referred to as critical facilities were identified in the network based on the discussed SNA metrics and recommendations were provided to mitigate the risks associated with them. Eliminating the identified critical facilities based on the provided metrics or mitigating their risk using the provided guidelines enables stronger planning for redundancy in the network as well as allocating and prioritizing resources efficiently and effectively. We believe that using the proposed SNA metrics in supply chain networks results in higher quality strategic and operational planning of facilities and flows of products to improve flexibility and resilience.

The proposed framework based on SNA metrics is a decision making tool which can improve the performance of supply chain networks. Most of the existing methodologies in closed loop supply chain network design including De Rosa et al. (2014), El-Sayed et al. (2010), Kang et al. (2017), Pishvaee et al., (2009), and Ponce-Cueto and Molenat Muelas (2015) mainly focus on minimizing the total cost. Adopting such design approaches results in several optimal and near optimal alternative designs which are similar in terms of cost, while their performance in the real world may be significantly different. An analytical decision making tool to identify strengths and weaknesses of the alternative network designs is the key to select the best alternative. The proposed SNA based framework can help with the evaluation of all components of the alternative supply chain network designs and the interpretation of the results. For example, a distribution center having the highest involvement in the network with respect to out-degree strength centrality combined with the lowest number of relations with the manufacturers in the forward logistics imposes a weakness in the network design. Consequently, decision makers should either modify the design or consider a higher investment on storage and transportation infrastructure, human resources, and equipment to mitigate the risks. Furthermore, a contingency plan for potential interruptions in the operation of such critical distribution centers is vital.

In conclusion, The SNA metrics in the proposed framework can be used in strategic, operational and tactical level planning for existing supply chain networks. The application of SNA metrics in the proposed framework to supply chain networks is facilitated through the “SNAinSCM” R package introduced in this study (AkbarGhanadian, 2020/2020a). Network design models generate a weighted assignment matrix which is used for calculating the SNA metrics. The R package is available on GitHub and calculates and visualizes degree centrality, strength degree centrality, and R factor for all components of supply chains including manufacturers, distribution centers, and retailers. Figure 3-6 shows the results (on the left) and plots (on the right) from the SNAinSCM R package.

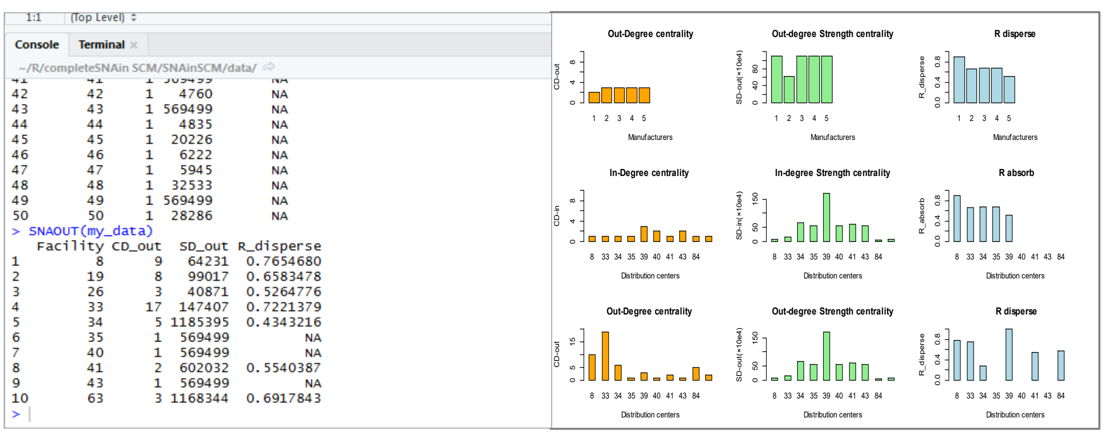


Figure 3-6. “SNAinSCM” R package results applied on the forward logistics network

CHAPTER 4: EVALUATING ALTERNATIVE SUPPLY CHAIN NETWORK DESIGNS BASED ON NETWORK-LEVEL SNA METRICS

4.1. Introduction

Network design problems are well-known types of problems to be implied in making decision in the companies (Aravendan and Panneerselvam, 2016; Pati et al., 2013). While the main focus in traditional supply chain network design was the flow of products in forward logistics (i.e. transporting material and products from manufacturers to distribution centers, retailers, and customers), many companies are adopting reverse logistics to deal with the flow if returned products from customers to retailers, which is referred to as a Closed-Loop Supply Chain (CLSC) (Al-Salem et al., 2016).

The majority of the supply chain network design models discussed in the literature focused on minimizing cost as the objective function (De Rosa et al., 2013; El-Sayed et al., 2010; Ghadge et al., 2016a; Kang et al., 2017b; Lee et al., 2013; Pishvaee et al., 2009; Ponce-Cueto and Molenat Muelas, 2015). Solving medium and large sized supply chain network design problems results in many optimal and near-optimal solutions. Despite being close to the optimal solution in terms of cost, near optimal solutions can be significantly different in terms of the network configuration which affects the performance of the network in many key aspects. In real world, the vulnerability of individual facilities to disruptions is considered a risk for the entire supply chain (Craighead et al., 2007). In supply chains, disruption is defined as unexpected events which disrupt the normal flow of material (Craighea et al., 2007; Snyder & Daskin, 2006). Supply chains are exposed to partial or complete disruptions caused by equipment breakdown, human mistakes, and natural disasters (Jabbarzadeh et al., 2012).

Resilience is the ability of a supply chain to return to its original state or transfer to a new desirable state after disruption takes place. Reducing negative impacts of disruptions needs to be considered in the supply chain strategies to improve resilience (Christopher & Peck, 2004).

In this study a framework based on network level SNA metrics including degree centrality and R factor is proposed to evaluate alternative supply chain network designs to improve resilience as well as balance of the flow. The proposed approach in this research is the first instance of the application of the aforementioned SNA metrics to supply chain network evaluation and the results are expected to improve decision making in supply chain network designs.

The proposed framework is developed based on network-level SNA metrics to evaluate the performance of sets of facilities of the same type in forward and reverse logistics networks. An R package titled NetworkSNA is developed to facilitate the calculation ad visualization of network level SNA metrics in supply chain networks and shared on GitHub (AkbarGhanadian, 2020/2020b). Furthermore, the network-level SNA metrics for each set of facilities are used to calculate total scores to evaluate the entire network for optimal and near optimal alternative network designs. This can be used to select the most desirable network design in terms of resilience and balance of flow.

In this chapter, first, the relevant literature on Closed-Loop Supply Chain (CLSC) networks, social network analysis metrics, and network resilience is presented in 3.2. The proposed research methodology is discussed in 3 categories section 4.3. In this section, first, the case study is presented. Then, the SNA metrics is used to evaluate set of facilities. Finally, these metrics are applied to evaluate entire CLSC networks in terms of resilience and balance of flow. The empirical results and discussion from the application of the proposed framework on a case study are provided in section 4.4 and conclusions are summarized in section 0.

4.2. Literature Review

In traditional supply chain network design, the main concern is the structure of a supply chain network from suppliers to customers (Pishvaee et al., 2009). In design of traditional supply chain network, strategic decisions are made on the facility locations, and required capacity of facilities, while tactical decisions include the flow between the facilities, transportation mode, and inventory (Farahani et al., 2014). Traditional supply chain definition can be extended by introducing the reverse logistics in the network design. Dealing with reverse logistics is more complicated than having only forward logistics. Developing reverse logistic processes requires understanding of new processes which are quite different from the processes in forward logistics (Srivastava, 2007).

In today’s competitive environment, supply chains have to cope with disruptions and operational risks (Craighead et al., 2007), and the costly nature of the disruptions has resulted in relevant emphasize on resilience (Craighead et al., 2007) as well as robustness of supply chains in many research studies (Ponnambalam et al., 2014). Robustness is defined as the ability of a network to withstand the removal of nodes and links from the network (Sydney et al., 2008). In other words, robustness represents the ability of a system to remain functional and withstand the changes despite failure conditions (Thai and Pardalos, 2012). A robust supply chain can maintain acceptable level of performance when several nodes are disrupted. Robustness is the network capacity to tolerate damages from complete or partial disruptions (Ponnambalam et al., 2014). Longo and Ören (2008) defined resilience as the capability of a supply chain to react quickly to internal or external risks and quickly recover to the original state while high performance and efficiency is guaranteed. Resilience of a supply chain indicates how strong and how fast it can recover when disruptions happen, within a reasonable length of time (Ponnambalam et al., 2014). Alternatively, the terms of resilience and robustness are frequently used interchangeably in the literature (Al-Shehri et al., 2017).

Graph theory has been applied to understand network elements including nodes and links and their configuration. Some of the graph measures are considered relevant theoretical measures for evaluating the robustness of a network and has been applied in different studies (Ellens & Kooij, 2013). Graph robustness means how well a graph remains connected when nodes are removed from the network (Alenazi & Sterbenz, 2015). Providing a mathematical formula to measure robustness or resilience is quite challenging (Ellens & Kooij, 2013). Therefore, several studies have worked on the effect of the network structural properties based on graph theory on robustness or resilience. Some of the common metrics including network connectivity, betweenness, and degree centrality are applied in different studies (Alenazi & Sterbenz, 2015; J.-B. Kim, 2015; Ponnambalam et al., 2014).

Network level degree-centrality is one of the well-known metrics in analyzing different type of networks including social networks (Borgatti, 2005), biological networks (Pavlopoulos et al., 2011), computer networks (Alenazi & Sterbenz, 2015), and telecommunication networks (Rueda et al., 2017). Alenazi and Sterbenz (2015) used network centrality to measure the resilience of computer networks. Similarly, this metric has been used to evaluate the resilience of supply networks. Supply networks are typically composed of various suppliers connected to a main firm where nodes represent facilities and links represents deliver mechanisms between nodes in order to deliver physical goods from a node to the next. Removing a node or link from a supply network disrupts the flow of material between the affected facilities (Y. Kim et al., 2015).

Network-level degree centrality is a metric to demonstrate how the centrality values are distributed in a network. If a node has high degree centrality while the majority of the nodes have low degree centrality, the network-level degree centrality would be higher than a network with equal degree centrality on all nodes (Wei et al., 2011). High network-level degree centrality is expected to result in a less robust network. When critical nodes are disrupted in the network, the entire supply chain is likely to remain disabled for a long time (Ponnambalam et al., 2014).

The literature review concluded that no study has practically applied, measured, and interpreted network-level SNA metrics in supply chain networks. Although the effect of the structure of the network and disruption of individual nodes and links on resilience of the network has been researched, no study has discussed the relationships between facilities and introduced a metric for evaluating resilience in supply chains. Moreover, there is no evidence on the application of SNA metrics to more complex supply chain networks such as CLSC in the literature.

In this study, network-level SNA metrics including degree centrality (in and out) and Reducing factor ($R_{disperse}$ and R_{absorb}) are measured and interpreted for all facility types (i.e. sets of facilities of the same type) in forward and reverse logistics in CLSC networks for Manufacturer-Distribution Center (M-DC), Distribution Centers-Retailer (DC-Re), Retailers-Distribution Centers (Re-DC), and Distribution Centers-

Remanufacturer (DC-RM) relationships in the network. The collection of the aforementioned SNA metrics forms a new decision-making tool to evaluate the facility types in terms of resilience and balance of flow as well as improving decision making for selecting desirable CLSC network between all the alternative networks.

4.3. Research Methodology

In this study, network-level degree centrality and balance of allocation are applied to all facility types including manufacturers /manufacturers, distribution centers, and retailers in forward and reverse logistics in a case study involving a Closed Loop Supply Chain (CLSC) network. A total weighted score based on degree centrality and R factor are calculated to compare optimal and near optimal network design alternatives in terms of resilience and balance of flow.

4.3.1. Case Study

The same case study CLSC network discussed in chapter 3 case study is used in this chapter. The network consists of 5 manufacturers, 10 distribution centers, 50 retailers and 3 remanufacturers. Walmart store locations in the state of Ohio (Holmes, 2011) are used as the potential location for distribution centers. Data from the OpenStreetMap project is used to compute real road network distance between the potential locations (OpenStreetMap, 2013). Optimal and near-optimal solutions for the case study model were captured in a solution pool in CPLEX and then exported to Excel. Then, the optimal and 10 high-quality near-optimal solutions were selected from the solution pool for further analysis based on the proposed metrics.

To select the near optimal solutions, first, a maximum acceptable relative gap tolerance of 0.01% from the optimal Objective Function Value (OFV) was selected.

Then, the actual optimality gap was computed for each solution using Equation (26). 42 near optimal solutions from the pool were within the selected 0.01% gap. Finally, after sorting the near optimal solutions based on quality, the top ten solutions presented in Table 4-1 were selected for further analysis in this chapter.

$$\text{Gap} = {(OFV\ for\ the\ solution - optimal\ OFV)}/{Optimal\ OFV} \tag{26}$$

Table 4-1. Selected optimal and near-optimal solutions

Id	Objective Function Value (OFV)	Gap
Optimal	893217547	0
S1	893233227	0.00002
S2	893233227	0.00002
S3	893336841	0.00013
S4	893393743	0.00020
S5	893433640	0.00024
S6	893433640	0.00024
S7	893520019	0.00034
S8	893823505	0.00068
S9	893869474	0.00073
S10	894311320	0.00122

All assignment matrices (X_{ij}, U_{jk}, Q_{kj}, P_{ji}) for optimal and near-optimal solutions were exported to the Excel for computing the SNA metrics using NetworkSNA R package. It is worth mentioning that the calculation and interpretation procedure proposed in this research is applicable to traditional supply chains with only forward logistics.

4.3.2. Evaluating Facility Types Using Network-Level SNA Metrics

4.3.2.1. Network-Level Degree Centrality

Network-level degree centrality is defined as the ratio of the sum of differences between each node's degree centrality and the highest degree centrality over the maximum possible sum of differences in the network (Wei et al., 2011). In other words, network degree centrality is the ratio of the total differences between the most central node and other nodes to the maximum possible total of degree differences in a network with the same number of nodes (Freeman, 1978). Network-level degree centrality is presented in Equation (27).

$$C_{d\_NL} = \frac{\sum_{i=1}^{n}\left(C_d\,(i^*) - C_d\,(i)\right)}{\mathrm{Max}\left\{\sum_{i=1}^{n}\left(C_d\,(i^*) - C_d\,(i)\right)\right\}} \tag{27}$$

In Equation (27), n indicates the number of nodes, $C_d\,(i)$ denotes the degree centrality of node i, and $C_d\,(i^*)$ is the highest degree centrality for the most central node in the network. We refer to $\mathrm{Max}\left\{\sum_{i=1}^{n}\left(C_d\,(i^*) - C_d\,(i)\right)\right\}$ as the Maximum Total Degree Difference (MTDD). This indicates the maximum possible total degree difference for a network with n nodes. $C_{d\text{-}NL}$ represents the network-level centrality as the ratio of the observed sum of degree differences from the most central node to the maximum possible value for this difference, which is a value in [0, 1] interval. This metric can be calculated independently for in-degree, out-degree, and total degree. As mentioned previously, network-level degree centrality is a metric to demonstrate how the centrality values are distributed in a network. Therefore, high degree centrality for a node is desirable only if the degree centrality for all nodes are close to the highest observed degree centrality in the network. Consequently, low network-level degree centrality is desirable as it increases the resilience or robustness of the network.

In the proposed methodology, C_{d_NL} is used as a metric to evaluate the degree centrality for groups of facilities of the same type (referred to as facility types) as well as analyzing the total score of degree centrality for the whole network.

To interpret network-level degree centrality C_{d_NL}, in-degree and out-degree centrality for similar facilities should be considered separately for forward and reverse flows in the network. The numerator of the ratio is calculated based on the total observed difference of the degree centralities in the network being evaluated, while we need to define a scenario to calculate MTDD based on the type of the facility being analyzed and constraints governing the network in question. Therefore, a total of four scenarios are developed for calculating MTDD under different facility types and directions of the flow to be used for computing network-level degree centrality in closed loop supply chain networks.

The following symbols and notations are used in the scenarios covered in this section:

MTDD	$\mathrm{Max}\left\{\sum_{i=1}^{n}\left(C_d\,(i^*) - C_d\,(i)\right)\right\}$
m	Number of manufactures or remanufacturers
d	Number of distribution Centers
r	Number of retailers
$C_d\,(i^*)$	Max value of the specific degree centrality for all nodes in the network
$C_d\,(i)$	Degree centrality of all nodes in the network

Scenario 1. Manufacturer-Distribution center (M-DC) relationship in forward flow: When considering Manufacturer-Distribution center (M-DC) relationships in the CLSC networks with constraints on the manufacturing capacity, the out-degree MTDD

for the manufacturers happens when one distribution center has the highest out-degree (i.e. supplying to all distribution centers), while other manufacturers have minimum out-degree centrality as shown in Figure 4-1. Since manufacturer has to supply to at least one distribution center, the minimum out degree centrality is equal to one. MTDD for the M-DC out-degree relationship is presented in Equation (28).

$$\max \sum_{i=1}^{m} \left(C_d(i^*) - C_d(i)\right) = \sum_{i=1}^{m} \left(d - C_d(i)\right) = \sum_{i=i^*} (d-d) + \sum_{i \in \{1,\dots,m\}-\{i^*\}} (d-1) = (m-1).(d-1) \tag{28}$$

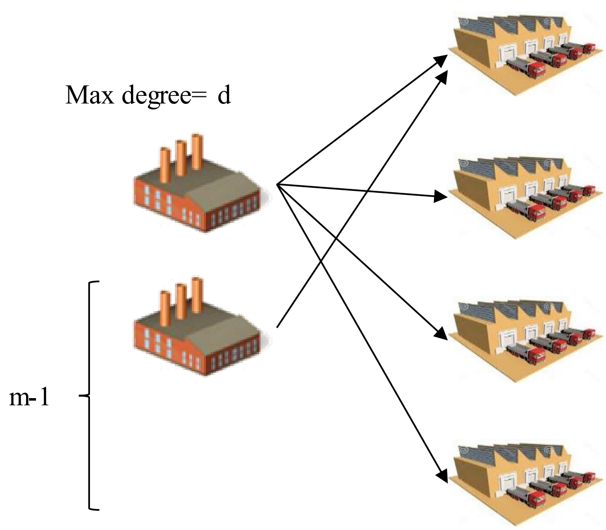


Figure 4-1. Out-degree MTDD for manufacturers in M-DC relationship

In M-DC relationship with the constraint on manufacturing capacity, in-degree MTDD for each distribution center happens when one distribution center has the highest in-degree centrality (i.e. receiving from all the manufacturers) while other distribution centers have in-degree centrality equal to one as shown in Figure 4-2. Each distribution center needs to receive products from at least one manufacturer to distribute it through the supply chain. The reason is that opening a distribution center that does not receive any flow is not justifiable. Applying an approach similar to Equation (28), the in-degree MTDD for distribution centers is equal to $(d-1) \times (m-1)$.

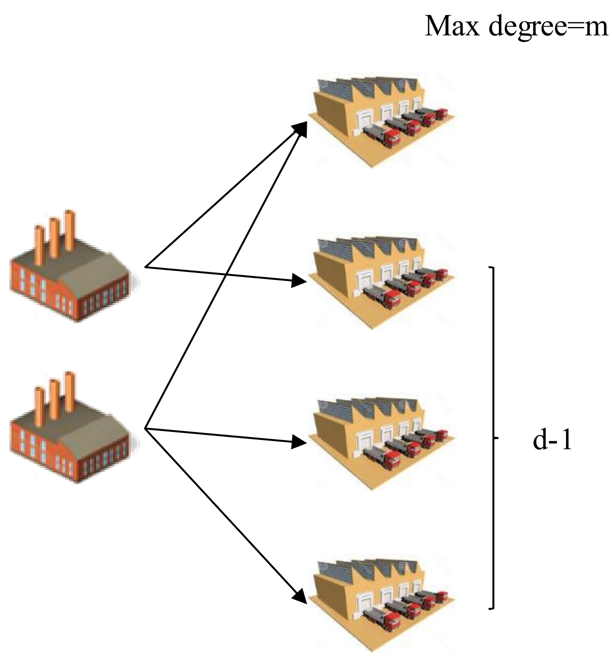


Figure 4-2. In-degree MTDD for distribution centers in (M-DC) relationship

Scenario 2. Distribution Center-Retailer (DC-Re) relationship in forward flow: Considering DC-Re relationship in the supply network under single allocation assumption (i.e. each retailer can only work with one distribution center), the out-degree MTDD for distribution centers can be achieved when one distribution center has the highest out-degree centrality possible (i.e. serving *(r-d)* retailers), while other distribution centers have an out-degree centrality equal to 1 as shown in Figure 4-3 Similar to the previous scenario, the out-degree MTDD for DC is equal to *(r-d)* × *(d-1)* as shown in Equation (29).

$$\begin{aligned} &\max\left\{\sum_{i=1}^{d}(C_d(i^*) - C_d(i))\right\} \\ &= \sum\nolimits_{i=1}^{d}\big(r-d+1-C_d(i)\big) \\ &= \sum_{i=i^*} r-d+1-(r-d+1)+\sum_{i\in\{1,\dots,\mathrm{d}\}-\{i^*\}}(r-d+1-1) \\ &= \sum_{i\in\{1,\dots,\mathrm{d}\}-\{i^*\}}(r-d)=(r-d).(d-1) \end{aligned} \tag{29}$$

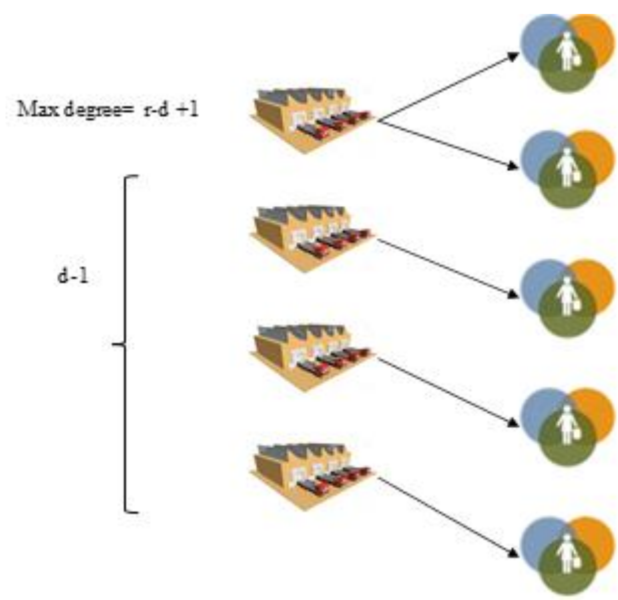


Figure 4-3. Out-degree MTDD for distribution centers in DC-Re relationship

In-degree MTDD for DC-Re relationship with multi allocation and no capacity constraints on distribution centers can be achieved when one retailer has the highest in-degree centrality (i.e. serving all retailers), while other retailers have in-degree centrality equal to 1 as presented in Figure 4-4. MTDD in this scenario would be *(r-1)* × *(d-1)*.

Since in our case study, the in-degree centrality for all retailers is equal to one, we don't calculate in-degree MTDD for the retailers.

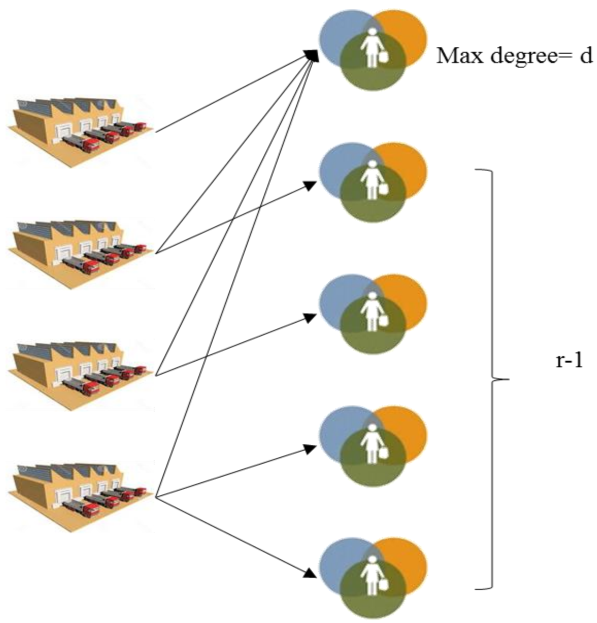


Figure 4-4. In-degree MTDD for retailers in DC-Re relationship

Scenario 3. Retailer-Distribution center (Re-DC) relationship in reverse flow: In Re-DC relationship with no capacity constraints on distribution centers, the out-degree MTDD for retailers is zero because the out-degree centrality for all retailers is 1 and each retailer sends the returned products to its closest distribution center as shown in Figure 4-5.

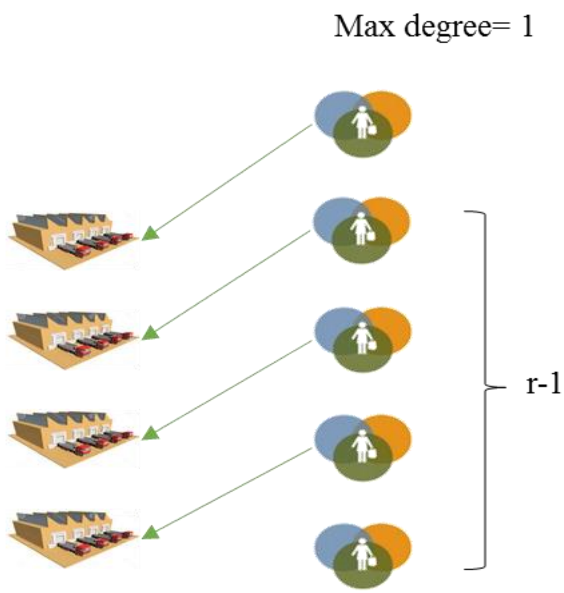


Figure 4-5. Out-degree MTDD for retailers in Re-DC relationship

In-degree MTDD for DC-Re relationship with no capacity constraints on distribution centers can be a when one distribution center has the highest in-degree centrality (i.e. allocated to all retailers), while other distribution centers have in-degree centrality equal to 0 as shown in Figure 4-6. The in-degree MTDD for distribution centers in this case is $r \times (d\text{-}1)$.

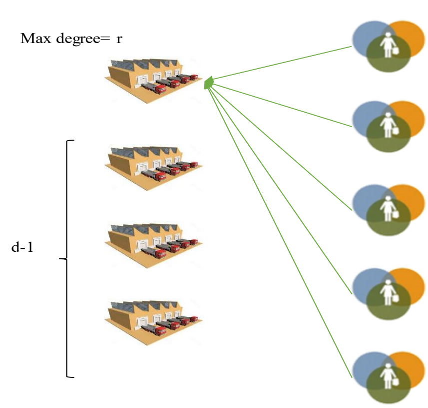


Figure 4-6. In-degree MTDD for distribution centers in Re-DC relationship

Scenario 4. Distribution Center-Remanufacturer (DC-RM) relationship in reverse flow: Out-degree MTDD for DC-RM relationship with capacity constraints on remanufacturers happens when one distribution center has the highest out-degree centrality (i.e. supplying to all remanufacturers), while other distribution centers have zero out-degree centrality as shown in Figure 4-7. The out-degree MTDD for distribution centers is equal to $m \times (d-1)$.

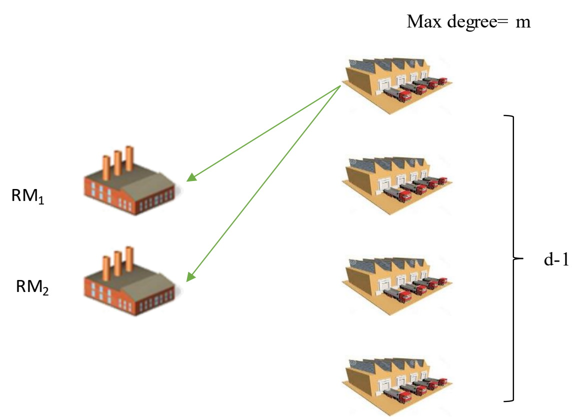


Figure 4-7. Out-degree MTDD for distribution centers in DC-RM relationship

In-degree MTDD for DC-RM relationship with capacity constraints on remanufacturers can be obtained when one remanufacturer has the highest in-degree centrality (i.e. receiving returned products from all distribution centers), while other remanufacturers have zero in-degree centrality as shown in Figure 4-8. The in-degree MTDD for remanufacturers is equal to $(m-1) \times d$.

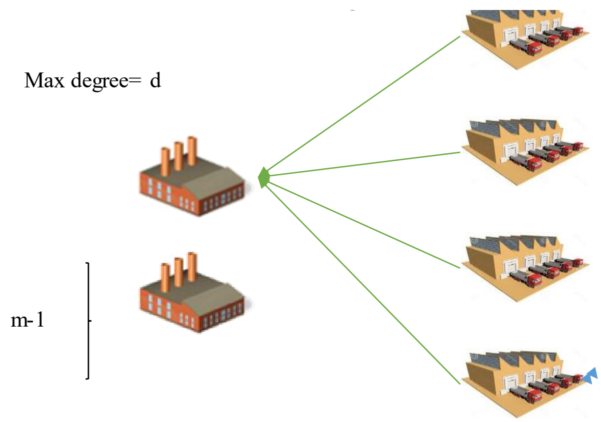


Figure 4-8. In-degree MTDD for remanufactures in DC-RM relationship

Having discussed how to construct MTDD for each type of facility, the C_{d_NL} can be computed for manufacturers, distribution centers, retailers, and remanufacturers based on Equation (27). This metric is used to measure the variability in centrality for each facility type. As an example, having one distribution center with high out-degree centrality while other distribution centers have low centrality, results in a relatively large total sum of differences in the numerator of Equation(27) which leads to a high C_{d_NL}, which reflects the vulnerability of the network to the failure of the facility with high centrality and result in low resilience of the network from the DC-Re relationship perspective. We define resilience as the ability of the supply chain to quickly react to disruptions or failures of facilities while remaining operational.

Network-level degree centrality is applied in this research to evaluate the resilience of each facility type in both forward and reverse networks from the perspective of manufacturer-distribution center (M-DC), distribution center-retailer (DC-Re), retailer-distribution center (Re-DC), and distribution center-remanufacturer (DC- RM) relationships. High network-level degree centrality is not desirable for each facility type and leads to low resilience of the network. High deviation from the maximum centrality for each facility type increases the severity of disruptions, which renders the network vulnerable to failures and reduces the resilience of the entire supply chain network.

4.3.2.2. Network-level R factor in CLSC

Candeloro et al. (2016) proposed reducing factor (R) as a multiplier to calculate a weighted strength centrality. We used R as a standalone measure for the weight distribution in this study. Two types of node-level R factor referred to as absorbed and dispersed R factor is discussed in the previous chapter for CLSC networks. For facilities receiving flow, the absorbed R factor (R_{absorb}) is defined as a measure to indicate how balanced the flows of the incoming products are. Comparatively, the dispersed R factor ($R_{disperse}$) is applicable to facilities sending products to measure the uniformness of the distribution of the products being sent. Low reducing R factor indicates significant deviation from uniformly distributed product flows for a node while a close to one value shows well-balanced flows. The degree centrality needs to be greater than one for a node to be able to calculate R_{absorb} or $R_{disperse}$. This is due to the fact that a facility must be connected to two or more facilities in order to have a valid R factor.

Network-level R factor has not even been discussed in social network analysis literature. We propose network-level R factor referred to as NL-R for CLSC networks. This metric is used for evaluating the distribution of flows for each facility type as well as evaluating the balance of flows in the entire network. Network-level R factors denoted by R_{absorb} and $R_{disperse}$ are calculated as the average of the node-level R factors for facilities of the same type for facilities with out-degree centrality greater than one. As an example, the average R_{absorb} for distribution centers indicates the balance of flows from manufacturers to the distribution centers in M-DC relationship. Since the average R factor indicates the departure from equal or uniform distribution of flows or weights for each facility type, higher R factor results in better utilization of transportation, loading, and shipping infrastructure for all facilities which reduces the transportation costs and simplifies planning for the entire supply chain network.

4.3.3. Evaluating the Entire CLSC Networks

Having discussed how to compute network-level degree centrality and R factor for each facility type including manufacturers, distribution centers, retailers, and remanufacturers in pervious sections, these metrics can be used to calculate the total centrality score and allocation balance for entire CLSC network. A weighted decision matrix is created based on the importance of each metric for each facility type in the CLSC network to calculate a total score. Total scores are weighted sum of the network level metrics which are can be used in any type of supply chain network. The weights can be generated based on the perceived importance of each facility type in the supply chain. In this study, we compare optimal and near-optimal network designs based on the calculated network-level scores.

4.4. Result and Discussions

Network-level SNA metrics including degree centrality and reducing factor were implemented in “NetworkSNA” R package to analyze the weighted adjacency matrices for analyzing each facility type as well as optimal and near optimal network designs. The package can be installed in RStudio using following script.

```
install.packages("NetworkSNA")
devtools::install_github("Saraghanadian/NetworkSNA")
```
Figure 4-9. "NetworkSNA" R package installation Script box

NetworkSNA R package is developed to be used on any supply chain network. The weighted assignment matrix which can be extracted from the supply chain network design solutions needs to be provided as input to the package.

Network level degree centrality and R factor metrics are applied to a case study involving one optimal and 10 near optimal alternative designs for a CLSC to evaluate the degree centrality and the balance of flows for each facility type in forward and reverse logistics. Finally, a weighted decision matrix is used to calculate the total centrality and R score for each of the alternative designs.

4.4.1. Analyzing Facility Types in CLSC based on Network-Level SNA Metrics

Network-level degree centrality and R-factor are the metrics selected for evaluating each set of facilities in terms of resilience and balance of the product flows. The results and discussions are presented in the following sections.

4.4.1.1. Network-Level Degree Centrality

Network-level degree centrality denoted by $C_{d\text{-}NL}$ is computed based on the Maximum Total Degree Difference (MTDD) values developed in the four scenarios presented in 4.3.2.1. MTDD values for the CLSC network in the case study are calculated using the NetworkSNA R package, and presented in Table 4-2 and Table 4-3. The number of manufacturers, distribution centers, retailers, and remanufacturers in the case study are 5, 10, 50, and 3 respectively.

Table 4-2. Maximum Total Degree Difference (MTDD) in forward flow

Scenario for facility type	MTDD (out-degree)	MTDD (in-degree)
M	36	NA
DC	360	36
Re	NA	441

Table 4-3. Maximum Total Degree Difference (MTDD) in Reverse flow

Scenario for facility type	MTDD (out-degree)	MTDD (in-degree)
RM	NA	20
DC	27	450
Re	441	NA

The value of $C_{d\text{-}NL}$ for each facility type in forward and reveres logistics networks in the optimal solution are presented in Table 4-4 and Table 4-5.

Table 4-4. Network-level degree Centrality in forward logistics

Facility / Metric	Cd-NL out	Cd-NL in
M	0.03	NA
DC	0.39	0.44
Re	NA	0.39

Table 4-5. Network-level degree centrality in reverse logistics

Facility / Metric	Cd-NL out	Cd-NL in
RM	0.28	NA
DC	0.33	0.27
Re	0.12	NA

Network-level degree centrality ($C_{d\text{-}NL}$) is presented in two categories of $C_{d(out)\text{-}NL}$ and $C_{d(in)\text{-}NL}$. These metrics indicate the distribution of degree centrality values for each facility type in the optimal solution. Lower values (close to zero) are desirable and reflect better performance of the facility type in terms of resilience of the network. In forward logistics, the $C_{d\text{-}NL}$ for all set of facilities are between 0 and 0.5 which is quite low. The highest observed $C_{d(in)\text{-}NL}$ was 0.44 pertaining to distribution centers in DC-Re relationship. Likewise, in reverse logistics, $C_{d\text{-}NL}$ values are between 0 and 0.4 between 0 and 0.4. The highest observed $C_{d(in)\text{-}NL}$ pertains to the distribution centers (DC-Re relationship) which is 0.27. Although all facility types show fairly good performance ($C_{d\text{-}NL}$ Lower than 0.5) in terms of resilience of the network in the optimal solution, it is possible to achieve better resilience at about the same total cost by considering near-optimal solutions as discussed in section 4.3.3.

4.4.1.2. Network- Level R_{absorb} and $R_{disperse}$

Reducing factor ($R_{disperse}$ and R_{absorb}) indicates how balanced the flow of products sent or received by each facility type. High reducing factor (i.e. close to 1.0) indicates more balanced allocation of flow. In both forward and reverse logistics, the reported $R_{disperse}$ and R_{absorb} values for the optimal solution are greater than 0.6. Furthermore, the reverse logistics network performed better in terms of the balance of the flows compared to the forward logistics (i.e. all $R_{disperse}$ and R_{absorb} values in the reverse logistics networks are less than those of the forward logistics).

Table 4-6. Network-level Rabsorb and Rdisperse for the optimal solution in forward logistics network

Facility / Metric	$R_{disperse}$	R_{absorb}
M	0.69	NA
DC	0.70	0.69
Re	NA	NA

Table 4-7. Network-level Rabsorb and Rdisperse for the optimal solution in reverse logistics

Facility / Metric	$R_{disperse}$	R_{absorb}
Re	0.81	NA
DC	0.81	0.63
RM	NA	0.72

4.4.2. Evaluating Alternative Network Designs based on Network- Level SNA Metrics

In this section network-level degree centrality ($C_{d\text{-}NL}$) and R factor are computed for all facility types for optimal and near-optimal solutions. The results for both forward and reverse logistics networks are presented in Table 4-8 and Table 4-9 respectively.

Table 4-8. Computed Cd-NL for facility types in forward logistics network

Exp. #	$C_{d(out)-NL}$ (M)	$C_{d(in)-NL}$ (DC)	$C_{d(out)-NL}$ (DC)	$C_{d(in)-NL}$ (Re)
Optimal	0.03	0.44	0.39	NA
1	0.28	0.14	0.42	NA
2	0.31	0.17	0.42	NA
3	0.31	0.17	0.5	NA
4	0.31	0.17	0.39	NA
5	0.31	0.17	0.44	NA
6	0.17	0.17	0.44	NA
7	0.17	0.17	0.5	NA
8	0.17	0.44	0.78	NA
9	0.17	0.44	0.64	NA
10	0.03	0.17	0.5	NA

Table 4-9. Computed Cd-NL for facility types in reverse logistics network

Exp. #	$C_{d(out)-NL}$ (Re)	$C_{d(in)-NL}$ (DC)	$C_{d(out)-NL}$ (DC)	$C_{d(in)-NL}$ (RM)
Optimal	0.12	0.27	0.33	0.28
1	NA	0.27	0.33	0.28
2	NA	0.27	0.33	0.28
3	NA	0.34	0.33	0.28
4	0.12	0.27	0.33	0.28
5	0.12	0.29	0.33	0.28
6	0.12	0.29	0.33	0.28
7	NA	0.38	0.33	0.28
8	NA	0.56	0.33	0.28
9	0.12	0.44	0.33	0.28
10	NA	0.37	0.33	0.28

Alternative network designs based on optimal and near optimal solutions can be compared in terms of $C_{d\text{-}NL}$ for each facility type. $C_{d\text{-}NL}$ reflects on the variability of degree centrality associated with each facility type in forward and reverse logistics networks. For example, solutions 1 offers the lowest $C_{d(in)-NL}$ (0.14) for the distribution centers in M-DC relationship according to Table 4-8, and solutions 8, 9, and the optimal solution offer the lowest $C_{d(in)-NL}$ for distribution centers in Re-DC relationship according to Table 4-9. In order to compare the resilience of the alternative network designs, the weighted sum of $C_{d(in)-NL}$ and $C_{d(out)-NL}$ for all facility types needs to be calculated in each solution.

Weighted decision matrix is a quantitative technique to compare possible solutions and alternatives with respect to a set of criteria with different levels of importance. The evaluation criteria are the attributes that are needed to be judged. In this study, the elements in the weighted decision matrix are scaled from 1 (Not important at all) to 5 (extremely important). The weights are assigned proportional to the level of importance of the network-level degree centrality for each facility type in the network as shown in

Table 4-10 and Table 4-11.

In the case study network, the return rate accounting for the reverse logistics flow is assumed to be 5% of the demand assigned to each retailer in forward logistics network. Therefore, in the decision matrix, higher weights are assigned to facility types in forward logistics compared to the reverse logistics network due to its greater flow and therefore inherent importance. The highest weight was assigned to the distribution centers. Demirtaş and Tuzkaya (2012) discussed the importance of distribution centers in supply chain networks due to their significant role in the turnover and profitability of the network. In the case study CLSC network, hybrid distribution centers are the most important facilities where new and returned products are transferred through the network. The weights assigned to $C_{d(in)-NL}$ and $C_{d(out)-NL}$ for distribution centers are assumed 5

(Extremely important) and 4 (very important) in forward and reverse logistics networks respectively. Although network level degree centrality for manufacturers and remanufacturers are not as significant as distribution centers, they still have high impact on providing new products and processing the returned products in the CLSC network. The weights assigned to $C_{d(out)\text{-}NL}$ and $C_{d(in)\text{-}NL}$ for manufacturers and remanufacturers are 4 and 3 respectively. Furthermore, all in-degree centrality values for retailers are one since the case study model is assumed to be single allocation and therefore, network level degree centrality is not measured for retailers. Consequently, $C_{d(in)\text{-}NL}$ for retailers in DC-Re relationship in forward logistics network as well as $C_{d(out)\text{-}NL}$ for retailers in Re-DC relationship in reverse logistics networks are not considered in the scoring scheme.

Table 4-10. Weighted decision matrix for Cd_NL for facility types in forward logistics network

	$C_{d(out)\text{-}NL}$ (M)	$C_{d(in)\text{-}NL}$ (DC)	$C_{d(out)\text{-}NL}$ (DC)
Weight	3	5	5
Priority	important	Extremely important	Extremely important

Table 4-11. Weighted decision matrix for Cd_NL for facility types in reverse logistics network

	$C_{d(in)\text{-}NL}$ (DC)	$C_{d(out)\text{-}NL}$ (DC)	$C_{d(in)\text{-}NL}$ (RM)
Weight	4	4	3
Priority	Fairly important	Fairly important	Moderately important

In order to compare alternative network designs for optimal and near optimal solutions in terms of $C_{d\text{-}NL}$ for each facility type, the complement of each $C_{d\text{-}NL}$ (i.e. 1- $C_{d\text{-}NL}$) is used. First, the complement of the network-level degree centrality (1 - $C_{d\text{-}NL}$) is multiplied by the weights in the decision matrix, and then the sum of scores are reported as the total score for the network design represented by each solution. This metric is used to evaluate and rank all alternative network designs in terms of resilience. The network resilience scores are presented in Table 4-12. Higher scores mean better network resilience. Solutions 1 and 6 offer the highest total score which indicates the best resilience among all alternative network designs. The network design based on the optimal solution is ranked 6th while the solutions 1, 2, 4, 5, 6, and 10 offered better resilience despite being near optimal solutions.

Table 4-12. Comparing resilience of the alternative network designs

Exp. #	Forward flow	Reverse flow	Total score	Rank
Optimal	8.760	7.76	16.520	6
1	9.360	7.76	17.120	1
2	9.120	7.76	16.880	4
3	8.720	7.48	16.200	8
4	9.270	7.76	17.030	2
5	9.020	7.68	16.700	5
6	9.440	7.68	17.120	1
7	9.140	7.32	16.460	7
8	6.390	6.6	12.990	10
9	7.090	7.08	14.170	9
10	9.560	7.36	16.920	3

4.4.2.1. CLSC Network Resilience based on the Balance of Product Flow

The network-level R_{absorb} and $R_{disperse}$ are computed for all facility types in optimal and near-optimal solutions. The results are presented for both forward and reverse logistics networks in Table 4-13 and Table 4-14.

Table 4-13. Computed R-NL for facility types in forward logistics network

Exp. #	$R_{disperse\text{-}NL}$ (M)	$R_{absorb\text{-}NL}$ (DC)	$R_{disperse\text{-}NL}$ (DC)	$R_{absorb\text{-}NL}$ (Re)
Optimal	0.69	0.73	0.7	NA
1	0.68	0.62	0.7	NA
2	0.71	0.65	0.7	NA
3	0.72	0.65	0.7	NA
4	0.71	0.67	0.71	NA
5	0.7	0.67	0.71	NA
6	0.68	0.67	0.71	NA
7	0.63	0.67	0.76	NA
8	0.71	0.72	0.66	NA
9	0.71	0.72	0.74	NA
10	0.68	0.73	0.63	NA

Table 4-14. Computed R-NL for facility types in reverse logistics network

Exp. #	$R_{disperse\text{-}NL}$ (Re)	$R_{absorb\text{-}NL}$ (DC)	$R_{disperse\text{-}NL}$ (DC)	$R_{disperse\text{-}NL}$ (RM)
Optimal	0.81	0.63	0.81	0.72
1	NA	0.62	0.83	0.68
2	NA	0.62	0.83	0.68
3	NA	0.63	0.77	0.75
4	0.81	0.63	0.81	0.72
5	0.81	0.61	0.82	0.71
6	0.81	0.61	0.82	0.71
7	NA	0.61	0.82	0.75
8	NA	0.56	0.83	0.7
9	0.81	0.64	0.82	0.7
10	NA	0.61	0.83	0.73

The alternative network designs based on optimal and near optimal solutions can be compared in terms of R-NL for each facility type. Higher R-factor (close to 1) in each column (facility type) is preferable in terms of the balance of the flows in the network. For example, solutions 7 offers the highest $R_{disperse\text{-}NL}$ (0.76) for distribution centers in DC-Re relationship according to Table 4-13, and solution 9 offers the highest $R_{absorbe\text{-}NL}$ for distribution centers in Re-DC relationship as shown in Table 4-14.

In order to compare the alternative network designs in terms of the balance of flows, the weighted sum of $R_{absorb\text{-}NL}$ and $R_{disperse\text{-}NL}$ for all facility types in each design is calculated based on the weighted decision matrix. The weights are assigned proportional to the level of importance of the network-level R factor for each facility type in of the case study CLSC network and shown in Table 4-15 and Table 4-16. The weights assigned to $R_{absorb\text{-}NL}$ and $R_{disperse\text{-}NL}$ for distribution centers are 5 and 4 in forward and reverse logistics networks, respectively. The balance of flow for manufacturers and remanufacturers are fairly important, so the weights assigned to $R_{disperse\text{-}NL}$ and $R_{absorb\text{-}NL}$ for manufacturers and remanufacturers are 4 and 3, respectively. Furthermore, R-NL is not applicable to the retailers due to the single allocation assumption. However, computation of network level R factor for retailers is possible in multi allocation problems. The reported R factor are calculated using the NetworkSNA R package (AkbarGhanadian, 2020/2020).

Table 4-15. Weighted decision matrix for R-NL for facility types in forward logistics networks

	$R_{disperse}$ (M)	R_{absorb} (DC)	$R_{disperse}$ (RM)
Weight	4	5	5
Priority	Fairly important	Extremely important	Extremely important

Table 4-16. Weighted decision matrix for R-NL facility types in reverse logistics network

	R_{absorb} (DC)	$R_{disperse}$ (DC)	R_{absorb} (RM)
Weight	4	4	3
Priority	Fairly important	Fairly important	important

To calculate the network balance score, first the values of $R_{absorb\text{-}NL}$ and $R_{disperse\text{-}NL}$ are multiplied by their corresponding weights from the matrix, and then the sum of scores are reported for each alternative network design. This metric is used to evaluate and rank all alternative network designs in terms of the balance of flows. The results are presented in Table 4-17. Higher weighted scores are more desirable for the balance of the flows in the network. Solution 9 has the highest total score which indicates this design offers the best balance of product flows, while the optimal solution is ranked the 2nd best network design.

Table 4-17. Comparing the alternative network designs in terms of the balance of flows

Exp. #	Forward flow	Reverse flow	Total score	Rank
Optimal	9.220	7.92	17.140	2
1	8.640	7.84	16.480	10
2	8.880	7.84	16.720	8
3	8.910	7.85	16.760	7
4	9.030	7.92	16.950	4
5	9.000	7.85	16.850	5
6	8.940	7.85	16.790	6
7	9.040	7.97	17.010	3
8	9.030	7.66	16.690	9
9	9.430	7.94	17.370	1
10	8.840	7.95	16.790	6

4.5. Conclusion

This study set out to develop a novel decision-making tool to evaluate CLSC alternative network designs based on two network-level SNA metrics including degree centrality and R factor. Degree centrality and R factor have not been applied to quantitatively evaluate and compare supply chains networks structure in terms of resilience and balance of flows. Moreover, there is no evidence on the application of SNA metrics on complex networks such as CLSC networks in the literature for performance evaluation. The proposed framework based on network-level SNA metrics can be used by experts and managers to compare CLSC network design alternatives for existing or new networks. Although the total cost captured by the objective function value is quite similar for optimal and near optimal solutions, different network designs can be significantly different in terms of network structure which affect characteristics such as resilience and balance of flow. This also means that selecting the design with superior resilience and balance of flow does not make a noticeable difference in the total operating cost of the network.

The main challenge in the application of network-level SNA metrics in supply chain networks is dealing with different types of facilities such as manufacturers, distribution centers, and so on and how the metrics are calculated and interpreted for each instance. One challenge in calculating degree centrality equation is finding MTDD which is the maximum total observed difference of the degree centralities for the specific facility and network configuration being evaluated. This study offers generalized formulas to calculate MTDD for all facility types in forward and reverse logistics networks in CLSCs. Furthermore, the NetworkSNA (AkbarGhanadian, 2020/2020b) R package provided in this study can be used to facilitate the calculation of MTDD and the discussed network-level SNA metrics for supply chain networks of different sizes. Figure 4-10 shows the results from the NetworkSNA R package.

```
Console   Terminal ×
~/R/Disseratation_SNAnetwork/data/
> ForwardMTDD(5, 10,50)
   MTDD out_degree MTDD in_degree
M                36               NA
DC              360               36
Re               NA              441
> NetDegreeCentrality(my_data,1)
     type   NL_CDout NL_CDin
[1,] "M_DC" "0.03"   "0.44"
> SummaryNetDC_Optimal(Optimal_test)
     type    NL_CDout NL_CDin
[1,] "M_DC"  "0.03"   "0.44"
[2,] "DC_Re" "0.39"   NA
[3,] "Re_DC" "0.12"   "0.27"
[4,] "DC_RM" "0.33"   "0.28"
> NetRFactor(my_data)
     Nl_Rdisperse Nl_Rabsorb
[1,]         0.69       0.73
> SummaryNetRFactor(Optimal_test)
      Nl_Rdisperse Nl_Rabsorb
M_DC          0.69       0.73
DC_RE         0.70        NaN
RE_DC         0.81       0.63
DC_RM         0.81       0.72
```

Figure 4-10. NetworkSNA R package(AkbarGhanadian, 2020/2020b)

The other challenge addressed in this study is calculating a total score for degree centrality and R factor for an entire CLSC network. In addition to the facility type, the relationship between the facilities and the direction of flow when combining the metric values. A weighted decision matrix was used to combine network-level degree centrality and R factor metrics for all facility types in the network to enable the comparison between alternative network designs in terms of resilience and balance of flow. Optimal and near-optimal solutions from a big sized CLSC network design problem was used as a case study to demonstrate the proposed network-level SNA metrics. Although the network design resulting from the optimal solution offers fairly good resilience according to the close to zero network-level degree centrality values for all facility types, five near-optimal solutions show relatively better network resilience. Furthermore, the analysis based on the network level R factor revealed that one near-optimal solution offers a better balance of flow compared to the optimal solution. This proves that optimal solutions are not always the best alternative despite offering the lowest total cost. The proposed decision-making tool helps managers and decision-makers to select the best alternative based on arbitrarily defined decision criteria.

CHAPTER 5: CONCLUSION AND FUTURE WORK

This study provides the first comprehensive application of SNA metrics in CLSC networks. SNA metrics are not only useful in analyzing individual components (i.e. facilities) in CLSC networks, but also can be used for evaluating set of facilities as well as comparing alternative network designs in terms of resilience and balance of the flows.

In the first part of this study, node-level SNA metrics are used to identify critical facilities which help mangers and decision makers to identify the major sources of risk in the network which are more likely to cause disruption or their failure have a significant effect on the whole network. Identifying critical facilities enables stronger planning for redundancy and mitigating the risks associated with them. We believe that the application of the proposed SNA metrics in supply chain networks results in higher quality strategic and operational planning of facilities and flows of products to improve flexibility and resilience.

In the next part of the study, network-level SNA metrics are applied and interpreted in the CLSC networks. A novel decision making tool is provided based on network-level SNA metrics that can help experts and managers to compare optimal and near-optimal CLSC network designs in terms of balance of flow and resilience. This also allows the mangers to select the design with superior resilience or balance of flow without a noticeable difference in total cost compared to the optimal network design.

This study has some limitations. First, the case study is based on a CLSC network with integrated forward-reverse logistics and hybrid distribution centers. Hybrid distribution centers are used to send the products to retailers in forward flow and collect the returned products from retailers or customers. Although integrated forward-reverse logistics is identified in the literature as the best choice in terms of cost, considering forward and reverse logistics separately is a common approach in both academic and industrial cases. The application of the proposed framework on CLSC networks with different structure or facilities may not only require modifications to the metrics and calculation methods, but also needs changes in the interpretation of the results and conclusions. The calculation procedures and interpretation of the results are presented in great details to enable the researchers and practitioners to perform the necessary changes when needed.

The proposed framework is intended to be used as a guideline to choose the best alternative design in terms of resilience, balance of flows, and critical facilities within an acceptable distance from the cost optimal design. Therefore, the selected network design does not necessarily offer maximum resilience which can be considered a limitation. Maximizing the resilience as an objective can result in an extremely expensive network in terms of transportation and operational costs, which may be acceptable in rare cases such as military communication, emergency response, and disaster relief networks where achieving the highest resilience is vital. However, as the literature suggests, most of the models being discussed used cost based objective functions which implies the common application of cost based models in the real world.

A possible direction for future work involves the application of the proposed metrics on other types of facilities not discussed in this study including collection centers, disassembly centers, recycling centers, and so on to widen the potential application areas for the proposed framework. Furthermore, other social network analysis metrics not included in the current framework such as eigenvector centrality can be experimented with in evaluating the facilities in supply chain networks. Although closeness, betweenness, and eigenvector centrality were considered as potential metrics in the early stages of this study, it was not included in the framework due to the scarcity of empirical results on the application of this metric in relevant real world scenarios. Providing new metrics for evaluating supply chain networks can affect strategic, tactical and operational planning and control in the supply chain management.

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APPENDIX A: CPLEX CODE USED IN CHAPTERS 3 AND 4

```
/*********************************************
 * OPL 12.6.0.0 Data
 * Author: sa129715
 * Creation Date: Oct 14, 2018 at 6:22:14 PM
 *********************************************/

 SheetConnection my_sheet("DataWalmart1.xlsx");
 CapM from SheetRead(my_sheet, "Capacity");
 CapREM from SheetRead(my_sheet, "REMCAPACITY");
 d  from SheetRead(my_sheet, "Demand");
 r  from SheetRead(my_sheet, "returnRate");
DistPrd_DC from SheetRead(my_sheet, "DistanceM_DC");
DistDC_Ret from SheetRead(my_sheet, "DistanceDC_RE");

/*********************************************
 * OPL 12.6.0.0 Model
 * Author: sa129715
 * Creation Date: Oct 14, 2018 at 6:22:14 PM
 *********************************************/

int n=5;
int m= 118;
int p=50;

range I=1..n;
range J=1..m;
range K=1..p;

// parameters

float  DistPrd_DC[J][I] =...;
float  DistDC_Ret[J][K]=...;

float d [K] =...;
float r [K] =...;
float CapREM[I]=...;
int M=20000000;


// Decision variables

dvar int+ X[i in I][j in J];
dvar int+ U[j in J][k in K];
dvar int+ Q[k in K][j in J];
dvar int+ P[j in J][i in I];
dvar boolean Y [j in J] ;
dvar boolean assign[j in J][k in K] ;

/////////////////////////// Main Model //////////////////////////////////
```

```
dexpr float transportation_cost= sum ( i in I, j in J) DistPrd_DC[j][i] *
(X[i][j]+ P[j][i]) + sum (j in J, k in K) DistDC_Ret[j][k]* (U[j][k]+Q[k][j])
;

minimize transportation_cost;

subject to {
forall ( k in K)Demand_Satisfying :
sum (j in J) U [j][k] >= d[k];

forall( k in K) Return_Poduct_Collecting :
sum (j in J) Q [k,j] >= ceil( (r[k] * d[k])) ;

forall (j in J) Flow_Balance1 :
sum (i in I) X [i,j] == sum (k in K) U[j,k];

forall ( i in I) Flow_Balance2 :
sum (j in J) P [j,i] <= sum (j in J) X[i,j];

forall ( j in J) Flow_Balance3 :
sum (k in K) Q [k,j] == sum (i in I) P[j,i];

ExactNumber_Distribution_center:
sum (j in J) Y [j] == 10;

forall(j in J) Constraint1:
sum (i in I) X[i][j] <= M * Y [j];

forall( i in I , j in J) Constraint2 :
sum( k in K) Q [k][j] <= M * Y [j];

forall ( k in K, j in J) Constraint3 :
 U[j][k] <= M* assign [j][k];

forall( k in K) Constraint4 :
sum (j in J) assign[j][k] == 1;

forall ( j in J, k in K) Constraint5 :
assign[j][k] <= Y[j];

forall(i in I) Constraint6 :
sum (j in J) X [i][j] <= CapM[i];


forall(i in I) Constraint7 :
sum (j in J) P [j][i] <= CapREM[i];

}
```

APPENDIX B: DATASET

(1) M-DC distances matrix

	119	120	121	122	123
1	26.95	88.02	221.88	92.53	124.73
2	86.62	74.37	275.99	84.27	190.42
3	89.13	109.69	237.94	150.66	146.18
4	42.84	55.64	259.74	120.19	162.59
5	124.17	125.02	274.86	192.79	186.85
6	163.4	155.79	331.93	144.2	250.35
7	94.23	56.76	304.91	112.41	214.94
8	44.66	28.47	275.25	112.96	182.78
9	157.17	184.86	257.81	217.24	184.84
10	102.58	133.52	217.52	35.93	137.56
11	153.04	210.54	174.42	162.99	106.59
12	92.79	90.6	277.41	169.93	180.94
13	113.4	69.42	323.6	131.09	234.11
14	137.14	94.91	340.69	148.18	255.12
15	191.99	249.16	170.62	194.2	105.91
16	163.98	221.24	82.1	132.17	24.69
17	56.52	43.05	268.32	84.12	175.8
18	248.87	253.24	335.6	188.92	280.57
19	48	20.76	272.34	98.15	179.88
20	69.56	32.41	286.84	102.64	194.31
21	76.31	30.95	297.32	113.12	204.8
22	173.86	186.02	256.64	112.55	200.98
23	134.54	80.51	349.68	157.19	258.3
24	141.02	199.75	101.45	114.81	14.05
25	198.3	199.16	306.02	138.35	240.73
26	125.75	167.47	143.17	61.82	77.87
27	46.68	103.92	188.05	54.78	95.58
28	137.65	198.12	160.81	143.57	87.17
29	186.08	246.55	143.35	181.05	83.04
30	311.73	362.09	79.8	257.19	179.23
31	113.74	166.2	195.94	154.43	112.63
32	184.12	241.37	55.69	139.06	57.91
33	66.38	6.03	291.2	116.99	198.74
34	85.76	144.49	155.65	82.16	58.5

	119	120	121	122	123
35	195.8	253.05	48.52	157.15	56.92
36	227.08	285.8	102.66	201.72	94.25
37	302.19	359.45	105.14	269.11	161.66
38	291.39	348.64	97.24	258.3	150.86
39	220.82	278.08	63.18	187.74	80.3
40	237.93	295.18	44.67	203.91	96.61
41	240.93	298.18	24.32	202.28	102.52
42	148.81	200.63	217.89	190.48	147.48
43	256.19	313.44	61.3	222.29	114.87
44	183.82	230.95	77.09	126.05	87.81
45	179.53	238.26	122.35	164.34	61.79
46	74.04	130.22	166.8	46.33	74.34
47	74.81	42.54	306.82	149.67	211.26
48	304.02	361.27	77	265.37	163.71
49	253.18	310.43	84.26	220.09	112.65
50	245.39	286.03	167.56	172.07	197.18
51	83.3	129.8	169.75	26.4	85.54
52	224.9	275.67	38.43	170.77	99.64
53	53.13	29.46	274.57	94.76	182.1
54	129.55	186.8	108.9	87.85	37.99
55	122.83	69.8	335.43	142.94	244.05
56	182.55	190.04	295.5	244.08	216.75
57	294.89	335.88	90.39	228.12	178.9
58	310.2	367.45	88.72	271.55	169.89
59	282.84	323.83	135.3	216.07	201.66
60	162.97	203.96	122.01	96.81	101.76
61	314.4	371.64	80.17	273.91	175.75
62	130.73	83.1	340.99	148.5	251.45
63	242.39	299.65	80.45	209.31	101.86
64	125.15	65.24	348.19	167.72	255.72
65	113.06	61.81	327.28	134.79	235.9
66	266.09	323.34	54.19	228.48	124.77
67	245.59	304.31	93.1	215.19	107.74
68	251.14	308.39	44.05	212.86	109.82
69	176.51	204.2	262.59	236.58	196
70	356.39	413.65	150.23	323.31	215.86
71	238.79	296.03	9.98	197.97	102.12
72	275.28	332.54	85.91	242.2	134.75
73	65.76	106.75	194.07	14.65	107.68

	119	120	121	122	123
74	25.31	46.23	246.56	74.47	154.09
75	118.52	64.49	340.83	151.93	248.31
76	146.17	94.39	357.69	165.2	266.88
77	62.77	113.59	185.04	27.53	95.89
78	262.16	319.4	47.92	223.5	121.85
79	261.48	318.73	26.91	220.65	126.18
80	114.75	141.75	232.86	176.27	148.85
81	153.11	162.97	269.4	93.16	195.55
82	223.34	235.51	263.93	162.04	235.98
83	118.45	177.17	132.21	110.03	45.3
84	81.06	122.05	190.03	6.78	104.7
85	75.44	129.16	169.41	34.31	79.64
86	96.65	137.64	169.35	30.98	90.68
87	289.63	346.87	54.9	248.74	154.33
88	213.54	270.79	26.85	168.71	84.4
89	223.54	280.79	45.82	189.29	82.22
90	81.21	109.9	230.83	142.73	137.84
91	249.5	306.76	67.53	216.42	108.98
92	86.22	88.59	246.74	55.03	161.17
93	201.79	242.78	98.86	134.95	135.9
94	147.89	184.58	191.91	73.72	135.52
95	70.68	86.94	246.39	138.91	149.92
96	143.1	106.07	342.15	150.44	256.58
97	190.58	227.26	204.85	116.4	173.49
98	110.86	56.83	332.67	140.55	240.14
99	111.02	104.13	283.54	91.83	197.97
100	95.21	43.99	315.31	127.21	222.78
101	126.27	170.1	136.76	65.2	70.96
102	162.96	203.95	132.34	95.5	110.83
103	327.74	385	128.8	294.66	187.21
104	37.15	40.13	269.16	112	176.69
105	176.02	226.94	225.55	215.16	158.96
106	183.98	236.02	215.82	211.63	149.23
107	181.96	230.62	231.88	221.11	165.28
108	239.1	297.83	105.63	213.93	106.46
109	251.45	308.7	79.37	218.36	110.92
110	281.68	338.93	83.48	247.78	140.36
111	65.73	25.68	287.18	103.93	194.71
112	95.31	136.3	185.07	22.59	104.95

	119	120	121	122	123
113	68	108.99	194.23	10.34	108.03
114	45.51	80.83	220.77	37.36	128.24
115	245.06	302.31	10.62	204.22	109.76
116	66.95	127.42	190.83	108.03	96.27
117	99.6	32.8	324.1	147.66	231.64
118	304.7	361.94	89.98	266.04	163.91

(2) DC-RE distance

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	0	107.18	63.17	40.76	105.3	183.96	115.28	64.72	131.2	119.08	126.18	82.53	134.45	158.19	165.13	144.45	77.3	265.37	68.54	91.51	96.86	190.35	155.09
2	107.18	0	165.75	114.73	193.68	82.49	36.26	89.82	237.77	75.5	230.45	162.29	50.55	65.68	265.72	214.24	33.3	181.13	62.5	43.4	49.15	127.14	79.2
3	63.17	165.75	0	55.36	42.85	247.13	155.9	82.23	77.84	181.5	105.92	49.06	171.1	196.52	144.54	160.06	133.58	327.79	107.68	129.75	130.82	252.77	187.21
4	40.76	114.73	55.36	0	84.12	196.15	101.33	28.19	130.53	144.74	156.21	52.74	116.53	141.95	194.83	182.31	82.56	288.99	53.11	75.18	76.25	216.01	133.17
5	105.3	193.68	42.85	84.12	0	275.1	178.44	105.42	81.76	223.63	136.59	37.84	192.48	217.83	175.21	196.99	161.51	369.92	132.06	153.02	152.57	294.9	188.75
6	183.96	82.49	247.13	196.15	275.1	0	105.18	171.25	315.16	120.77	300.58	243.72	99.35	80.32	335.78	274.17	114.72	119.19	143.92	124.72	130.47	102.47	119.92
7	115.28	36.26	155.9	101.33	178.44	105.18	0	75.33	231.07	111.76	241.46	144.9	21.46	45.18	280.41	236.67	39.78	210.15	54.29	28.21	26.55	160.9	46.29
8	64.72	89.82	82.23	28.19	105.42	171.25	75.33	0	157.4	133.08	183.08	74.04	90.53	115.95	221.7	204.51	57.65	267.91	28.2	49.18	50.25	198.43	105.99
9	131.2	237.77	77.84	130.53	81.76	315.16	231.07	157.4	0	249.53	90.52	116.48	246.27	271.68	111.99	182.73	205.6	395.82	181.75	204.92	205.98	320.81	262.38
10	119.08	75.5	181.5	144.74	223.63	120.77	111.76	133.08	249.53	0	193.74	194.68	126.05	141.17	224.94	161.53	90.9	154	114.35	109.41	119.9	77.45	154.7
11	126.18	230.45	105.92	156.21	136.59	300.58	241.46	183.08	90.52	193.74	0	152.78	260.63	284.37	38.95	101.12	203.48	347	194.03	217.69	222.34	270.44	280.57
12	82.53	162.29	49.06	52.74	37.84	243.72	144.9	74.04	116.48	194.68	152.78	0	157.56	182.91	191.39	199.56	130.12	338.93	100.67	121.06	120.6	265.96	153.82
13	134.45	50.55	171.1	116.53	192.48	99.35	21.46	90.53	246.27	126.05	260.63	157.56	0	26.59	299.58	255.84	58.95	212.35	70.09	47.39	40.28	168.05	28.65
14	158.19	65.68	196.52	141.95	217.83	80.32	45.18	115.95	271.68	141.17	284.37	182.91	26.59	0	323.32	278.37	82.64	193.33	95.51	71.13	65.7	158.92	41.31
15	165.13	265.72	144.54	194.83	175.21	335.78	280.41	221.7	111.99	224.94	38.95	191.39	299.58	323.32	0	97.32	242.43	378.2	232.98	256.65	261.3	301.64	319.53
16	144.45	214.24	160.06	182.31	196.99	274.17	236.67	204.51	182.73	161.53	101.12	199.56	255.84	278.37	97.32	0	197.52	301.67	201.61	216.04	226.53	222.08	280.03
17	77.3	33.3	133.58	82.56	161.51	114.72	39.78	57.65	205.6	90.9	203.48	130.12	58.95	82.64	242.43	197.52	0	210.61	30.32	18.94	29.43	143.39	83.14
18	265.37	181.13	327.79	288.99	369.92	119.19	210.15	267.91	395.82	154	347	338.93	212.35	193.33	378.2	301.67	210.61	0	240.58	223.36	229.11	82.71	233.94
19	68.54	62.5	107.68	53.11	132.06	143.92	54.29	28.2	181.75	114.35	194.03	100.67	70.09	95.51	232.98	201.61	30.32	240.58	0	26.1	29.81	171.76	88.04
20	91.51	43.4	129.75	75.18	153.02	124.72	28.21	49.18	204.92	109.41	217.69	121.06	47.39	71.13	256.65	216.04	18.94	223.36	26.1	0	11.83	161.91	69.93
21	96.86	49.15	130.82	76.25	152.57	130.47	26.55	50.25	205.98	119.9	222.34	120.6	40.28	65.7	261.3	226.53	29.43	229.11	29.81	11.83	0	172.39	59.51
22	190.35	127.14	252.77	216.01	294.9	102.47	160.9	198.43	320.81	77.45	270.44	265.96	168.05	158.92	301.64	222.08	143.39	82.71	171.76	161.91	172.39	0	192.68
23	155.09	79.2	187.21	133.17	188.75	119.92	46.29	105.99	262.38	154.7	280.57	153.82	28.65	41.31	319.53	280.03	83.14	233.94	88.04	69.93	59.51	192.68	0
24	121.5	196.57	137.54	159.36	175.05	256.81	217.59	182.45	173.04	142.45	93.9	176.45	236.76	259.29	95.7	23.88	178.44	289.82	180.12	196.96	207.13	210.23	260.94
25	214.8	125.85	277.22	235.48	316.81	63.91	154.88	214.41	345.25	103.43	296.43	285.43	157.07	138.05	327.63	264.7	157.11	55.28	187.08	168.08	173.83	52.37	178.66
26	128.79	144.73	181.79	166.79	223.92	188.76	173.25	162.66	242.01	74.35	172.52	205.78	191.93	209.02	182.81	98.97	137.37	205.12	147.85	155.88	166.37	125.53	218.03
27	41.6	108.3	99.29	80.67	141.42	178.42	124.98	87.2	163.45	88.53	125.65	118.59	144.15	167.89	160.92	117.31	86.91	241.79	84.3	102.96	111.3	165.23	168.34
28	110.79	211.03	101.37	148.65	132.03	281.15	226.07	174.56	104.27	174.31	20.68	148.22	245.24	268.98	56.18	82.23	188.09	327.57	178.64	202.31	206.96	251.01	265.19
29	159.22	252.57	154.09	197.08	184.76	322.64	269.26	222.99	130.1	211.8	48.47	200.94	288.43	312.17	27.71	70.79	231.19	363.62	227.07	247.24	255.38	284.03	312.61
30	301.69	337.31	317.74	339.55	354.67	377	368.27	352.26	333.45	262.59	250.07	357.21	386.96	402.98	241.95	161.9	331.98	368.73	342.46	350.5	360.98	299.38	413.03
31	86.88	194.06	61.58	111.87	92.25	270.84	202.15	138.75	74.43	185.63	45.25	108.44	221.33	245.07	83.86	117.36	164.18	338.89	154.73	178.39	183.04	262.33	241.27
32	177.62	221.22	203.72	216.68	241.39	277.66	250.14	224.64	237.03	163	153.64	238.63	268.83	285.92	149.84	57.49	213.86	290.33	221.74	232.38	242.86	210.97	294.91
33	86.92	68.34	111.05	57	128.36	149.77	51.48	29.83	186.22	127.5	211.9	95.96	64.38	89.88	250.52	220.47	37.02	247.21	19.42	26.38	24.92	179.99	76.84
34	66.82	148.86	92.99	104.68	135.12	218.99	165.54	127.19	145.69	112.91	81.59	126.49	184.72	208.46	116.85	78.21	127.48	266.17	124.86	143.53	151.87	189.61	208.9
35	179.98	239.31	195.55	217.84	232.47	296.7	268.23	236.32	210.68	181.14	127.3	235.05	286.91	304	123.5	36.27	229.4	310.05	233.42	247.92	258.4	230.46	311.9
36	202.44	283.8	198.99	240.3	229.66	343.72	306.22	266.2	178.2	231.08	94.81	245.84	325.39	347.92	76.13	69.6	267.08	370.19	266.18	284.84	293.18	290.6	349.58
37	279.37	351.19	275.92	317.23	306.59	411.11	374.88	342.73	253.62	299.08	171.45	322.78	394.06	415.88	150.83	138.26	335.74	428.28	339.82	354.26	364.74	348.69	418.24
38	268.57	340.38	265.12	306.43	295.79	400.3	364.07	331.92	242.81	288.27	160.64	311.97	383.25	405.08	140.02	127.46	324.93	417.48	329.02	343.45	353.93	337.89	407.43
39	201.3	269.82	213.76	239.16	244.43	329.74	293.51	261.36	200.34	217.71	116.96	256.41	312.69	334.51	110.43	56.89	254.37	346.92	258.46	272.89	283.37	267.32	336.87
40	219.67	286.07	232.61	257.53	263.27	343.46	310.62	278.46	221.54	227.9	138.15	274.74	329.79	350.77	131.63	75.74	271.47	356.82	275.55	289.99	300.47	277.23	353.98
41	225.03	284.44	240.64	262.89	276.01	341.83	313.36	281.45	241.53	226.27	158.14	280.14	332.04	349.13	151.62	80.63	274.53	353.12	278.55	293.05	303.53	274.15	357.03
42	121.95	229.13	96.01	146.29	119.7	305.91	237.23	173.17	43.32	224.22	50.6	142.86	256.4	280.14	71.01	144.59	199.25	377.31	189.8	213.46	218.11	300.92	276.34
43	237.61	304.36	248.65	275.47	279.32	364.28	328.88	296.72	230.75	251.43	147.37	292.72	348.05	369.06	131.92	93.21	289.73	380.34	293.81	308.25	318.73	300.75	372.24
44	177.31	208.21	215.98	216.66	258.11	254.86	237.13	224.34	266.11	140.45	185.64	249.47	255.82	272.91	181.84	89.49	200.84	259.05	211.32	219.36	229.84	180.09	281.9
45	157.65	242.63	154.69	195.51	185.36	306.33	259.31	220.96	137.67	194.43	54.28	201.54	278.49	302.23	50.48	49.05	221.25	342.36	218.63	237.29	245.63	262.77	302.67
46	68.62	121.91	120.37	107.96	162.5	187.91	142.92	114.14	180.78	77.08	116.67	144.58	162.1	184.62	147.88	96.07	103.78	230.34	110.59	122.3	132.78	153.78	186.28
47	89.38	116.24	96.09	48.84	85.41	197.66	96.85	37.31	165.64	169.99	197.84	50.48	109.5	134.77	236.46	230.98	84.92	295.11	61.46	74.28	72.82	227.89	103.83
48	286.77	347.52	302.34	324.63	335.28	404.3	376.45	344.54	293.55	289.36	210.16	341.84	395.13	412.22	201.28	143.21	337.62	403.74	341.64	356.14	366.62	326.68	420.12
49	232.8	302.17	229.35	270.66	260.02	362.09	325.87	293.71	208.34	250.06	124.95	276.21	345.04	366.87	108.54	89.25	286.72	379.27	290.81	305.24	315.72	299.68	369.22
50	256.28	232.84	314.42	287.55	356.55	232.88	269.1	281.21	367.84	157.82	292.29	333.69	283.38	285.99	299.09	206.74	247.07	181.13	266.4	265.58	276.07	133.46	312.03
51	87.1	108.47	144.78	125.1	186.91	168.39	137.39	122.99	209.52	55.6	148.86	164.09	156.08	173.17	176.21	109.36	101.01	209.34	110.18	119.53	130.01	132.67	182.16
52	218.4	252.93	245.45	257.46	283.13	298.28	281.85	265.42	269.9	183.87	186.52	280.36	300.54	317.63	182.72	94.02	245.57	299.63	256.05	264.08	274.57	220.66	326.62
53	75.08	50.09	121.39	66.82	145.77	131.51	43.98	41.92	195.61	106.82	201.26	114.39	63.15	86.89	240.21	203.84	18.02	228.63	16.03	16.92	26.8	160.61	85.75
54	123.05	170	159.26	162.11	201.39	229.93	198.93	170.08	209.38	111.84	133.62	192.75	217.61	234.7	143.21	56.41	161.77	250.08	167.17	180.29	190.78	170.49	243.69
55	143.37	64.94	176.51	122.46	186.65	110.04	32.04	95.29	251.68	140.45	268.86	151.73	14.4	35.27	307.81	265.78	68.89	223.04	76.33	57.09	46.67	179.15	14.35
56	156.59	258.7	95.38	146.83	67.11	340.12	243.46	170.44	39.13	274.92	128.2	104.2	257.56	283.05	145.88	219.17	226.53	421.21	197.07	218.04	217.59	346.19	255.11
57	293.02	302.95	323.94	332.36	360.86	342.63	339.2	331.07	344.38	228.22	260.99	359.62	353.49	368.61	257.19	168.49	305.78	334.36	316.26	324.3	334.78	265.01	382.14
58	292.95	353.7	308.52	330.81	339.67	411.1	382.63	350.72	291.92	295.54	208.53	348.02	401.31	418.4	195.87	149.39	343.8	421.3	347.82	362.32	372.8	342.33	426.3
59	292.43	290.9	336.15	325	378.28	330.58	327.15	319.02	374.39	216.17	291	369.42	341.44	356.56	287.2	198.5	293.73	286.18	304.21	312.25	322.73	237.02	370.09
60	168.91	173.32	222.19	205.13	264.33	213.01	208.24	199.15	272.43	98.6	196.87	245.9	223.87	238.99	206.71	117.42	173.86	214.35	184.34	192.37	202.86	135.39	252.52
61	298.5	356.06	314.1	336.36	347.97	404.77	384.99	354.92	308.71	290.36	225.32	353.61	403.67	420.76	216.44	154.09	348	401.47	352.02	366.51	377	327.15	429.75
62	151.78	68.93	187.88	133.31	201.49	98.97	38.79	107.31	263.05	144.43	277.96	166.56	18.59	19.35	316.91	273.17	76.29	211.97	86.88	64.72	57.07	173.09	22.72
63	222.86	291.38	224.16	260.72	254.83	351.31	315.08	282.93	203.92	239.28	120.54	271.02	334.26	356.08	104.78	78.46	275.94	368.48	280.02	294.46	304.94	288.89	358.44
64	145.7	91.57	171.64	118.68	160.95	151.7	55.31	91.51	241.19	167.07	271.19	126.03	54.24	75.44	310.14	277.45	84.37	264.64	78.65	66.77	56.07	215.39	35.4
65	133.6	58.4	167.51	112.94	180.98	112.45	23.89	86.59	242.68	133.9	259.09	146.05	14.59	37.57	298.04	257.63	60.74	224.88	66.56	47.32	36.9	180.37	22.96
66	247.57	310.64	258.48	285.43	289.15	368.03	338.77	306.61	240.58	252.47	157.2	302.69	357.95	375.34	146.57	103.17	299.63	381.39	303.71	318.15	328.63	301.8	382.13
67	221.73	297.26	218.28	259.59	248.95	357.19	320.24	285.5	197.19	245.1	113.81	265.14	339.42	361.94	97.36	83.63	281.1	377.01	284.69	299.62	310.1	297.42	363.6
68	232.88	295.01	245.81	270.74	276.48	352.41	323.82	291.66	234.75	236.85	151.36	287.95	342.62	359.71	143.5	88.95	284.68	365.76	288.76	303.2	313.68	286.17	367.18
69	150.55	257.12	97.18	149.87	99.83	334.51	250.41	176.75	19.35	268.88	98.22	134.81	265.61	291.03	109.64	189.29	224.95	415.17	201.1	224.26	225.33	340.15	281.73
70	333.57	405.38	330.12	371.43	360.79	465.31	429.08	396.92	307.82	351.4	225.65	376.97	448.25	470.08	205.03	192.46	389.94	480.31	394.02	408.45	418.94	400.72	472.44
71	225.18	280.12	240.75	263.04	277.68	336.56	309.05	279.31	253.4	221.9	170.01	280.25	327.73	344.82	164.9	81.47	272.38	343.18	276.41	290.9	301.39	264.21	353.81
72	253.13	324.27	249.68	290.99	280.35	384.2	347.97	315.81	227.47	272.17	145.2	296.53	367.14	388.97	124.68	111.35	308.83	401.37	312.91	327.34	337.83	321.78	391.33
73	79.04	89.38	137.18	107.92	179.31	150.48	115.79	101.94	204.25	48.39	156.32	156.45	134.96	153.29	189.13	131.5	76.65	201.65	87.13	95.16	105.65	125.09	159.15
74	46.23	64.07	108.33	60.29	141.62	140.85	70.08	38.97	177.25	94.58	172.41	110.24	89.25	112.99	211.36	175.83	32.37	230.19	26.61	46.1	54.44	159.93	112.67
75	139.06	75.79	171.19	117.15	168.08	131.48	39.53	89.97	246.33	151.29	264.55	133.16	34.02	55.21	303.5	270.03	72.94	244.48	72.02	55.13	44.68	199.36	22.8
76	167.21	86.69	201.1	146.98	203.45	111.39	54.87	119.88	276.27	162.19	293.13	168.52	36.16	33.73	332.08	288.61	91.72	226.36	100.59	80.15	70.93	190.58	16.34
77	67.61	102.1	125.29	104.93	167.42	163.81	124.52	102.47	190.08	61.28	141.45	144.6	143.69	166.01	174.76	119.71	85.37	214.54	93.97	103.89	114.38	137.98	167.88
78	244.91	305.66	260.47	282.77	291.63	363.05	334.58	302.68	248.47	247.5	165.08	299.98	353.27	370.36	155.41	101.35	295.76	376.41	299.78	314.27	324.76	296.82	378.26
79	248.64	302.8	264.69	286.5	301.62	355.96	331.73	302	273.85	241.55	190.47	304.17	350.41	367.5	183.94	106.01	295.08	359.49	299.1	313.6	324.08	280.53	376.49
80	88.78	194.67	35.72	87.42	54.84	272.74	187.96	114.3	44.71	207.11	84.13	82.17	203.16	228.58	122.75	154.27	162.5	353.4	138.65	161.81	162.88	278.39	219.28
81	169.61	94.37	232.03	194.66	274.16	70.22	127.56	175.16	300.07	58.24	251.24	244.61	133.26	124.14	282.45	219.51	120.34	98.45	148.72	135.35	143.4	42.49	157.89
82	239.84	176.63	302.26	265.5	344.39	144.16	210.39	247.92	370.3	126.94	319.93	315.45	217.41	208.27	340.93	257.08	192.88	74.72	221.25	211.4	221.88	50.84	242.04
83	98.92	181.55	106.84	136.78	142.66	251.61	198.23	159.87	140.65	140.77	62.24	148.36	217.4	241.14	87.55	54.33	160.17	294.03	157.55	176.21	184.55	217.47	241.59
84	93.59	90.63	151.73	123.21	193.86	150.56	118.77	117.23	218.14	33.75	159.99	171	137.45	154.54	191.2	128.52	89.26	187.01	102.42	107.78	118.27	110.45	163.55
85	74.12	115.97	131.81	113.19	173.94	175.89	141.87	115.5	193.19	64.65	129.08	151.11	161.04	180.67	160.29	103.4	102.72	217.91	109.54	121.24	131.72	141.35	185.23
86	106.75	114.01	164.88	138.81	207.01	169.34	142.41	132.83	230.01	48.76	166.45	184.15	161.09	178.18	186.79	114.97	107.53	202.57	118.01	126.05	136.54	121.59	187.19
87	276.79	330.89	292.84	314.65	329.77	380.48	359.82	330.15	297.88	266.07	214.5	332.31	378.5	395.59	206.38	134.3	323.23	379.93	327.25	341.74	352.23	302.86	404.58
88	206.52	250.87	224.47	244.39	261.4	306.31	279.79	254.06	244.91	191.9	161.52	263.92	298.48	315.57	157.72	69.03	243.5	310.51	251.16	262.02	272.5	231.54	324.55
89	205.28	271.45	220.84	243.14	253.89	328.84	296.22	264.06	216.89	213.28	133.5	260.35	315.4	336.15	126.98	61.72	257.08	342.2	261.16	275.6	286.08	262.61	339.58
90	55.24	159.23	8.65	55.56	50.78	239.2	156.02	82.44	79.31	173.57	102.39	53.14	171.31	196.72	141.01	152.98	127.06	319.86	103.22	129.18	131.02	244.85	187.42
91	229.98	298.5	235.69	267.84	266.36	358.42	322.19	290.04	217.79	246.39	134.4	282.54	341.37	363.19	119.69	85.58	283.05	375.59	287.14	301.57	312.05	296	365.55
92	104.18	29.79	166.6	122.57	203.9	89.17	66.05	101.66	234.63	46.25	211.7	172.51	80.33	94.92	246.61	184.99	45.96	167.4	74.33	64.48	74.96	98.53	108.98
93	211.38	209.78	263.5	243.95	305.63	249.47	246.04	237.97	313.63	135.05	234.86	288.37	260.32	275.44	231.06	138.71	212.68	240.21	223.16	231.2	241.68	170.04	288.97
94	159.4	126.56	217.53	190.05	259.66	150.23	162.82	182.86	283.7	51.55	225.16	236.8	177.11	185.21	240.47	156.62	141.96	146.52	165.41	160.47	170.96	66.93	205.76
95	51.51	145.55	22.75	32.61	59.53	226.97	133.15	59.49	98.82	169.75	124.5	31.93	148.35	173.77	163.12	168.54	113.37	316.04	84.93	107	108.07	241.02	164.47
96	164.14	67.66	206.34	151.78	228.88	69.37	54.33	125.78	281.51	141.66	290.32	194.08	37.76	12	329.28	280.4	88.47	184.71	104.86	80.27	76.87	155.84	50.54
97	202.08	169.24	260.22	232.74	302.35	164.65	205.08	225.55	326.39	94.22	267.85	279.49	216.67	216.88	278.44	194.59	184.63	135.4	208.08	203.15	213.63	65.23	244.05
98	131.41	64.4	163.54	109.49	169.51	125.33	28.14	82.32	238.71	139.9	256.9	134.59	27.47	50.45	295.85	261.87	64.98	236.91	64.36	47.4	36.94	188.22	25.94
99	131.58	30.82	194.75	144.49	223.44	52.95	61.39	119.58	262.78	80.63	248.2	192.05	70.16	63.89	283.4	221.79	63.06	151.57	92.26	73.05	78.8	103.74	95.81
100	115.76	52.66	149.66	95.09	167.06	121.99	18.03	68.78	224.83	127.48	241.25	132.13	26.73	52.45	280.2	244.51	47.41	227.36	48.71	29.6	19.15	178.11	41.84
101	129.31	147.35	181.44	167.32	223.57	195.67	176.28	165.28	239.64	81.26	165.61	205.65	194.96	212.05	175.91	92.06	139.99	210.54	150.47	158.51	168.99	130.95	221.04
102	172.61	162.24	226.1	205.12	268.23	201.92	198.49	199.14	281.49	87.51	205.93	249.61	212.78	227.9	215.77	126.49	173.85	203.27	184.33	192.36	202.85	124.3	241.43
103	304.92	376.73	301.47	342.78	332.14	436.66	400.43	368.27	279.16	324.63	197	348.32	419.6	441.43	176.37	163.81	361.29	453.83	365.37	379.8	390.29	374.24	443.79
104	55.33	99.61	71.48	17.29	96.85	181.03	86.21	12.76	146.65	136.56	172.33	65.46	101.41	126.83	210.95	197.08	67.44	277.7	37.99	60.06	61.13	207.83	117.66
105	149.16	256.34	120.91	172.61	135.29	333.12	264.43	199.48	54.5	245.91	61.54	167.35	283.61	307.35	68.45	152.25	226.46	399.17	217.01	240.67	245.32	322.61	303.55
106	157.12	264.3	131.4	181.68	147.94	341.08	272.39	208.56	67.14	242.37	51.81	178.25	291.57	315.31	56.55	142.52	234.42	395.63	224.97	248.63	253.28	319.08	311.51
107	155.1	262.29	124.59	176.29	138.1	339.07	270.38	203.16	57.31	251.86	67.86	171.03	289.55	313.29	74.78	158.57	232.4	405.12	222.95	246.62	251.27	328.56	308.14
108	214.46	296.01	211.01	252.32	241.68	355.93	318.43	278.23	187.35	243.29	105.39	257.86	337.61	360.13	84.56	81.81	279.29	379.47	278.2	296.87	305.21	299.88	361.79
109	231.92	300.44	230.5	269.78	261.17	360.36	324.13	291.98	210.86	248.33	127.47	277.35	343.31	365.14	111.02	87.52	284.99	377.53	289.08	303.51	313.99	297.94	367.49
110	262.64	329.85	259.19	300.5	289.86	389.77	354.36	322.2	236.98	276.92	154.72	306.04	373.54	394.55	134.19	118.76	315.22	405.83	319.3	333.74	344.22	326.24	397.72
111	86.99	50.47	123.02	68.45	146.29	131.89	35.44	42.45	198.19	110.71	212.48	114.33	53.01	76.75	251.43	216.44	20.24	230.42	19.95	7.49	13.58	163.2	72.9
112	106.2	105	164.34	137.46	206.47	154.42	133.25	131.48	230.5	33.84	171.96	183.6	151.94	169.03	199.42	128.92	104.96	187.65	116.67	123.48	133.97	107.42	178.05
113	82.42	86.76	140.56	110.16	182.69	146.8	114.89	104.18	207.45	44.09	158.29	159.83	133.58	150.67	191.09	131.85	76.96	197.35	89.37	95.48	105.97	120.79	159.47
114	62.01	65.68	124.43	87.67	166.56	134.7	86.7	76.02	192.46	58.54	166.51	137.61	105.87	128.4	201.68	149.97	47.55	204.83	61.2	66.07	76.55	129.81	130.05
115	232.22	286.38	248.27	270.08	285.2	339.73	315.3	285.58	264.98	225.32	181.6	287.75	333.99	351.08	176.48	91.39	278.66	343.26	282.68	297.18	307.66	264.3	360.07
116	40.09	147.27	51.69	76.68	93.82	224.05	155.37	102.58	113.28	141.78	88.81	86.58	174.54	198.28	127.6	112.99	117.39	294.86	107.94	131.61	136.26	218.48	194.49
117	119.9	90.57	138.28	86.23	127.6	166.63	62.67	59.06	207.83	157.31	240.04	92.68	71.46	95.58	278.66	253.37	66.84	270.53	52.88	55.12	45.75	209.81	63.49
118	286.65	348.2	289.52	324.51	320.19	405.59	377.12	345.22	267.8	290.03	185.12	336.37	395.81	412.9	165.01	142.25	338.29	418.95	342.32	356.81	367.3	339.36	420.8

	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
1	121.5	214.8	128.79	41.6	110.79	159.22	301.69	86.88	177.62	86.92	66.82	179.98	202.44	279.37	268.57	201.3	219.67	225.03	121.95	237.61	177.31	157.65	68.62	89.38	286.77	232.8	256.28
2	196.57	125.85	144.73	108.3	211.03	252.57	337.31	194.06	221.22	68.34	148.86	239.31	283.8	351.19	340.38	269.82	286.07	284.44	229.13	304.36	208.21	242.63	121.91	116.24	347.52	302.17	232.84
3	137.54	277.22	181.79	99.29	101.37	154.09	317.74	61.58	203.72	111.05	92.99	195.55	198.99	275.92	265.12	213.76	232.61	240.64	96.01	248.65	215.98	154.69	120.37	96.09	302.34	229.35	314.42
4	159.36	235.48	166.79	80.67	148.65	197.08	339.55	111.87	216.68	57	104.68	217.84	240.3	317.23	306.43	239.16	257.53	262.89	146.29	275.47	216.66	195.51	107.96	48.84	324.63	270.66	287.55
5	175.05	316.81	223.92	141.42	132.03	184.76	354.67	92.25	241.39	128.36	135.12	232.47	229.66	306.59	295.79	244.43	263.27	276.01	119.7	279.32	258.11	185.36	162.5	85.41	335.28	260.02	356.55
6	256.81	63.91	188.76	178.42	281.15	322.64	377	270.84	277.66	149.77	218.99	296.7	343.72	411.11	400.3	329.74	343.46	341.83	305.91	364.28	254.86	306.33	187.91	197.66	404.3	362.09	232.88
7	217.59	154.88	173.25	124.98	226.07	269.26	368.27	202.15	250.14	51.48	165.54	268.23	306.22	374.88	364.07	293.51	310.62	313.36	237.23	328.88	237.13	259.31	142.92	96.85	376.45	325.87	269.1
8	182.45	214.41	162.66	87.2	174.56	222.99	352.26	138.75	224.64	29.83	127.19	236.32	266.2	342.73	331.92	261.36	278.46	281.45	173.17	296.72	224.34	220.96	114.14	37.31	344.54	293.71	281.21
9	173.04	345.25	242.01	163.45	104.27	130.1	333.45	74.43	237.03	186.22	145.69	210.68	178.2	253.62	242.81	200.34	221.54	241.53	43.32	230.75	266.11	137.67	180.78	165.64	293.55	208.34	367.84
10	142.45	103.43	74.35	88.53	174.31	211.8	262.59	185.63	163	127.5	112.91	181.14	231.08	299.08	288.27	217.71	227.9	226.27	224.22	251.43	140.45	194.43	77.08	169.99	289.36	250.06	157.82
11	93.9	296.43	172.52	125.65	20.68	48.47	250.07	45.25	153.64	211.9	81.59	127.3	94.81	171.45	160.64	116.96	138.15	158.14	50.6	147.37	185.64	54.28	116.67	197.84	210.16	124.95	292.29
12	176.45	285.43	205.78	118.59	148.22	200.94	357.21	108.44	238.63	95.96	126.49	235.05	245.84	322.78	311.97	256.41	274.74	280.14	142.86	292.72	249.47	201.54	144.58	50.48	341.84	276.21	333.69
13	236.76	157.07	191.93	144.15	245.24	288.43	386.96	221.33	268.83	64.38	184.72	286.91	325.39	394.06	383.25	312.69	329.79	332.04	256.4	348.05	255.82	278.49	162.1	109.5	395.13	345.04	283.38
14	259.29	138.05	209.02	167.89	268.98	312.17	402.98	245.07	285.92	89.88	208.46	304	347.92	415.88	405.08	334.51	350.77	349.13	280.14	369.06	272.91	302.23	184.62	134.77	412.22	366.87	285.99
15	95.7	327.63	182.81	160.92	56.18	27.71	241.95	83.86	149.84	250.52	116.85	123.5	76.13	150.83	140.02	110.43	131.63	151.62	71.01	131.92	181.84	50.48	147.88	236.46	201.28	108.54	299.09
16	23.88	264.7	98.97	117.31	82.23	70.79	161.9	117.36	57.49	220.47	78.21	36.27	69.6	138.26	127.46	56.89	75.74	80.63	144.59	93.21	89.49	49.05	96.07	230.98	143.21	89.25	206.74
17	178.44	157.11	137.37	86.91	188.09	231.19	331.98	164.18	213.86	37.02	127.48	229.4	267.08	335.74	324.93	254.37	271.47	274.53	199.25	289.73	200.84	221.25	103.78	84.92	337.62	286.72	247.07
18	289.82	55.28	205.12	241.79	327.57	363.62	368.73	338.89	290.33	247.21	266.17	310.05	370.19	428.28	417.48	346.92	356.82	353.12	377.31	380.34	259.05	342.36	230.34	295.11	403.74	379.27	181.13
19	180.12	187.08	147.85	84.3	178.64	227.07	342.46	154.73	221.74	19.42	124.86	233.42	266.18	339.82	329.02	258.46	275.55	278.55	189.8	293.81	211.32	218.63	110.59	61.46	341.64	290.81	266.4
20	196.96	168.08	155.88	102.96	202.31	247.24	350.5	178.39	232.38	26.38	143.53	247.92	284.84	354.26	343.45	272.89	289.99	293.05	213.46	308.25	219.36	237.29	122.3	74.28	356.14	305.24	265.58
21	207.13	173.83	166.37	111.3	206.96	255.38	360.98	183.04	242.86	24.92	151.87	258.4	293.18	364.74	353.93	283.37	300.47	303.53	218.11	318.73	229.84	245.63	132.78	72.82	366.62	315.72	276.07
22	210.23	52.37	125.53	165.23	251.01	284.03	299.38	262.33	210.97	179.99	189.61	230.46	290.6	348.69	337.89	267.32	277.23	274.15	300.92	300.75	180.09	262.77	153.78	227.89	326.68	299.68	133.46
23	260.94	178.66	218.03	168.34	265.19	312.61	413.03	241.27	294.91	76.84	208.9	311.9	349.58	418.24	407.43	336.87	353.98	357.03	276.34	372.24	281.9	302.67	186.28	103.83	420.12	369.22	312.03
24	0	245.62	87.11	98.23	74.48	74.89	181.25	100.83	67.27	198.98	55.26	59.37	93.44	162.1	151.29	80.73	99.06	104.46	135.55	117.04	98.21	54.85	76.99	208.03	166.16	113.08	206.43
25	245.62	0	171.42	191.22	277	314.49	348.77	288.32	260.31	193.13	215.6	279.35	334.25	397.58	386.77	316.21	326.11	323.54	326.74	349.64	229.47	297.12	179.77	241.03	376.06	348.57	180.93
26	87.11	171.42	0	88.76	153.09	160.91	197.23	169.8	88.9	166.68	97.08	107.93	168.07	226.16	215.36	144.79	154.7	153.06	210.11	178.22	66.1	139.66	66.61	197.39	216.15	177.15	136
27	98.23	191.22	88.76	0	106.23	147.78	265.06	101.47	137.44	103.16	44.06	149.12	185.38	255.53	244.72	174.16	191.26	194.25	136.69	209.52	137.14	137.83	28.17	118.77	257.34	206.51	218.13
28	74.48	277	153.09	106.23	0	53.84	240.61	39.8	138.06	197.02	62.16	114.98	98.11	175.05	164.24	113.62	132.66	147.27	66.45	147.77	170.06	53.32	97.25	193.29	204.66	128.48	272.86
29	74.89	314.49	160.91	147.78	53.84	0	214.64	92.6	123.31	245.45	103.71	96.96	48.82	123.52	112.71	82.79	103.99	123.98	90.18	104.61	155.31	23.95	134.74	245.75	173.98	81.23	272.56
30	181.25	348.77	197.23	265.06	240.61	214.64	0	275.74	128.96	361.3	235.45	128.32	166.36	142.9	144.76	135.07	111.94	96.21	293.54	113.73	134.43	195.78	243.81	383.83	57.06	140.09	193.7
31	100.83	288.32	169.8	101.47	39.8	92.6	275.74	0	167.18	167.56	73.48	150.11	137.42	214.36	203.55	152.19	171.04	184.05	42.29	187.09	193.9	93.13	108.57	153.5	243.05	167.79	295.63
32	67.27	260.31	88.9	137.44	138.06	123.31	128.96	167.18	0	240.6	114.72	35.58	103.4	150.63	141.66	72.44	78.62	69.76	197.11	102.15	33.75	101.57	116.2	256.22	132.59	104.79	151.91
33	198.98	193.13	166.68	103.16	197.02	245.45	361.3	167.56	240.6	0	143.72	252.28	285.04	358.68	347.88	277.31	294.41	297.41	201.99	312.67	230.16	237.49	129.45	47.9	360.5	309.67	283.67
34	55.26	215.6	97.08	44.06	62.16	103.71	235.45	73.48	114.72	143.72	0	113.74	141.31	216.43	205.62	135.06	153.43	158.79	113.79	171.37	124.04	93.77	35.85	153.35	220.53	167.41	225.78
35	59.37	279.35	107.93	149.12	114.98	96.96	128.32	150.11	35.58	252.28	113.74	0	67.88	120.13	109.32	38.76	50.17	48.54	170.76	73.7	69.33	75.22	127.88	266.51	111.62	71.11	185.09
36	93.44	334.25	168.07	185.38	98.11	48.82	166.36	137.42	103.4	285.04	141.31	67.88	0	78.33	67.52	41.59	62.62	83.28	138.28	56.33	137.15	50.32	165.62	288.97	125.69	32.95	252.91
37	162.1	397.58	226.16	255.53	175.05	123.52	142.9	214.36	150.63	358.68	216.43	120.13	78.33	0	11.72	81.37	74.75	83.53	213.7	48.66	177.61	125.75	234.28	365.91	87.56	50.92	271.18
38	151.29	386.77	215.36	244.72	164.24	112.71	144.76	203.55	141.66	347.88	205.62	109.32	67.52	11.72	0	70.56	65.77	74.54	202.89	39.71	168.62	114.94	223.48	355.1	94.19	40.11	263.7
39	80.73	316.21	144.79	174.16	113.62	82.79	135.07	152.19	72.44	277.31	135.06	38.76	41.59	81.37	70.56	0	23.15	43.81	160.42	37.83	104.76	62.67	152.91	287.83	95.16	32.35	218.49
40	99.06	326.11	154.7	191.26	132.66	103.99	111.94	171.04	78.62	294.41	153.43	50.17	62.62	74.75	65.77	23.15	0	20.85	181.62	26.26	107.92	83.87	170.01	306.2	72.03	39.61	207.71
41	104.46	323.54	153.06	194.25	147.27	123.98	96.21	184.05	69.76	297.41	158.79	48.54	83.28	83.53	74.54	43.81	20.85	0	201.61	37.07	94.08	103.86	173.01	311.56	69.29	60.43	189.16
42	135.55	326.74	210.11	136.69	66.45	90.18	293.54	42.29	197.11	201.99	113.79	170.76	138.28	213.7	202.89	160.42	181.62	201.61	0	190.84	229.11	97.75	148.88	187.93	253.63	168.42	333.18
43	117.04	349.64	178.22	209.52	147.77	104.61	113.73	187.09	102.15	312.67	171.37	73.7	56.33	48.66	39.71	37.83	26.26	37.07	190.84	0	130.86	97.87	188.27	324.14	73.06	27	225.96
44	98.21	229.47	66.1	137.14	170.06	155.31	134.43	193.9	33.75	230.16	124.04	69.33	137.15	177.61	168.62	104.76	107.92	94.08	229.11	130.86	0	133.57	115.69	255.91	151.21	136.93	120.08
45	54.85	297.12	139.66	137.83	53.32	23.95	195.78	93.13	101.57	237.49	93.77	75.22	50.32	125.75	114.94	62.67	83.87	103.86	97.75	97.87	133.57	0	124.2	244.18	155.87	79.01	250.82
46	76.99	179.77	66.61	28.17	97.25	134.74	243.81	108.57	116.2	129.45	35.85	127.88	165.62	234.28	223.48	152.91	170.01	173.01	148.88	188.27	115.69	124.2	0	145.72	236.1	185.27	201.63
47	208.03	241.03	197.39	118.77	193.29	245.75	383.83	153.5	256.22	47.9	153.35	266.51	288.97	365.91	355.1	287.83	306.2	311.56	187.93	324.14	255.91	244.18	145.72	0	373.3	319.34	317.03
48	166.16	376.06	216.15	257.34	204.66	173.98	57.06	243.05	132.59	360.5	220.53	111.62	125.69	87.56	94.19	95.16	72.03	69.29	253.63	73.06	151.21	155.87	236.1	373.3	0	99.43	231.76
49	113.08	348.57	177.15	206.51	128.48	81.23	140.09	167.79	104.79	309.67	167.41	71.11	32.95	50.92	40.11	32.35	39.61	60.43	168.42	27	136.93	79.01	185.27	319.34	99.43	0	246.03
50	206.43	180.93	136	218.13	272.86	272.56	193.7	295.63	151.91	283.67	225.78	185.09	252.91	271.18	263.7	218.49	207.71	189.16	333.18	225.96	120.08	250.82	201.63	317.03	231.76	246.03	0
51	92.01	158.77	44.31	47.07	129.43	159.29	237.54	140.75	114.99	129.01	68.03	133.07	178.92	246.3	235.5	164.94	179.83	178.2	181.06	199.48	104.79	141.53	32.19	154.94	241.29	197.29	173.17
52	109.01	270.05	110.82	178.22	172.73	156.18	90.36	207.86	43.33	274.88	156.45	61.63	129.45	142.05	134.56	91.07	78.57	60.02	229.98	96.83	44.74	134.44	156.98	297	108.12	116.9	130.97
53	182.35	174.88	148.01	86.53	185.87	230.8	342.62	161.96	223.97	23.44	127.09	235.65	268.41	342.05	331.24	260.68	277.78	280.78	197.03	296.04	211.48	220.86	112.82	71.24	343.87	293.04	261.64
54	47.51	213.35	47.37	82.88	114.2	121.03	182.18	137.17	54.57	186.03	67.32	70.89	125.92	189.13	178.32	107.76	117.66	116.02	174.51	141.18	58.2	99.78	61.63	201.65	179.11	140.11	163.88
55	246.69	167.77	203.78	154.09	253.47	298.36	398.78	229.56	280.66	66.14	194.65	297.65	335.33	403.99	393.18	322.62	339.72	342.78	264.63	357.98	267.64	288.42	172.03	102.76	405.87	354.97	297.78
56	204.95	370.64	272.21	192.28	140.71	167.78	371.14	106.34	271.3	193.38	177.6	248.37	215.88	291.3	280.5	238.03	259.23	279.22	80.81	268.44	298.02	175.36	210.8	151.77	331.23	246.03	399.75
57	187.42	314.4	177.31	252.84	247.2	230.66	43.17	282.33	122.59	335.09	235.71	136.1	192.29	177.2	178.69	152.81	132.1	111.75	304.46	147.3	116.37	208.92	231.39	366.53	94.43	171.69	159.33
58	172.34	391.72	222.33	263.52	208.94	168.56	76.21	247.44	142.59	366.68	226.71	117.81	120.28	70.32	76.94	98.94	77.45	76.29	252	64.49	162.92	159	242.28	379.48	20.87	89.04	249.74
59	211.02	285.99	165.26	252.4	277.21	260.67	97.2	310.93	144.91	323.04	244.21	166.11	233.93	226.91	226.25	195.03	177.49	157.14	334.47	192.68	120.38	238.92	230.55	354.48	150.08	217.07	105.06
60	111.01	184.78	44.84	128.88	177.45	184.81	171.36	200.21	76.21	203.17	130.36	111.79	174.02	222.53	213.55	147.77	151.53	139.01	237.76	175.25	44.94	163.55	107.02	234.61	196.13	180.13	96.66
61	177.93	376.53	220.25	267.72	218.72	189.14	46.35	256.01	135.76	370.88	232.26	122	140.85	100.28	106.91	110.32	87.19	76.63	268.79	88.22	154.17	171.03	246.48	385.03	18.36	114.59	226.44
62	254.09	156.7	209.34	161.48	262.57	305.76	404.35	238.66	286.22	78.26	202.05	304.31	342.73	411.39	400.58	330.02	347.12	349.44	273.73	365.38	273.21	295.82	179.43	117.07	412.53	362.37	296.59
63	102.3	337.78	166.36	195.73	123.29	77.47	140.06	162.6	94.01	298.88	156.63	60.33	29.19	59.8	48.99	21.57	35.81	56.63	164	29.11	126.33	73.83	174.48	309.4	99.4	10.78	240.06
64	255.97	209.37	221.31	160.14	255.8	304.23	415.92	229.05	297.59	67.46	200.71	309.26	342.02	415.67	404.86	334.3	351.4	354.39	263.48	369.66	284.78	294.48	186.44	75.58	417.48	366.65	324.41
65	238.54	169.61	195.63	145.94	243.7	290.21	390.63	219.79	272.51	56.97	186.5	289.5	327.18	395.84	385.03	314.47	331.57	334.63	254.86	349.83	259.49	280.27	163.88	97.91	397.72	346.82	291.23
66	127.01	350.68	179.27	219.41	157.6	119.26	96.33	196.92	103.19	322.57	181.34	74.74	70.98	51.55	48.98	47.8	31.1	33.62	200.66	17.43	127.7	107.66	198.17	334.11	55.66	43.8	220.23
67	107.46	346.31	174.89	200.89	117.41	70.05	152.08	156.72	102.54	303.55	159.82	67.46	21.77	59.45	48.64	33.2	48.46	69.28	157.27	38.98	136.29	67.94	179.64	308.26	111.41	11.99	251.57
68	112.27	335.06	163.64	204.46	145.87	116.19	103.46	184.25	87.57	307.62	166.64	59.11	67.91	63.73	54.75	35.51	14.27	19.79	194.83	17.32	113.87	97.08	183.22	319.41	62.8	43.22	208.95
69	185.79	364.6	261.36	182.79	118.35	133.27	338.23	93.78	241.81	205.57	165.04	215.46	179.37	256.02	245.21	205.12	226.32	246.31	54.48	232.91	273.81	142.45	200.13	183.71	298.32	209.53	385.91
70	216.3	449.61	278.19	309.73	229.24	177.72	144.15	268.56	202.01	412.88	270.63	173.67	132.53	54.53	66.03	135.57	129.21	132.25	267.9	103.12	224.5	179.95	288.48	420.1	90.87	105.12	314.84
71	104.57	313.6	147.8	192.11	157.8	137.26	86.49	194.57	59.82	295.27	158.94	47.75	96.56	97.56	89.49	57.09	36.22	15.98	213.48	53	84.14	117.14	170.87	310.88	74.6	75.81	177.34
72	135.19	370.67	199.25	228.61	148.8	97.38	135.29	188.12	124.45	331.77	189.52	93.22	52.19	29.77	19.41	54.46	48.69	61.68	187.55	25.01	153.94	99.34	207.37	339.66	92.46	24.01	250.57
73	114.15	151.08	62.81	41.82	136.9	175.99	257.42	142.28	139.3	105.96	74.74	157.38	201.05	268.44	257.64	187.08	203.36	202.51	177.49	221.62	126.28	163.67	41.52	137.4	265.6	219.43	181.91
74	154.34	176.68	124.16	58.52	157.02	202.79	318.77	133.1	195.96	45.97	99.08	207.64	240.4	314.04	303.23	232.67	249.77	252.77	168.18	268.03	187.64	192.85	84.81	75.94	315.86	265.03	242.71
75	249.33	189.21	209.88	153.51	249.16	297.59	404.49	225.25	286.37	60.82	194.07	301.91	335.39	408.25	397.44	326.88	343.98	347.04	260.32	362.24	273.35	287.84	176.29	83.16	410.13	359.23	308.62
76	269.52	171.08	226.04	176.92	277.74	321.19	421.05	253.82	302.92	90.73	217.48	320.48	358.16	426.82	416.01	345.45	362.56	365.61	288.9	380.82	289.91	311.25	194.86	118.52	428.7	377.8	314.08
77	102.35	163.97	66.22	27.63	122.02	161.62	258.91	128.1	131.91	112.8	59.86	146.64	189.26	256.65	245.84	175.28	191.57	191.77	163.32	209.83	125.24	151.1	27.15	134.41	254.86	207.63	191.26
78	124.3	345.7	174.29	215.48	161.01	128.1	87.8	199.39	98.07	318.64	178.67	69.76	79.82	63.97	62.27	50.89	29.41	28.34	208.55	28.38	122.38	112.22	194.24	331.44	47.14	55.14	212.81
79	128.2	329.91	167.2	214.8	179.25	156.3	63.82	216.03	82.5	317.96	182.4	72.29	114.72	95.38	95.27	75.47	52.34	33.95	233.93	63.95	101.12	136.18	193.56	333.58	50.87	90.04	191.46
80	137.05	302.83	202.57	122.64	79.58	132.3	312.66	39.79	203.4	143.12	109.7	187.03	177.2	254.13	243.33	191.97	210.82	223.55	65.05	226.86	230.12	132.9	141.16	129.06	282.82	207.56	331.86
81	200.43	45.19	126.23	146.03	231.82	269.3	314.47	243.13	215.13	156.95	170.42	234.16	289.07	352.4	341.59	271.03	280.93	279.29	281.55	304.45	192.33	251.93	134.58	204.84	341.77	303.38	172.9
82	245.23	80.74	160.53	214.72	300.5	319.02	294.01	311.82	223	229.48	239.1	258.57	320.8	367.54	360.02	294.56	298.32	285.48	350.41	322.03	191.72	297.77	203.27	277.38	329.02	326.91	106.41
83	32.39	243.46	112.9	76.75	42.82	74.41	212.01	68.44	98.73	176.41	32.68	89.82	109.45	185.77	174.96	110.49	129.34	134.6	103.29	146.8	129.23	61.91	63.71	185.45	196.61	139.03	232.49
84	111.16	136.44	57.74	55.69	140.57	178.06	253.39	151.89	135.26	121.25	79.17	153.35	198.07	265.46	254.65	184.09	200.11	198.48	191.38	218.64	122.25	160.69	43.33	152.69	261.57	216.44	167.36
85	86.18	167.34	57.37	33.52	109.66	147.15	243.89	120.98	116.28	128.4	48.26	131.01	172.95	240.37	229.56	159	175.32	176.14	161.29	193.57	112.39	133.75	12.42	147.08	239.23	191.35	191.49
86	96.32	152	32.08	67.56	147.03	167.87	227.5	160.28	114.59	136.85	87.57	132.68	184.49	250.91	240.11	169.54	179.45	177.81	200.6	202.97	96.36	150.11	51.73	168.29	240.9	201.9	156.17
87	156.35	352.25	194.23	242.95	205.82	179.07	38.15	242.59	110.59	346.11	210.55	100.57	130.79	107.7	109.19	99.5	76.37	60.64	257.96	78.15	128.15	160.21	221.71	361.72	26.74	104.52	208.32
88	87.95	280.93	117.55	166.86	147.74	131.19	99.83	182.87	30.78	270.02	141.68	36.64	104.46	126.54	117.55	66.07	57.54	43.01	204.99	79.33	52.53	109.45	145.62	285.64	102.55	92.67	154.35
89	84.67	311.49	140.08	176.86	123.27	99.33	119.91	161.66	64	280.02	139.04	35.55	58.64	89.05	78.83	19.16	17.15	24.82	176.97	40.57	94	79.21	155.62	291.81	83.58	43.17	203.1
90	129.87	269.29	173.44	91.36	97.83	150.56	310.63	58.05	195.52	111.26	84.65	188.47	195.45	272.39	261.58	209.82	228.16	233.56	92.47	245.12	207.64	151.15	112.03	97.48	295.26	225.82	306.49
91	109.41	344.89	173.47	202.84	134.81	92.38	126.31	174.13	97.42	306	163.74	67.44	44.2	56.71	46.34	29.99	22.89	43.71	177.87	12.96	127.42	85.35	181.59	316.51	85.65	18.71	229.53
92	167.64	113.89	115.48	89.54	192.27	233.46	308.06	187.35	191.97	82.56	130.11	210.05	254.54	321.93	311.13	240.57	256.82	255.19	222.57	275.11	178.96	217.16	98.74	130.46	318.27	272.92	203.59
93	147.81	220.79	84.21	171.35	218.64	204.53	133.64	241.41	81.22	241.99	171.56	113.96	181.78	202.48	194.96	147.36	138.97	120.42	278.33	157.22	52.84	182.79	149.5	273.43	166.72	177.29	71.24
94	144.76	116.31	60.07	121.25	205.74	218.56	234.65	217.05	145.51	178.56	144.34	165	225.14	283.23	272.42	201.86	211.76	209.42	256.94	235.29	115.36	197.31	108.5	219.53	261.95	234.21	106.81
95	145.42	263.32	174.76	87.57	119.94	172.67	326.19	80.16	207.6	88.3	94.85	204.03	217.56	294.5	283.69	225.38	243.72	249.12	114.59	261.69	217.84	173.27	113.56	74.76	310.82	247.93	302.66
96	261.76	129.43	210.89	172.06	274.79	316.34	403.47	251.02	287.38	101.04	212.63	305.46	349.95	417.34	406.53	335.97	352.23	350.59	286.09	370.52	274.37	306.39	187.1	145.94	413.68	368.33	286.25
97	182.74	115.99	98.04	163.94	248.42	256.54	239.65	259.74	159.58	221.24	187.02	195.16	257.38	305.9	296.91	231.14	234.9	222.37	299.63	258.62	128.31	235.28	151.19	262.22	274.18	263.49	70.85
98	241.68	181.64	201.39	145.85	241.51	289.94	396.33	217.59	278.2	53.17	186.42	293.74	327.73	400.08	389.27	318.71	335.82	338.87	252.67	354.08	265.19	280.19	168.12	85.63	401.96	351.07	297.24
99	204.43	96.29	152.27	126.05	228.77	270.26	342.44	218.46	228.77	98.1	166.61	246.85	291.34	358.73	347.92	277.36	293.62	291.98	253.53	311.91	215.75	253.95	135.53	146	355.07	309.71	227.69
100	225.43	172.09	184.35	130.2	225.86	274.29	378.97	201.94	260.84	39.15	170.77	276.38	312.08	382.72	371.91	301.35	318.46	321.51	237.02	336.72	247.83	264.54	150.76	84.08	384.6	333.7	284.81
101	80.2	178.32	6.91	89.28	146.19	154	195.75	167.43	81.99	169.3	95.47	101.02	161.17	219.26	208.45	137.89	147.79	146.15	206.5	171.31	63.68	132.75	66.26	197.91	209.24	170.24	138.5
102	120.07	173.69	45.38	132.58	186.51	193.87	175.08	209.28	87.06	203.16	139.42	122.64	184.86	233.38	224.39	158.62	162.38	149.85	246.82	186.1	55.79	172.62	110.92	234.6	202.38	190.97	94.38
103	187.65	423.13	251.71	281.07	200.59	149.07	147.33	239.91	176.51	384.23	241.98	145.68	103.88	25.88	37.38	106.92	100.63	108.23	239.25	74.54	202.31	151.3	259.83	391.45	91.99	76.47	293.92
104	174.13	224.2	159.73	81.11	163.42	211.85	346.17	127.99	218.55	41.5	119.45	230.23	255.07	332	321.2	253.93	272.3	275.36	162.42	290.24	218.25	210.28	108.05	37.68	338.45	285.43	279.36
105	148.75	348.6	230.08	163.89	81.31	95.19	301.2	69.35	204.77	228.3	133.76	178.43	142.31	218.32	207.51	168.08	189.28	209.27	27.24	195.86	236.77	105.41	168.85	214.24	261.29	172.47	353.15
106	139.02	345.06	224.22	167.43	71.58	83.28	291.46	72.74	195.04	237.38	130.22	168.69	131.72	206.41	195.61	158.35	179.55	199.54	36.4	186.12	227.04	95.68	165.31	223.32	251.55	162.74	343.99
107	155.08	354.55	236.03	169.84	87.63	101.51	307.52	75.3	211.09	231.98	139.71	184.75	148.63	224.64	213.84	174.41	195.6	215.59	33.19	202.18	243.09	111.73	174.79	217.92	267.61	178.8	359.09
108	105.65	346.46	177.35	197.4	110.13	57.26	164.24	149.45	107.16	297.06	153.34	71.64	12.76	66.97	56.16	42.74	62.48	83.3	147.43	53.21	140.92	62.35	177.83	300.99	123.58	26.92	256.67
109	111.35	346.83	175.41	204.78	129.62	83.71	137.4	168.94	101.97	307.94	165.68	69.38	35.43	52.35	41.55	30.9	34.73	55.55	170.94	23.89	131.97	80.16	183.54	318.45	96.74	5.37	241.07
110	142.6	375.13	203.71	235.01	158.32	106.89	130.99	197.63	127.64	338.16	196.93	99.18	61.7	23.33	14.34	63.39	51.75	60.77	197.06	25.81	154.85	108.85	213.76	349.17	86.55	33.52	249.93
111	194.96	175.26	157.18	99.13	197.09	243.41	351.79	173.18	233.67	19.65	139.7	248.26	281.01	354.66	343.85	273.29	290.39	293.39	208.25	308.65	220.65	233.47	123.59	67.55	356.47	305.64	266.88
112	109.84	137.08	44.7	68.05	152.54	181.39	241.93	163.86	130.3	135.51	91.14	148.53	198.47	266.61	255.81	185.24	195.29	193.66	203.74	218.82	110.8	163.63	55.3	166.95	256.75	217.6	152.83
113	114.5	146.78	62.97	45	138.86	177.94	257.59	145.47	139.46	108.2	76.7	157.55	201.41	268.79	257.99	187.43	203.71	202.68	180.69	221.97	126.45	164.02	43.48	139.64	265.76	219.78	178.61
114	130.89	154.26	90.53	44.36	147.09	188.53	285.15	142.17	167.02	80.04	84.93	181.85	219.53	288.19	277.38	206.82	223.92	226.98	177.39	242.18	154.01	178.05	56.23	112.93	290.07	239.17	205.76
115	111.78	313.68	150.97	198.38	169.38	148.84	74.74	205.23	66.08	301.54	165.98	57.53	108.15	99.46	96.49	68.67	46.6	26.25	225.06	61.42	84.89	128.72	177.14	317.16	66.57	86.19	175.23
116	89.87	244.29	134.17	54.24	73.42	121.85	270.63	49.32	153.95	126.32	42.95	148.47	165.07	242	231.2	169.83	188.16	193.56	86.01	206.14	165.93	120.28	72.75	125.35	255.26	195.43	267.67
117	231.88	215.25	199.6	136.06	230	278.43	394.22	195.7	273.5	35.1	176.62	285.18	317.94	391.58	380.77	310.21	327.31	330.31	230.12	345.57	263.08	270.39	162.35	42.68	393.4	342.57	313.48
118	166.08	388.24	216.83	258.02	188.64	137.7	108.88	227.96	140.65	361.18	220.41	112.3	92.55	35.51	42.13	86.88	71.3	70.88	227.88	49.05	164.25	139.18	236.77	373.18	53.55	60.17	254.59