2018년 2월
박사학위 논문

년
월

3mm

박사학위논문

Efficient Operational Strategy of a Closed-Loop Supply Chain Network Model : Focusing on Tire Industry in Korea

- 패쇄루프공급망 네트워크 모델의 효율적인 운용전략: 한국 타이어 산업을 중심으로

논문제목

14포인트

조선대학교 대학원

경영학과

진 성 (CHEN XING)

성

명

Efficient Operational Strategy of a Closed-Loop Supply Chain Network Model
: Focusing on Tire Industry in Korea

패쇄루프공급망 네트워크 모델의 효율적인 운용전략:
한국 타이어 산업을 중심으로

2018년 2월 23일

조선대학교 대학원

경영학과

진 성 (CHEN XING)

Efficient Operational Strategy of a Closed-Loop Supply Chain Network Model : Focusing on Tire Industry in Korea

- 패쇄루프공급망 네트워크 모델의 효율적인 운용전략:
한국 타이어 산업을 중심으로

지도교수 윤 영 수

이 논문을 경영학박사학위신청 논문으로 제출함

2017년 10 월

조선대학교 대학원

경 영 학 과

진 성 (CHEN XING)

진 성 (CHEN XING)의 박사학위논문을 인준함

위원장	조선대학교	교 수	이청호	(인)
위 원	조선대학교	교 수	최현도	(인)
위 원	조선대학교	교 수	민진영	(인)
위 원	동의대학교	교 수	이정은	(인)
위 원	조선대학교	교 수	윤영수	(인)

2017년 12 월

조선대학교 대학원

TABLE OF CONTENTS

TABLE LISTS

TABLE LISTS

FIGURE LISTS 1.

FIGURE LIST 2.

ABSTRACT

패쇄루프공급망 네트워크 모델의 효율적인 운용전략:
한국 타이어 산업을 중심으로

CHEN XING
Advisor : Prof. YoungSu Yun, Ph.D.
Department of Business Administration,
Graduate School of Chosun University

본 연구는 폐쇄루프공급망(Closed-Loop Supply Chain: CLSC) 네트워크의 설계와 효율적 운용 전략에 관한 방법론을 제안한다. CLSC 네트워크는 순방향물류(Forward Logistics: FL)와 역물류 (Reverse Logistics RL)를 통합하여 구성된다. FL은 원자재 조달에서 부터 생산, 유통 단계를 거처 최종적으로 고객에게 제품이 전달되는 네트워크 구조를 가지고 있으며, RL은 고객이 사용한 제품을 수집 후 재사용이 가능한 제품, 재가공이 필요한 제품, 폐기해야 할 제품 등으로 분류 한 후, 이를 재가공센터, 물류센터, 폐기센터 등으로 보내는 네트워크 구조를 가지고 있다. 즉 CLSC 네트워크이 FL과 RL을 통합적으로 운영하기 때문에 재사용 가능한 제품의 판매를 통한 수익 증대, 재활용 가능한 원자재의 확보를 통한 재고관리의 효율성 증대 등을 기대할 수 있어 기업의 경쟁력을 한층 더 강화시킬 수 있다.

본 연구에서는 한국 타이어산업의 사례를 중심으로 CLSC 네트워크를 설계하고, 이를 효율적으로 운용하기 위한 전략을 제시하고 있다. 먼저 기존의 한국 타이어산업 운용방식을 반영한 M1 CLSC 네트워크를 설계하였다. M1에서 FL 구성은 타이어제조업체, 물류센터, 타이어 구매고객을 고려하였고, RL에서는 타이어 수집센터, 재제조센터, 재활용센터, 국내 중고 타이어 판매업체, 국외 중고 타이어 판매업체, 국내 재활용 원자재 판매업체, 국외 재활용 원자재 판매업체, 소각센터를 고려하여 네트워크를 구성하였다. 또한 수송방식으로는 정상배송(Normal Delivery) 방법만을 사용하였다. 최근 들어 온라인 구매 확산과 신속한 수송(배송)을 원하는 고객의 증가로 인해 기존의 정상배송에 직접배송(Direct Delivery) 및 직접선적(Direct Shipment)을 추가한 다양한 수송방식이 사용되고 있다. 따라서 본 연구에서도 기존의 타이어산업 운용방식을 반영한 M1에 직접배송과 직접선적을 추가한 새로운 M2 CLSC 네트워크를 제안한다. M1과 M2의 운용방식은 각각의 수리모형으로 공식화되었다. 수리모형의 목적함수로서는 총비용 최소화(Minimization of Total Cost)와 총이익 최대화(Maximization of Total Revenue)가 함께 고려되었으며, 이러한 목적함수를 최적화하기 위해 다양한 제약조건들이 고려되었다.

제시된 수리모형의 이행을 위해 유전알고리즘(Genetic Algorithm: GA) 접근법이 사용되었으며, 사례연구에서는 GA 접근법을 이용해 M1과 M2의 수행도를 비교분석하였다. 현실적인 비교분석을 위해 한국타이어산업협회에서 제공한 실제데이터를 이용하였고, 몇 가지 형태의 CLSC 네트워크 문제와 다양한 시나리오를 사용하여 M1과 M2의 효율성을 비교분석하였다. 비교분석결과는 본 연구에서 제안한 M2가 기존의 M1보다 더 우수한 수행도를 나타내는 것을 확인할 수 있었다. 다만 사례연구에서 제시한 CLSC 네트워크의 규모가 비교적 작기 때문에 좀 더 큰 규모의 CLSC 네트워크와 다양한 시나리오를 고려할 필요가 있으며, 타부서치(Tabu Search), 쿠쿠서치(Cuckoo Search), 입자군집최적화(Particle Swarm Optimization) 등과 같은 최신의 방법론을 GA와 함께 고려한 혼합형접근법을 적용하는 문제, 최근 이슈가 되고 있는 재사용, 재활용 및 폐기처리에 따른 환경영향 문제, 실제 현장에서 발생하는 다양한 현실 데이터를 활용하는 문제 등을 추가적으로 고려하여 M1과 M2의 수행도를 비교분석할 필요가 있을 것이다. 이러한 필요성은 추후 연구로 남겨 둔다.

I. Introduction

1.1 Background of Study

Before the 1950s, the term ‘logistics’ was a word used in military terms (Ballou, 1978). Around the 1950s, manufacturing companies recognized the importance of logistics when physical distribution occurred, and logistics was firstly changed to “transformation” (Heskett et al. 1964). The American Production and Inventory Control Society (APICS, 1990) defined supply chain as the processes from the initial raw materials to final consumption of the finished products linking across supplier-user industries. A basic supply chain is consisted of suppliers, manufacturers, distributors, retailers, and customers (Chopra et al. 2001). Therefore, during this phase, on the basis of time and quality-based competition and environmental uncertainties, and in order to satisfy the needs of customers, supply chain management (SCM) played an important role in the entire production processes and economic activities. The concept of SCM was appeared in the early 1980s (Oliver et al. 1992). The Council of SCM Professionals (CSCMP) defined SCM as encompass—all activities of planning and management involved in sourcing and procurement, conversion, and logistics management activities (Habib, 2011). During this period, many researchers realized the importance of forward logistics (FL) in the area of SCM (Devanné, 1975; Morris, 1980; Holland, 1995). In addition, the key to SCM is to make a coordinated relationship from supplier to consumer through production and distribution activities (John et al. 2001).

Reverse logistics (RL) in the area of SCM was realized at the starting of remanufacturing. However, in the early 1990s, research in remanufacturing was neglected due to the complexity of remanufacturing activities. Lund (1984) first recognized remanufacturing as an area of getting technology and saving energy from remanufacturing products in U.S. The early research which was sponsored by the U.S. military, focused on the relationship and coordination between each stage of supply chain (Guide, 1996; Guide et al. 1998). Simultaneously, research mainly focused on increasing profitability of remanufacturing. For example, the U.S. steel industry has earned $53 billion from the sales of remanufacturing products (Lund, 1996).

Contrary to expectations, in Europe, the RL was subjected to legislation by the European Union directives on end-of-life products. Further research has taken more attention on the directive toward recycling, such as the Waste Electrical and Electronic Equipment (WEEE) directive. To comply with those legislations or directives, manufacturers began to study how to minimize total costs. Therefore, the area of minimizing the total cost in RL has also been taken into account (Bloemhof-Ruwaard et al. 1996; Fleischmann et al. 2001).

On the basis of active research in the RL, the area of designing efficient network for RL through optimizing operations research (OR) has become more and more popular. Van der laan et al (1999) proposed that remanufactured components in conventional inventory problems can be reused. Simultaneously, the return activities of used products have attracted much more attention. Other researchers have considered that used products should be collected at optimal price and quality (Guide et al. 2001; Guide et al. 2003a; Guide et al. 2003b; Aras et al. 2004; Galbreth et al. 2006). With emerging solutions for return problems, the sight of researchers has shifted to explore how to coordinate the relationships within each stage of the RL network in order to maintain information symmetry (Yadav et al. 2003). Meanwhile, companies have also taken attention to minimize return and disposal costs (Stock et al. 2002).

By this point of view the integration or link of FL and RL, closed-loop supply chain (CLSC) network model was developed. The importance of the CLSC network model is reflected in various industries. Hewlett-Packard has estimated that more than $700 million of recoverable computer equipment was destroyed, less than half of the value of those product returns were being recovered. (Guide et al. 2006). For example, in a tire industry, areas of remanufacturing and recycling for used tire have taken the attention of manufacturers and producers. The demand for the reuse of truck and bus tires accounts for 85% in the replacement market, and the remaining 15% are taken by Original Equipment Manufacturer (OEM) (Sasikumar, 2010). In addition, used tires can be recycled in the form of raw materials, such as rubber powder, steel wires, fiber, and so on (Kemal et al. 2015).

Daniel et al. (2009) defined the conception of the CLSC network model as a system which maximizes value creation over the entire life cycle by the design, control, and operation of the product. In this system, the dynamic recovery of the value is maximized through different types and volumes of returns over time. Therefore, the CLSC network model focuses on recovering added-value when a used product has been returned, along with the remanufacturing used product, recycling materials, or disassembling components or parts. The development of the CLSC network model can be concluded as following:

1) The CLSC network model extends the life cycle of used products by remanufacturing used products, recycling materials or disassembling components or parts (Van der laan et al. 1999; Guide et al. 2001; Guide et al. 2003a; Guide et al. 2003b; Aras et al. 2004; Galbreth et al. 2006; Guide et al. 2006; Daniel et al. 2009).
2) Ways of minimizing cost have become diverse, not just in saving return costs (Yadav et al. 2003; Stock et al. 2002), but in terms of designing a CLSC network model, selling remanufactured products, disassembled parts, or recycling material.

In other words, the CLSC network model can be described as an optimization process of resource integration, cost savings and creating profit.

1.2 Objective and Contents of Study

As mentioned above, the CLSC network model is a process of integrating the remanufacturing and recycling activities through designing and/or redesigning the supply chain network. The remanufacturing process refurbishes entire discarded products for reuse as second-hand devices; the recycling process consists of recovering materials, such as metals, plastics, repairing, and reusing parts or components to producing new products (Guide et al. 2002; Spengler et al. 2004; Özceylan et al. 2017).

In the review of the literatures mentioned above, most researches proposed an objective using mathematical formulation, and finding solutions through various programming methodologies in common. The objectives of mathematical formulation are divided into two types: minimization and maximization. There are various programming methodologies to solve the mathematical formulation. Several common programming methodologies can be summarized as follows: nonlinear programming (NP), mixed integer linear programming (MILP), stochastic programming (SP), fuzzy programming (FP), robust optimization (RO), bender decomposition (BD), genetic algorithm (GA), particle swarm optimization (PSO), memetic algorithm (MA), simulated annealing (SA), Tabu search (TS), and so on.

Recently, along with the evolution of the CLSC network model, research has moved to profitability and maximizing value. The contents of profitability consider minimizing cost or maximizing revenue. The contents of maximizing value are considered to create new value or to maximize resource utilization. On this point of view, constructing the CLSC network model is important. The CLSC network model for achieving the profitability and maximizing value should include the following six characteristics.

- Treatment methods
- Transportation routes/types
- Limitation of treatment capacities
- Ratio regulations
- Technology coefficients
- Location and allocation decisions

The treatment methods of used products have several recovery options, in other words, used products can be remanufactured, recycled, or incinerated (Charlle, 2017). Chen et al. (2015) proposed a MILP to solve the CLSC network model, with a cartridge recycling problem in Hong Kong. In this paper, the objective is to minimize total costs using the GA method. Meanwhile, two characteristics need to be considered when a CLSC network model is designed. The first characteristic is to consider the treatment method for used products, which is divided into remanufacturing products and recycling materials. This option of remanufacturing refers to the quality of used products that need to be repaired or remanufactured, while the option of recycling refers to the good quality of used products that need to be refurbished or renovated. The second characteristic is to optimize the location and allocation decision at stage of manufacturers, warehouse, retailers, collection centers and recycling centers.

The transportation routes/types are divided into normal delivery, direct delivery and shipment. According to Tedeschi (2000), 42% of manufacturers, such as IBM, Pioneer Electronics, Cisco System, Estee Lauder, and Nike, have sold to customers through direct delivery or shipment via e-commence. The direct delivery and shipment prompts many manufacturers to change their traditional transportation routes/types and redesign their supply chain structures. Direct delivery and shipment help the manufacturers to improve their overall profitability by reducing the degree of inefficient sales (Kelvin, 2003). Thus, direct delivery and shipment have been taken into greater consideration when supply chains are designed (Jamrus et al. 2015).

The limitation of treatment capacities can better coordinate the relationship between each stage in a CLSC network model. The problem of uncertainty parameters should be always considered, such as return time, capacity, demands, and so on. Limitation of treatment capacities are preferred to be adopted as a method to control the uncertain parameters (Krikke et al. 2003; Üser, 2007; Pishvaee et al.2009; Wang et al. 2010; Pishvaee et al. 2011; Sasikumar et al. 2011; Amin et al. 2012, 2013; Özceylan et al. 2013, 2014; Zeballos et al. 2014; Ramezani et al. 2014; Jindal et al. 2014; Soleimani et al. 2015; Chen et al. 2017; Amin et al. 2017). Simultaneously, the optimal distribution of a product has a great influence on the performance of the CLSC network model when the treatment capacity is limited. Several researches have explored this area, considering the limitation of treatment capacity in terms of return rate, demand change, and so on (Özceylan, 2013; Amin, 2017).

The ratio regulations can be applied to the activities of remanufacturing, recycling, and waste disposal. The application of ratio regulation is used to find the interaction among the activities of remanufacturing, recycling, waste disposal and performance of the CLSC network model (Özceylan et al. 2013; Kevin et al. 2003). However, it has rarely received attention. Furthermore, ratio regulations can also be applied to the characteristic of transportation routes/types in terms of normal delivery, direct delivery and shipment. However, this area has not yet taken the attention of most conventional literatures.

The effect of technology coefficients have been considered by many researchers (Krikke, 2003; Özceylan et al. 2017; Subulan et al. 2015; Collins et al. 2002; Pedram et al. 2017). They are measured by quality of used products (Chen et al. 2015). Chen et al. (2015) proposed that the efficiency of the CLSC network model has improved by differentiating the quality of used produces, thus, the technology has a positive effect on performance of the CLSC network model, but, most of researchers have not added technological criteria as a major consideration.

Similar to the effect of technology coefficients, location and allocation decision problems have been considered by many researchers (Jayaraman et al. 1999; Realff et al. 2004; Üser et al. 2007; Min et al. 2008; Pishvaee et al. 2009; Wang et al. 2010; Amin et al. 2013; Ramezani et al. 2014; Özceylan et al. 2014; Zeballos et al. 2014; Jindal et al. 2014; Soleimani et al. 2015; Hasani et al. 2015; Chen et al. 2017; Amin et al. 2017) Üser et al. (2007) designed a multi-product CLSC network model to locate collection centers and remanufacturing facilities in the automotive industry. Zeballos et al. (2014) proposed a multi-period, multi-product CLSC network model to determine which stages to be opened. Optimization of location and allocation decisions is an essential characteristic in most of CLSC network model.

Among the above mentioned literatures, only two or three characteristics of the six ones are considered. None of the literatures has considered all six characteristics. As we know, the structure of the CLSC network model is complex, and requires strategic decision makings. Therefore, the efficiency of the CLSC network model is very important. For achieving it, the treatment method for used products should vary and various transportation routes/types need to be considered. Simultaneously, in order to extend a product life cycle, maximizing profits, saving costs, the limitation of treatment capacities, and ratio regulations should be considered. Moreover, technological coefficients have a great effect on the performance of the CLSC network model, so it also should be considered. Finally, any location and allocation problems should be optimized in the CLSC network model. Therefore, in order to design an integrative and efficient CLSC network model, these six characteristics should be considered together. The six characteristics are defined in terms of treatment methods, transportation routes/types, limitation of treatment capacities, ratio regulations, technology coefficients, location and allocation decisions.

In this study, we will design an CLSC network model for the tire industry in Korea and explore an efficient operational strategy to maximize total revenue and minimize total cost by building a mathematical formulation while considering the following six characteristics:

1) Making decision for treatment methods of used product in terms of remanufacturing, recycling,

and waste disposal.

2) Considering various transportation routes/types along with normal delivery, direct delivery and shipment.
3) Considering limitation of treatment capacities
4) Regulating the ratio of treatment method in terms of remanufacturing, recycling, and waste disposal; Regulating the ratio of various treatment routes/types in terms of normal delivery, direct delivery and shipment.
5) Considering technological coefficient to identify the quality of remanufactured products and recycling materials.
6) Optimizing location and allocation decision.

The structure of this study is as follows: Section 2 shows a review of conventional CLSC network models and it in the tire industry. The conventional CLSC network model for the tire industry in Korea and the proposed CLSC network models are proposed in Section 3. The proposed CLSC network model is represented in a mathematical formulation and is implemented using the GA approach in Sections 4 and 5, respectively. In Section 6, the CLSC network model for the tire industry in Korea is presented as a case study and various performance analyses, including a sensitivity analysis are taken into consideration. Finally, conclusions are summarized and a future study direction for improving the CLSC network model and GA approach are followed in Section 7.

II. Conventional CLSC Network Models and Tire Industry

Six characteristics have been mentioned in the previous section, which are important in designing an integrative and efficient CLSC network model. They include (1) making a decision for treatment method of used products in terms of remanufacturing, recycling, and waste disposal, (2) considering various transportation routes/types in terms of normal delivery, direct delivery, and shipment, (3) considering the limitation of treatment capacity, (4) ratio regulation for treatment method and transportation routes/types, (5) considering technological coefficient, and (6) optimizing the decision of location and allocation. Thus, in this section, we will analyze various conventional CLSC network models using previous literatures in terms of these six characteristics. In addition, we will also present the CLSC network models for tire industry.

2.1 Review of Conventional CLSC Network Models

We have proposed six characteristics for designing CLSC network model. Among these characteristics, the treatment method is divided into three types: activities in terms of remanufacturing, recycling, and waste disposal. Remanufacturing is defined as the used products that can are repaired or refurbished to be reused as secondary-hand goods. Recycling is defined as the used products that can are disassembled or resolved to be recycled as raw materials or parts. The transportation routes/types consider three routes in terms of normal delivery, direct delivery, and direct shipment. Limitation of treatment capacity is defined as the treatment of facility limited at each stage. The ratio regulation is divided into two parts: regulating ratios of transportation routes/types and ratios of amount of remanufacturing products, recycling materials, and waste disposal. The ratio regulation of transportation routes/types refers to the amount of transportation regulated in terms of normal delivery, direct delivery, and direct shipment. The amount of ratio regulation of remanufacturing products, recycling materials, and waste disposal is defined as the amount of remanufacturing products, recycling materials, and waste disposal that can be regulated according to demand, ability to disassemble technology, and so on. Technology coefficients consider two meanings. The first one refers to the disassembling activities for used products, those with good quality are reused as remanufacturable products, those with normal quality are reused as recyclable materials. The second one refers to the disassembling activities for remanufactured products, those with high quality are reused as new products, and sent back to the FL, those with normal quality are sold as used products. The location and allocation of facility are to determine which facility should be opened at each stage and the amount of transportation at the opened facility.

Previous literatures prefer to consider those characteristics in various views. Figure 2-1 shows a CLSC network model by Krikke et al. (2003). In this study, they developed a CLSC network model considering the limitation of treatment capacity. Simultaneously, various treatment methods of used products are considered. The treatment methods consist of modularity, re-manufacturability and recyclability. Using various treatment methods, both the structure of a product and the logistic network can be designed. However, they did not consider the technological effect. In addition, although various treatment methods are considered, they only used one type of transportation routes/types: normal delivery. The objective is to minimize total cost, but they did not consider relating the ratio of treatment method and transportation routes/types. They also did not pay attention to the optimization of location and allocation problems.

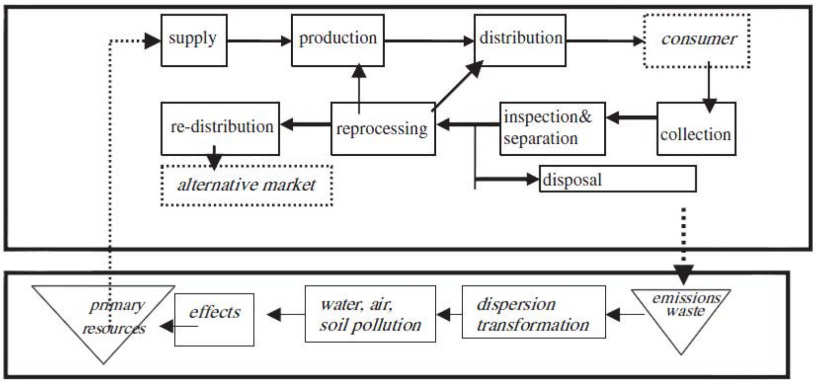


Figure 2-1. CLSC network model by Krikke et al. (2003)

Figure 2-2. shows a CLSC network model considering various transportation routes/types by Özceylan et al. (2017). They represents a CLSC network model based on a case study of the automotive industry in Turkey. The concept of used vehicles and used components are considered and the used components involve tires, batteries, fluids, and other materials that can be reused to produce new components. In this study, various transportation routes/types are mentioned. The user cluster showed in Figure 2-2 receives used vehicle and used components from dismantlers, and can consider direct shipment. Simultaneously, used components are sent to recyclers through normal delivery. The design of the CLSC network model focus on variability in treatment methods of used products and the flexibility of transportation routes/types. However, the limitation of treatment capacity, ratio regulations, technological coefficients, and location and allocation problems have been ignored.

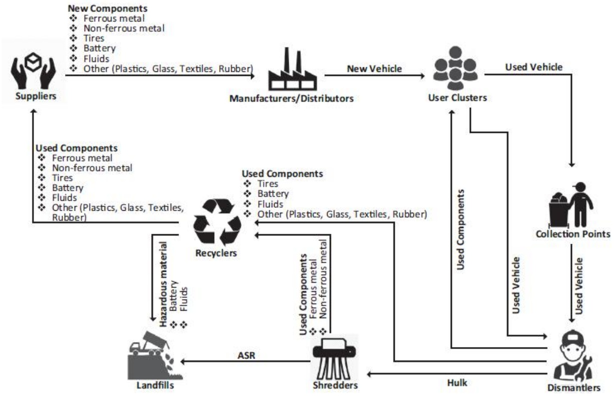


Figure 2-2. CLSC network model by Özceylan et al. (2017)

Figure 2-3 displays a framework of the green supply chain logistics in solving the problem of global warming by Wang et al. (2010). In this study, for the FL, the suppliers, manufactures, DCs, and customers are considered. For the RL, the used products are sent back to the DCs from the customers, and are then sent to dismantlers. At Dismantlers, the used products are dismantled for reuse or placed in landfill. The reused products are sent back to manufactures. The FL and the RL are integrated and subjected to the limitation of treatment capacity. Moreover, the location and allocation decision is optimized by solving the problem of minimization total costs. However, they did not consider various transportation routes/types, ratio regulation problem, and technological impact.

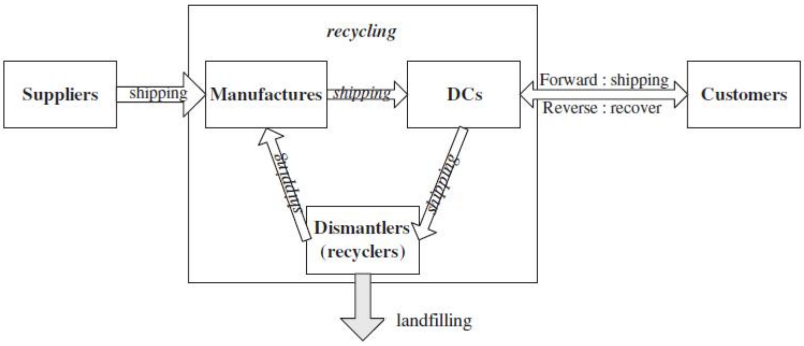


Figure 2-3. Framework of green supply chain logistics by Wang et al. (2010)

Figure 2-4 shows the structure of the CLSC network model by Özceylan et al. (2013). In the FL, the raw material suppliers, plants, retailers, and customers are considered. In the RL, collection centers, disassembly centers, refurbishing centers are considered. They proposed a mixed integer programming CLSC network model that considers multi-products and explored the effect of ratio regulation on total performance and total costs. They find that high collection rates and treatment capacities can reduce the total costs and improve performance. However, in this study, various transportation routes/types, technological coefficient, location and allocation problem have not been considered.

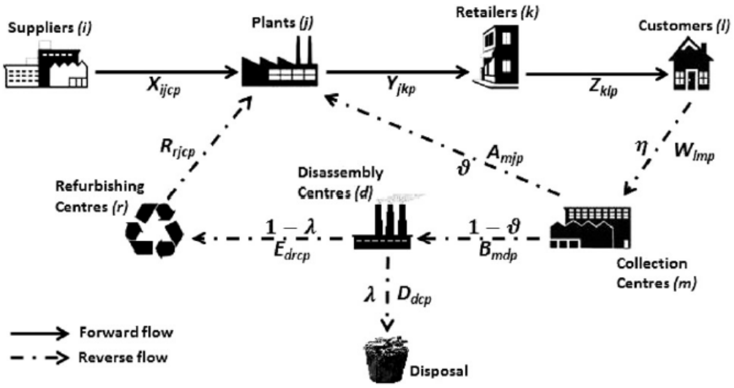


Figure 2-4. Structure of the CLSC network model by Özceylan et al. (2013)

Figure 2-5 shows a flexible multistage logistics network model by Jamrus et al. (2003). The structure of this network model consists of plants, distribution centers, retailers, and customers. In this study, in order to solve the complex factors - production distribution problems, an approach which integrates a discrete particles swarm optimization and an extended priority based-encoding/ decoding (nEP-HGA) is proposed. They focus on various transportation routes/types for direct delivery that transports from distribution center to customer and compare the performance of a proposed nEP-HGA approach. However, they did not consider the design of CLSC network model.

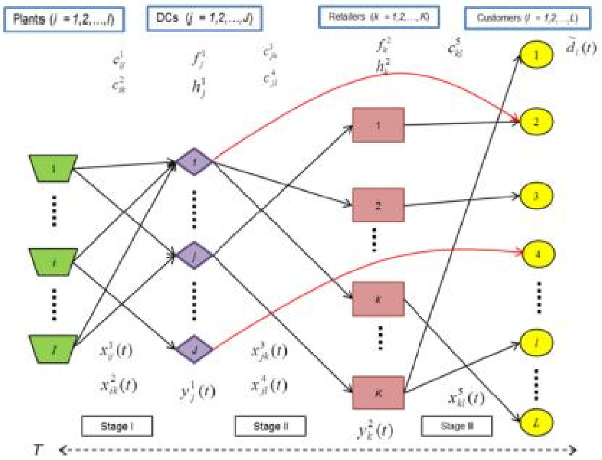


Figure 2-5. Flexible multistage logistics network model by Jamrus et al. (2003)

As mentioned above, most literatures are related to the characteristics of treatment methods, transportation routes/types, limitation of treatment capacities, ratio regulations, technological coefficients, location and allocation decisions. Among these literatures, researchers focus on these six characteristics differently, that is, some literatures are concerned about treatment method, technological effects, whereas others are concerned about transportation treatment method, transportation routes/types problems or limitation of treatment capacity. However, none of the literature involved has placed all the characteristics together. The conventional studies considering six important characteristics for designing CLSC network model are summarized in Table 2-1.

Table 2-1. A review of relevant studies.

	Treatment Methods			Transportation Routes/ Types			Limitation of treatment capacities	Ratio Regulations	Technological Coefficients	Location & Allocation Decisions
	Remanufacturing	Recycling	Waste Disposal	Normal Delivery	Direct Delivery	Direct Shipment				
[1]	■	■		■						■
[2]		■	■	■						
[3]	■	■	■	■			■		■	
[4]		■		■						■
[5]	■			■			■			■
[6]	■			■						■
[7]	■		■	■			■			■
[8]		■	■	■			■			■
[9]	■	■		■						
[10]	■		■	■			■			
[11]		■	■	■			■			
[12]	■		■	■						
[13]		■	■	■			■			
[14]		■	■	■			■			■
[15]	■	■	■	■			■	■		
[16]	■	■	■	■			■			■
[17]	■		■	■			■			■
[18]	■	■	■	■			■			■
[19]	■	■	■	■			■			■
[20]	■	■	■	■			■			■
[21]	■			■						■
[22]	■	■	■	■						
[23]	■		■	■		■				
[24]	■	■	■	■			■			■
[25]	■	■	■	■		■				
[26]	■	■					■	■		■
my research	■	■	■	■	■	■	■	■	■	■

Sources: [1] Jayaraman et al. (1999), [2] Fleischmann et al., (2001), [3] Krikke et al. (2003), [4] Realff et al. (2004), [5] Üser et al. (2007), [6] Min et al. (2008), [7] Pishvaee et al. (2009), [8] Wang et al. (2010), [9] Kannan et al. (2010), [10] Pishvaee et al. (2011), [11] Sasikumar et al. (2011), [12] Hasani et al. (2012), [13] Amin et al. (2012), [14] Amin et al. (2013), [15] Özceylan et al. (2013), [16] Zeballos et al. (2014), [17] Ramezani et al. (2014), [18] Özceylan et al. (2014), [19] Jindal et al. (2014), [20] Soleimani et al. (2015), [21] Hasani et al. (2015), [22] Subulan et al. (2015), [23] Keyvanshokooh et al. (2016), [24] Chen et al. (2017), [25] Özceylan et al. (2017), [26] Amin et al. (2017).

2.2 CLSC Network Model in Tire Industry

Designing the CLSC network model for tire industry is necessary, since the demand of worldwide tires is expected to rise 4.3% one year, it will reach 2.9 billion units in 2017, and the waste tire disposal has reached nearly 1 billion units (World Tires, 2014).

The utility value of used tires is high, but it also produces a lot of waste pollution. In the UK, about 37 million tires are replaced each year. 30% were remanufactured, 27% were recycled as fuel, and 16% were reused in whole or as granulated particles, 27% were disposal in stockpile or landfill. Tire disposal is a worldwide problem along with growing vehicle fleets. Because tire disposal is returning to the surface and breaking layer covers, it damages the land settlement in the long term. So disposal of tires in landfills is environmentally harmful (ANIP, 2012).

Sustainable use of energy resources is necessary for natural resources management of plant's reduction in environmental pollution. Thus, how a company optimizes its tire supply chain is needed to be investigated through a reviewing of previous literature.

Figure 2-6 shows the CLSC network model for tire remanufacturing by Amin et al. (2017). In the FL, suppliers, manufacturer, retailers, and customers are considered. In the RL, recycling center, and drop-odd depots are considered. The remanufacturing tire of the CLSC network model is considered. The objective is to maximize total profit, and researchers focused the effect of uncertain, cash flow, and the location and allocation problem under the situation of limitation of treatment capacity. However, they did not focus on the CLSC structure design, so the effect of treatment method, transportation routes/types, ratio regulation, technological coefficient have been ignored.

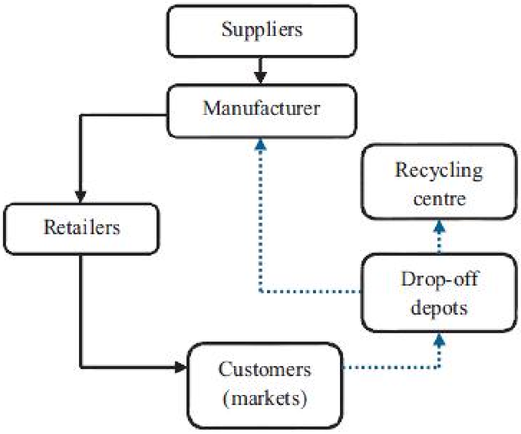


Figure 2-6. CLSC network model for tire remanufacturing by Amin et al. (2017).

Figure 2-7 shows a CLSC network model for the tire industry integrating FL and RL. In the FL, manufacturer, DC, aggregate delivery point are considered. In the RL, collection center, retreading center, and recycle center are considered. In this study, the treatment method of used tires are divided into the activities of remanufacturing and recycling. At the collection center, the re-manufacturable tires are sent to a retreading center and the remanufactured tires are sent back to DC for sale. The recycling tires are sent back to a recycling center to be reused as raw material.

The limitation of treatment capacity in DC, aggregate delivery point, retreading center and recycling center are considered. Simultaneously, the problem of determining the facility number and location at each stage has been solved. However, various transportation routes/types, ratio regulations, technological coefficient have not been considered.

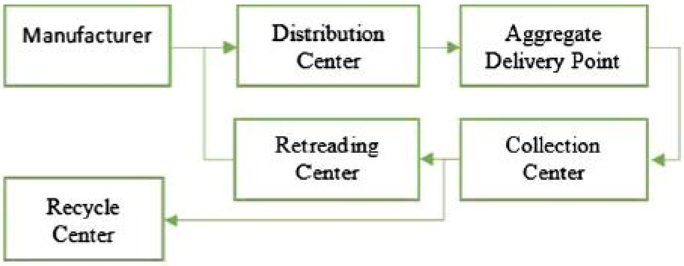


Figure 2-7. CLSC network model by Pedram et al. (2017).

Figure 2-8 shows the reverse logistics network for truck tire recovery. The used truck tires are returned from customers. The ICP, the CRC, the remanufacturing plants, the third-party recyclers, and the secondary markets are considered. At remanufacturing plants, the used truck tires are divided into two levels according to their qualities. High quality used tires are sent to third-party recyclers to be sold as new tires. Poor quality used tires are sent to secondary markets to be sold with discount. In these processes, the limitation of treatment capacity at each stage is considered, and the facility number and location at each stage are determined. However, in this study, various transportation routes/types, and ratio regulations have been ignored.

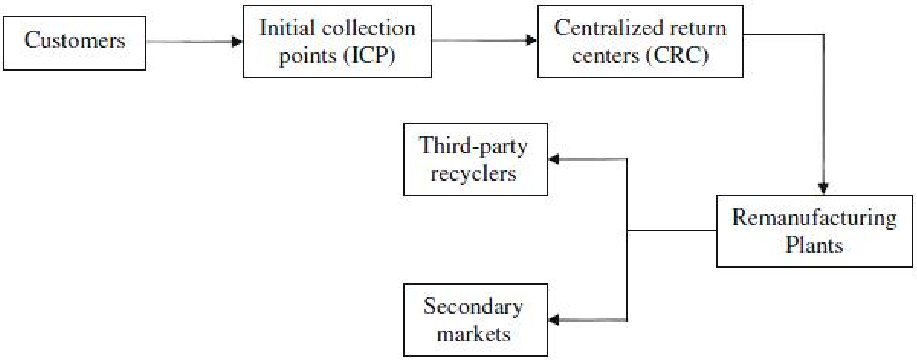


Figure 2-8. Reverse logistics network for tire recovery by Sakikumar et al. (2010)

Previous literatures mentioned above mostly concerned itself with the area of uncertainty such as customer demand, quantity, quality, and return timing. Researchers tried to maximize profit or minimize cost by controlling the uncertainty.

Actually, by designing a CLSC network model, and applying appropriate strategies, we can achieve the efficient reuse of the used tires by considering the six characteristics mentioned above. We will introduce the situations of the tire industry in Korea and then construct the CLSC network model for tire industry in Korea.

According to Korea Tire Manufacturers Association (KOTMA, 2017), the production amount of new tires are displayed in Table 2-2, and is 96,639 million units in 2016. It is 48.990 million units in 2017 from January to June with a slight growth of 1.8%.

Table 2-2. Production amount of new tires in Korea in the 2013-2017.

(Thou. units)

	2013	2014	2015	2016	2016 (Jan.-Jun.)	2017 (Jan.-Jun.)	↑↓ %
Passenger Car Tires	77,525	78,606	76,956	76,782	38,430	39,059	1.6
Light Truck Tires	15,079	15,459	14,555	14,882	7,232	7,431	2.8
Truck & Bus Tires	5,147	5,034	4,264	4,432	2,168	2,201	1.5
Other	680	616	553	543	289	299	3.5
Total	98,431	99,715	96,328	96,639	48,119	48,990	1.8

New tires are produced and sold every year. The total amount of production every year can be known by Table 2-2. The process of the FL for the Korean tire industry is displayed in Figure 2-9. The FL of the Korean tire industry starts from the Tire manufacturer (TM). New tires are produced at the TM. All new tires are then sent to a DC, and then sent to the tire dealer (TD). Finally, new tires are sold at tire end-user group (EU).

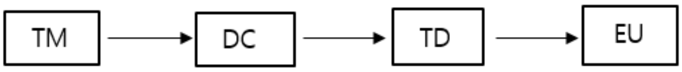


Figure 2-9. The process of the FL for Korean tire industry

The amount of used tires in Korea from 2012 to 2015 is showed in Table 2-3. The total amount of used tires are 351,000 tons in 2015, The amount of used tires produced by replacement is 284,557 tons, and account for 81.1% of the total. The amount of used tires produced by scrap is 66,443, and account for 18.9% of the total.

Table 2-3. Amount of used tires in Korea from 2012 to 2015

(units : ton)

		2012	2013	2014	2015
Replaced	Weight	244,013	258,862	291,185	284,557
	Component ratio	79.8%	80.7%	82.4%	81.1%
Scrapped	Weight	61,864	62,027	61,985	66,443
	Component ratio	20.2%	19.3%	17.6%	18.9%
Sum	Weight	305,877	320,889	353,170	351,000
	Component ratio	100%	100%	100%	100%

The recycling states of used tires by treatment path in Korea in the 2013 are shown in Table 2-4. Used tire are collected, and then remanufactured to be reused as a second-hand tire or disassembled into reused materials. The amount of recycled rubber powder is 53,656 tons, which accounts for 16.7% of the total amount. The amount of recycled rope is 7,592 tons, and accounts for 2.4% of the total amount. There are 14,947 unconfirmed tons of tires, and we must consider it as a recycling loss in the recycling process. Thus, the total amount of remanufactured and recycling tires is 30,5942(=320,889-14,947) tons.

Table 2-4. The recycling states of used tires by treatment path in Korea in the 2013

(units : ton)

	Weight	Proportion
Rubber Powder	53,656	16.7%
Rope	7,592	2.4%
Cement Kiln	108,540	33.8%
TDF	62,274	19.4%
Incineration	410	0.13%
Material Export	3,956	1.23%
Secondary Tire for Domestic	30,002	9.34%
Secondary Tire for Export	39,512	12.3%
Unconfirmed	14,947	4.7%
Sum	320,889	100%

According to Table 2-4, we can represent the process of remanufacturing and recycling tires for the Korean tire industry as shown in Figure 2-10. We assume that there are nine stages in the RL for used tires. They are collection centers (CC), remanufacturing centers (RM), recycling centers (RY), domestic product secondary market companies (DP), export product secondary market companies (EP), domestic material secondary market companies (DM), export material secondary market companies (EM), and incineration centers (IN). In the RL, the used tires are collected at the CC, and are divided into remanufacturing and recycling tires. The remanufactured tires are resold to the DP and the EP. The recycling tires are recycled into raw materials. The recycled materials are also resold to the DM and the EM.

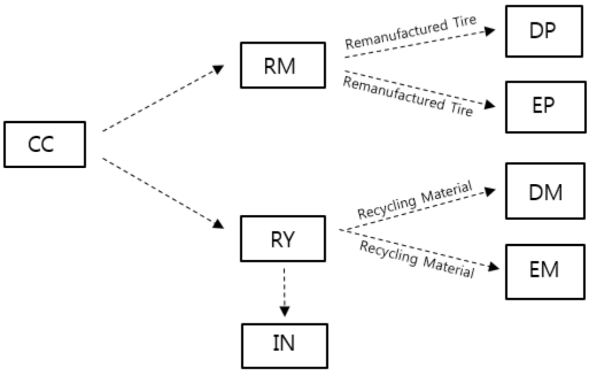


Figure 2-10. The process of remanufacturing and recycling for Korean tire industry

III. Proposed CLSC Network Model

We have discussed the Korean tire industry situation of production, waste disposal, and reuse in the previous section. In section 3, we will represent the conventional structure of the CLSC network model in the Korean tire industry and called it M1. We will also propose a new CLSC network model to offset the inadequacies of the M1 and call it M2. We will compare the M1 with the M2 and find which network model is more efficient, and what strategies will affect the performance of the CLSC network model by considering the treatment method, transportation routes/types, capacity limitations, ratio regulations, technological coefficients, and location and allocation decisions.

3.1 Conventional CLSC Network Model for Tire Industry in Korea

Figure 3-1 shows the structure of the M1, broken down into twelve parts. The stages of the TM, TD, and EU are considered in the FL. The stages of the CC, RM, RY, DP, EP, DM, EM, and IN are taken into account in the RL.

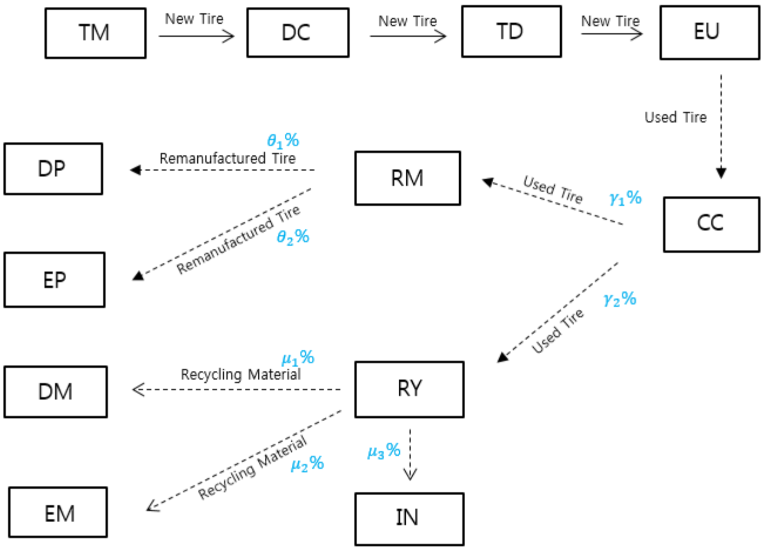


Figure 3-1. Structure of the M1

The movement of the FL starts from the TM. New tires are produced at the TM. New tires are sent to the DC, and then sent to the TD. Finally, all new tires are sold at the EU. The RL starts when a used tire has been returned from an EU to the CC. All used tires are divided into remanufacturable tires and recyclable tires. The remanufactured tires are sent to the RM with a ratio of γ_1%, the recycled tires are sent to the RY with a ratio of γ_2%. Within the RM, the remanufactured tires are sent to the DP with a ratio of θ_1% and the EP with a ratio of θ_2%, respectively. Within the RY, the recycling materials are sent back to the DM with a ratio of μ_1%, the EM with a ratio of μ_2%, and the IN with a ratio of μ_3%, respectively. According to real data of the Korea Tire Manufacturers Association (KOTMA, 2017), 85% of used tires are collected at a CC. Therefore, the amount of used tires transported from the EU is 305,942 tons at the CC. The amount of new tires transported from the TM is 359,931 tons. The ratio of transportation from the CC to the RM is 22.7% (γ_1), the ratio of transportation from the CC to the RY is 77.3% (γ_2). The ratio of transportation from the RM to the DP is 43.2% (θ_1), to the EP is 56.8% (θ_2). The ratio of transportation from the RC to the DM is 98.1% (μ_1), to the EM is 1.7% (μ_2), and to the IN is 0.2% (μ_3).

Six important characteristics are applied to the M1. The treatment methods is divided into remanufacturing, recycling, and incineration. Only single type transportation routes/types of normal delivery is considered when tires are transported in the FL and the RL. Due to limitations of the treatment capacity, we assume that the amount of new tires is fixed at 359,931 tons at the TM. The ratio regulation and technological coefficient should be considered at the stages of the CC, the RM, and the RY. The ratio of used tires is regulated at the CC according to the quality of the used tires.

We assume that the quality of used tires divided into re-manufacturable tires and recyclable tires which is determined by disassembled technology. Simultaneously, we assume that the technology is determined by the quality of used tires at the CC. The uses tires are disassembled into good quality tires and normal quality tires. The used tires with good quality are sent to the RM as remanufacturable tires. Those with normal quality are sent to the RY as recyclable tires. Therefore, the ratio of remanufactured tires are regulated according to both the qualities of the remanufactured tires at the RM. As a same meaning, the ratio of recycled materials are regulated according to both the qualities of recyclable tires at the RY. Finally, through careful application of the characteristics, the location of the stages of the TM, the DC, the TD, the CC, the RM, the RY, and the IN to be opened can be determined.

3.2 Proposed CLSC Network Model for Tire Industry in Korea

Figure 3-2 shows the structure of the M2. The same stages as shown in M1 are also considered in the M2. However, in the M2, the transportation routes/types in terms of normal delivery, direct delivery and direct shipment are simultaneously considered.

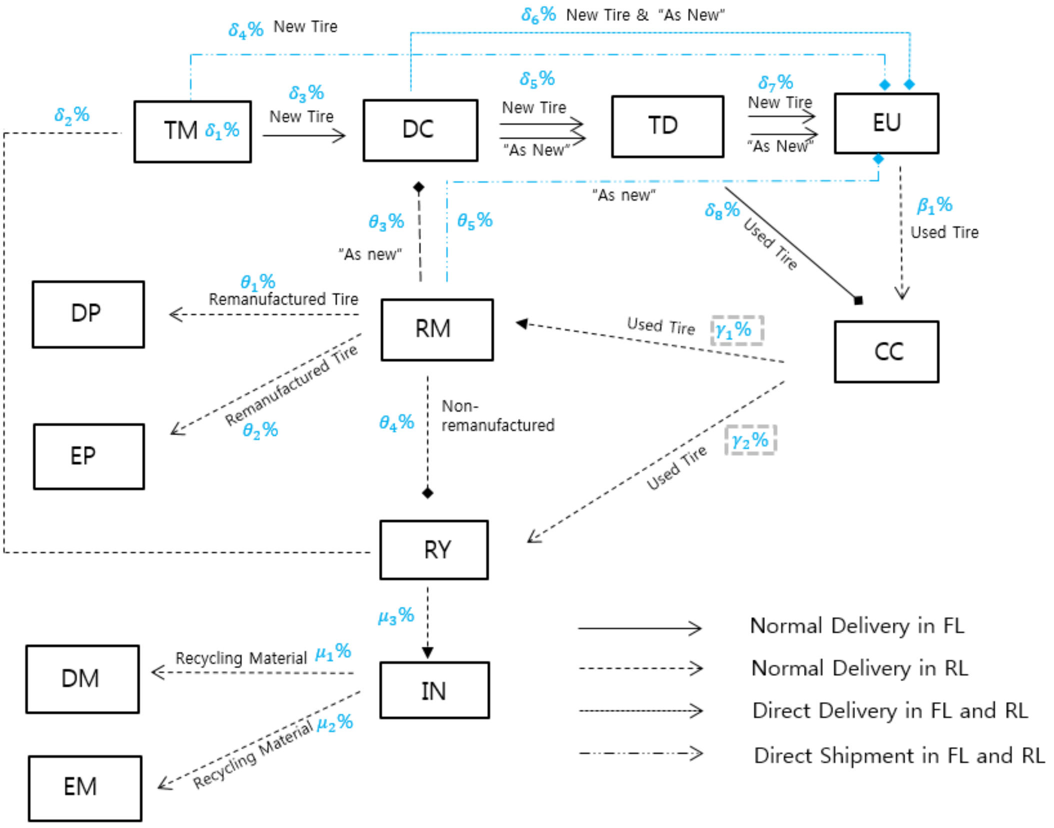


Figure 3-2. Structure of the M2

The performance of the M1 and the M2 are compared under the same situations. We assume that the amount of new tires is fixed at the TM as mentioned previously in the M1. Therefore, the amount of transportation from the TM to the DC is also 359,931 tons in the M2. The new tires are transported through various routes in terms of normal delivery, direct delivery, and delivery shipment. For example, the tires of 359,931 tons are transported from the TM to the DC using the normal delivery of transportation routes/types in the M1. But in the M2, the amount of transportation is divided into δ_3% and δ_4%, the amount of transportation with δ_3% is sent to the DC using normal delivery, and the amount of transportation with δ_4% is sent to the EU directly using direct shipment.

The movement of the FL in the M2 starts from the TM. The amount of transportation with δ_3% is sent to the DC using normal delivery, and that with δ_4% is sent to the EU using direct shipment. Within the DC, the amount of transportation with δ_5% is sent to the TD using normal delivery, and that with δ_6% is sent to the EU using direct shipment. Within the TD, the amount of transportation with δ_7% is send to the EU, and that with δ_8% is send to the CC.

In the RL, the used tires are returned from the EU and the TD, and they are sent to the RM with γ_1% and the RY with γ_2%. Within the RM, the used tires are divided into five parts: the amount of remanufactured tires is sent to the DP with θ_1% , to the EP with θ_2%, to the DC with θ_3%, to the RY which are non-remanufactured tires with θ_4%, and to the EU with θ_5% using direct shipment. Within the RY, the used tired are recycled into material, and the amount of recycled materials is sent to the DM with μ_1%, to the EM with μ_2%, to the IN with μ_3%, and to the TM with δ_2%.

We assume that the distribution ratio of the RM and the RY in the M2 is in approximation to the M1. For example, in the M1, the ratio of transportation from the RM to the DP is 43.2% (θ_1), to the EP is 56.8% (θ_2). But in the M2, the amount of used tires is divided into five parts, so we assume that the ratio of transportation from the RM to the DP is 40.0% (θ_1), to the EP is 50.0% (θ_2). The remaining 10% is divided into three parts: first part is sent to the DC, second part is sent to the EU, and last part is sent to the RY.

So in the M2, the EU receive tires from the TM, DC, and the RM stages. The transportation from the TM and the RM to the EU uses direct shipment, and the transportation from the DC to the EU uses direct delivery.

Six importance characteristics are applied into the M2. The application of treatment method and limitation of treatment capacity is the same with the M1. Except for the transportation routes/types of normal delivery, direct delivery and shipment are attached into the M2 when the tires are transported in the FL and the RL. Three transportation routes/types of normal delivery and direct delivery and shipment are attached: the first one is transported from the TM to the EU, the second one is transported from the DC to the EU, and the third one is transported from the RM to the EU. So the application of ratio regulation is divided into two parts. One part is the application of ratio regulation to transportation routes/types, and the other part is the application of ratio regulation to treatment method. The ratio of normal delivery and direct delivery and shipment is regulated at stages of the TM, DC, and RM.

Simultaneously, the ratio of treatment methods is also regulated variously. The ratio regulation is the same as the M1 at the CC. At the TD, the used tires that have passed their warranty period are attached into the M2. So the ratio regulation of new tires and used tires need to be considered. The ratio regulation is divided into five parts at the RM. There are three routes attached to the M2 which are transported from the RM to the DC, to the EU, and to the RY. Although the tires are only transported from the RM to the DP, and the EP in the M1, the ratio regulation is divided into four parts at the RY. There is one route attached to the M2 which is transported from the RY to the TM, except for the materials transported from the RY to the DM, and the EM. In addition, the application of technological coefficients is the same with the M1. Finally, through the application of the importance characteristics into the M2, the location of the stages of the TM, DC, TD, CC, RM, RY, and IN to be opened can be determined.

IV. Mathematical Formulation

Before presenting the mathematical formulation for the M1 and M2, some assumptions are considered as following:

- Only single product is considered.
- The number of facility at each stage is already known.
- The numbers of the EU, DP, EP, DM, and EM are fixed and already known.
- Only one facility is opened at each stage of the TM, DC, TD, CC, RM, RY, and IN.
- The fixed costs of the facilities opened at each stage are different and already known.
- The unit handling costs of the facilities considered at each stage are different and already known.
- The unit transportation costs of the facilities considered at each stage are different and already known.
- The unit transportation costs for normal delivery, direct shipment and delivery at same stage are different and already known.
- The return rate of used tires is 80% from the EU to the CC.
- The discount rate of used tires and recycling materials is 60% of the new tires's price.
- The revenues are divided into among the six stages of the TM, EU, DP, EP, DM, and EM.
- The proposed CLSC network model is considered under steady state situation.

Index set, parameters, and decision variables are defined as follows:

Index Set

a: index of new and "as new" tire types

b: index of used tire types

h: index of tire manufacturer

i: index of distribution center

j: index of tire dealer

k: index of collection center

l: index of remanufacturing center

m: index of recycling center

n: index of secondary market for domestic product

o: index of secondary market for export product

v: index of secondary market for domestic material

p: index of secondary market for export material

q: index of incineration center

r: index of end user group

s: index of type of recycled material

t: index of type of remanufactured tire

Parameters

FC_h^1: fixed setup cost at tire manufacturer h

FC_i^2: fixed setup cost at distribution center i

FC_j^3: fixed setup cost at tire dealer j

FC_k^4 : fixed setup cost at collection center k

FC_l^5 : fixed setup cost at re-manufacturer center l

FC_m^6 : fixed setup cost at recycling center m

FC_q^7 : fixed setup cost at incineration center q

PT_{ah} : unit production cost at tire manufacturer h of tire type a

HT_{ah} : unit handling cost at tire manufacturer h of tire type a

HD_{ai} : unit handling cost at distribution center i of tire type a

HL_{aj} : unit handling cost at tire dealer j of tire type a

HC_{bk} : unit handling cost at collection center k of tire type b

RM_{bl}: unit remanufacturing cost at remanufacturing center l of used tire b

RY_{sm} : unit recycling cost at recycling center m of recycling material s

CO_{bk} : unit collection cost at collection center k of tire type b

IE_l^1 : investment cost for remanufacturable tire at remanufacturing center l

IE_m^2 : investment cost for recycable tire at recycling center m

IN_q: unit incineration cost at incineration center q

TM_{hi}^1 : unit transportation cost from tire manufacturer h to distribution center i

TM_{hr}^2 : unit transportation cost from tire manufacturer h to end user group r

TD_{ij}^{1}: unit transportation cost from distribution center i to tire dealer j

TD_{ir}^{2}: unit transportation cost from distribution center i to end user r

TE_{jr}^{1}: unit transportation cost from tire dealer j to end user r

TE_{jk}^{2}: unit transportation cost from tire dealer j to collection center k

TU_{rk}^{1}: unit transportation cost from end user r to collection center k

TC_{kl}^{1}: unit transportation cost from collection center k to remanufacture center l

TC_{km}^{2}: unit transportation cost from collection center k to recycling center m

TR_{ln}^{1}: unit transportation cost from remanufacturing center l to secondary market for domestic product n

TR_{lo}^{2}: unit transportation cost from remanufacturing center l to secondary market for export product o

TR_{li}^{3}: unit transportation cost from remanufacturing center l to distribution center i

TR_{lr}^{4}: unit transportation cost from remanufacturing center l to end user group r

TR_{lm}^{5}: unit transportation cost from remanufacturing center l to recycling center m

TY_{mv}^{1}: unit transportation cost from recycling center m to secondary market for domestic material v

TY_{mp}^{2}: unit transportation cost from recycling center m to secondary market for export material p

TY_{mh}^{3}: unit transportation cost from recycling center m to tire manufacturer h

TY_{mh}^{4}: unit transportation cost from recycling center m to incineration h

VN_a : unit selling price of new tire a

VM_s: unit selling price of recycled material s

α_1 : technology level of remanufacturing activities at remanufacturing center

α_2: technology level of recycling activities at recycling center

δ_1 : ratio of new tire using new material at tire manufacturer

δ_2 : ratio of new tire using recycled material at tire manufacturer

δ_3 : ratio of new tire from tire manufacturer to distribution center

δ_4 : ratio of new tire from tire manufacturer sent to end user group

δ_5 : ratio of new tire and “as new” tire from distribution center to tire dealer

δ_6 : ratio of new tire and “as new” tire from distribution center to end user group

δ_7 : ratio of new tire and “as new” tire from tire dealer to end user group

δ_8 : ratio of used tire from tire dealer to collection center

β_1 : return rate from end user to collection center

ω_1 : discount rate of used tire reselling at secondary market for domestic or export product

ω_2 : discount rate of used tire reselling from tire dealer to collection center

γ_1 : ratio of used tire from collection center to remanufacturing center

γ_2 : ratio of used tire from collection center to recycling center

θ_1 : ratio of remanufactured tire for from remanufacturing center to secondary market for domestic product

θ_2 : ratio of remanufactured tire from remanufacturing center to secondary market for export product

θ_3 : ratio of remanufactured tire “as new” from remanufacturing center to distribution center

θ_4 : ratio of non-remanufactured tire from re-manufacturer center to recycling center

θ_5 : ratio of remanufactured tire from remanufacturing center to end user group

μ_1 : ratio of recycled material from recycling center to secondary market for domestic material

μ_2 : ratio of recycled material from recycling center to secondary market for export material

μ_3 : ratio of non-recycled material from recycling center to incineration center

QN: quantity of new tire at tire manufacturer

QN_{ahi}^{1}: quantity of new tire a transported from tire manufacturer h to distribution center i

QN_{aij}^{2}: quantity of new tire a transported from distribution center i to tire dealer j

QN_{ajr}^{3}: quantity of new tire a transported from tire dealer j to end user group r

QN_{brk}^{4}: quantity of used tire b collected from end user group r to collection center k

QN_{ahr}^{5}: quantity of used tire a transported from tire manufacturer h to end user group r

QN_{air}^{6}: quantity of used tire a transported from distribution center i to end user group r

QN^{7}_{bjk}: quantity of used tire b collected from tire dealer j to collection center k

QM^{1}_{bkl}: quantity of used tire b transported from collection center k to remanufacturing center l

QM^{2}_{bln}: quantity of used tire b transported from remanufacturing center l to secondary market for domestic product n

QM^{3}_{blo}: quantity of used tire b transported from remanufacturing center l to secondary market for expert product o

QM^{4}_{bli}: quantity of used tire b transported from remanufacturing center l to distribution center i

QM^{5}_{blm}: quantity of used tire b transported from remanufacturing center l to recycling center m

QM^{6}_{blr}: quantity of used tire b transported from remanufacturing center l to end user group r

QY^{1}_{bkm}: quantity of used tire b transported from collection center k to recycling center m

QY^{2}_{smv}: quantity of used tire s transported from recycling center m to secondary market for domestic material v

QY^{3}_{smp}: quantity of recycling material s transported from recycling center m to secondary market for export material p

QY^{4}_{smq}: quantity of recycling material s transported from recycling center m to incineration center q

QY^{5}_{smh}: quantity of recycling material s transported from recycling center m to tire manufacturer h

Decision Variables

Ca^{1}_{h}: treatment capacity at tire manufacturer h

Ca^{2}_{i}: treatment capacity at distribution center i

Ca^{3}_{j}: treatment capacity at tire dealer j

Ca^{4}_{r}: treatment capacity at end user r

Ca^{5}_{k}: treatment capacity at collection center k

Ca^{6}_{l}: treatment capacity at remanufacturing center l

Ca_m^7: treatment capacity at recycling center *m*

Ca_n^8: treatment capacity at secondary market for domestic product *n*

Ca_o^9: treatment capacity at secondary market for export product *o*

Ca_p^{10}: treatment capacity at secondary market for export material *p*

Ca_q^{11}: treatment capacity at incineration center *q*

Ca_v^{12}: treatment capacity at secondary market for domestic material *v*

y_h^1: takes the value of 1 if tire manufacturer *h* is opened and 0 otherwise

y_i^2: takes the value of 1 if distribution center *i* is opened and 0 otherwise

y_j^3: takes the value of 1 if tire dealer *j* is opened and 0 otherwise

y_k^4: takes the value of 1 if collection center *k* is opened and 0 otherwise

y_l^5: takes the value of 1 if remanufacturing center *l* is opened and 0 otherwise

y_m^6: takes the value of 1 if recycling center *m* is opened and 0 otherwise

y_q^7: takes the value of 1 if incineration center *m* is opened and 0 otherwise

Under the assumptions mentioned above, the objective functions are to maximize total revenues of the M1 (TR_M1) and the M2 (TR_M2) and to minimize the total costs of the M1 (TC_M1) and M2 (TC_M2). Total revenues of the M1 and the M2 are composed of sales of new tires, remanufactured tires, and recycling materials. Total costs of the M1 and the M2 are composed of total fixed costs (TFC), total production costs (TPC), total handling costs (THC), total collection costs (TCO), investment costs for remanufacturable and recyclable tire (IEC), incineration costs (INC), and total transportation costs (TTC) under satisfying various constraints. The suggested mathematical formulations for representing the M1 and the M2 are as follows:

$$\text{Maximize } TR\_M1 = TRM1\_1 + TRM1\_2 + TRM1\_3 + TRM1\_4 + TRM1\_5 \qquad (1)$$

$$\begin{aligned}\text{Minimize } TC\_M1 = {} & TFC\_M1 + TPC\_M1 + THC\_M1 + TCO\_M1 + IEC\_M1 \\ & + INC\_M1 + TTC\_M1 \qquad (2)\end{aligned}$$

$$TRM1\_1 = \sum_a \sum_j \sum_r QN_{ajr}^3 * VN_a \qquad (3)$$

$$TRM1\_2 = \sum_b \sum_l \sum_n * QM_{bln}^2 VN_a * \omega_1 \qquad (4)$$

$$TRM1\_3 = \sum_b \sum_l \sum_o QM_{blo}^{3} * VN_a * \omega_1 \tag{5}$$

$$TRM1\_4 = \sum_s \sum_m \sum_v QY_{smv}^{2} * VM_s \tag{6}$$

$$TRM1\_5 = \sum_s \sum_m \sum_p QY_{smp}^{3} * VM_s \tag{7}$$

$$\begin{aligned} TFC\_M1 = {} & \sum_h FC_h^1 * y_h^1 + \sum_i FC_i^2 * y_i^2 + \\ & \sum_j FC_j^3 * y_j^3 + \sum_k FC_k^4 * y_k^4 + \\ & \sum_l FC_l^5 * y_l^5 + \sum_m FC_m^6 * y_m^6 + \\ & \sum_q FC_q^7 * y_q^7 \end{aligned} \tag{8}$$

$$TPC\_M1 = \sum_a \sum_h PT_{ah} * QN * y_h^1 * Ca_h^1 \tag{9}$$

$$\begin{aligned} THC\_M1 = {} & \sum_a \sum_h HT_{ah} * QN * y_h^1 * Ca_h^1 + \\ & \sum_a \sum_i HD_{ai} * QN * y_i^2 * Ca_i^2 + \\ & \sum_a \sum_j HL_{aj} * QN * y_j^3 * Ca_j^3 + \\ & \sum_b \sum_k HC_{bk} * QN * \beta_1 * y_k^4 * Ca_k^5 + \\ & \sum_b \sum_k \sum_l RM_{bl} * QM_{bkl}^1 * y_l^5 * Ca_l^6 + \\ & \sum_s \sum_k \sum_m RY_{sm} * QY_{skm}^1 * y_m^6 * Ca_m^7 \end{aligned} \tag{10}$$

$$TCO\_M1 = \sum_b \sum_k CO_{bk} * QN * \beta_1 * y_k^4 * Ca_k^5 \tag{11}$$

$$IEC\_M1 = \sum_l IE_l^1 * \alpha_1 * y_l^5 * Ca_l^6 + \sum_m IE_m^2 * \alpha_2 * y_m^6 * Ca_m^7 \tag{12}$$

$$INC\_M1 = \sum_s \sum_m \sum_q IN_q * QY_{smq}^4 * \mu_3 * Ca_q^{11} * y_q^7 \tag{13}$$

$$\begin{aligned} TTC\_M1 = {} & \sum_a \sum_h \sum_i TM_{hi}^1 * QN_{ahi}^1 + \sum_a \sum_i \sum_j TD_{ij}^1 * QN_{aij}^2 + \\ & \sum_a \sum_j \sum_r TE_{jr}^1 * QN_{ajr}^3 + \sum_b \sum_k \sum_l TC_{kl}^1 * QM_{bkl}^1 + \\ & \sum_b \sum_k \sum_m TC_{km}^2 * QY_{bkm}^1 + \sum_b \sum_l \sum_n TR_{\ln}^1 * QM_{bln}^2 + \\ & \sum_b \sum_l \sum_o TR_{lo}^2 * QM_{blo}^3 + \sum_s \sum_m \sum_v TY_{mv}^1 * QY_{smv}^2 + \\ & \sum_s \sum_m \sum_p TY_{mp}^2 * QY_{smp}^3 + \sum_s \sum_m \sum_q TY_{mq}^4 * QY_{smq}^4 \end{aligned} \tag{14}$$

Subject to

$$\sum_h y1_h = 1 \tag{15}$$

$$\sum_i y2_i = 1 \tag{16}$$

$$\sum_j y3_j = 1 \tag{17}$$

$$\sum_k y4_k = 1 \tag{18}$$

$$\sum_l y5_l = 1 \tag{19}$$

$$\sum_m y6_m = 1 \tag{20}$$

$$\sum_q y7_q = 1 \tag{21}$$

$$\sum_h Ca^1_h * y^1_h - \sum_i Ca^2_i * y^2_i \leqq 0 \tag{22}$$

$$\sum_i Ca^2_i * y^2_i - \sum_j Ca^3_j * y^3_j \leqq 0 \tag{23}$$

$$\sum_j Ca^3_j * y^3_j - \sum_r Ca^4_r \leqq 0 \tag{24}$$

$$\sum_r Ca^4_r - \sum_k Ca^5_k * y^4_k \geqq 0 \tag{25}$$

$$\sum_k Ca^5_k * y^4_k - (\sum_l Ca^6_l * y^5_l + \sum_m Ca^7_m * y^6_m) = 0 \tag{26}$$

$$\sum_l Ca^6_l * y^5_l - (\sum_n Ca^8_n + \sum_o Ca^9_o) = 0 \tag{27}$$

$$QN = \sum_a \sum_h \sum_i QN^1_{ahi} \tag{28}$$

$$\sum_a \sum_h \sum_i QN^1_{ahi} = \sum_a \sum_i \sum_j QN^2_{aij} \tag{29}$$

$$\sum_a \sum_i \sum_j QN^2_{aij} = \sum_a \sum_j \sum_r QN^3_{ajr} \tag{30}$$

$$\sum_a \sum_j \sum_r QN^3_{ajr} \geqq \sum_b \sum_r \sum_k QN^4_{brk} \tag{31}$$

$$\sum_b \sum_r \sum_k QN^4_{brk} = \sum_b \sum_k \sum_l QM^5_{bkl} + \sum_b \sum_k \sum_m QY^1_{bkm} \tag{32}$$

$$\sum_b \sum_k \sum_l QM^1_{bkl} = \sum_b \sum_r \sum_k QN^4_{brk} * \gamma_1 \tag{33}$$

$$\sum_b \sum_k \sum_l QM^1_{bkl} = \sum_b \sum_l \sum_n QM^2_{bln} + \sum_b \sum_l \sum_o QM^3_{blo} \tag{34}$$

$$\sum_b \sum_l \sum_n QM^2_{bln} = \sum_b \sum_k \sum_l QM^1_{bkl} * \theta_1 \tag{35}$$

$$\sum_b \sum_l \sum_o QM^3_{blo} = \sum_b \sum_k \sum_l QM^1_{bkl} * \theta_2 \tag{36}$$

$$\sum_b \sum_k \sum_l QM^1_{bkl} = \sum_b \sum_r \sum_k QN^4_{brk} * \gamma_1 \tag{37}$$

$$\sum_{b}\sum_{k}\sum_{m} QY^{1}_{bkm} = \sum_{b}\sum_{r}\sum_{k} QN^{4}_{brk} * \gamma_2 \tag{38}$$

$$\sum_{b}\sum_{k}\sum_{m} QY^{1}_{bkm} = \sum_{s}\sum_{m}\sum_{v} QY^{2}_{smv} + \sum_{s}\sum_{m}\sum_{p} QY^{3}_{smp} + \sum_{s}\sum_{m}\sum_{q} QY^{4}_{smq} \tag{39}$$

$$\sum_{s}\sum_{m}\sum_{v} QY^{2}_{smv} = \sum_{b}\sum_{k}\sum_{m} QY^{1}_{bkm} * \mu_1 \tag{40}$$

$$\sum_{s}\sum_{m}\sum_{p} QY^{3}_{smp} = \sum_{b}\sum_{k}\sum_{m} QY^{1}_{bkm} * \mu_2 \tag{41}$$

$$\sum_{s}\sum_{m}\sum_{q} QY^{4}_{smq} = \sum_{b}\sum_{k}\sum_{m} QY^{1}_{bkm} * \mu_3 \tag{42}$$

$$y1_h = \{0,1\} \quad \forall H \tag{43}$$

$$y2_i = \{0,1\} \quad \forall I \tag{44}$$

$$y3_j = \{0,1\} \quad \forall J \tag{45}$$

$$y4_k = \{0,1\} \quad \forall K \tag{46}$$

$$y5_l = \{0,1\} \quad \forall L \tag{47}$$

$$y6_m = \{0,1\} \quad \forall M \tag{48}$$

$$\begin{aligned} &Ca_h, Ca_i, Ca_j, Ca_r, Ca_k, Ca_l, Ca_m, Ca_n, Ca_o, Ca_p, Ca_q, Ca_v \geqq 0, \\ &\forall h \in H,\ \forall i \in I,\ \forall j \in J,\ \forall r \in R,\ \forall k \in K,\ \forall l \in L,\ \forall m \in M, \\ &\forall n \in N,\ \forall o \in O,\ \forall p \in P,\ \forall q \in Q,\ \forall v \in V \end{aligned} \tag{49}$$

The above mentioned mathematical formulation is a nonlinear mixed integer programming (NMIP). The objective function of the M1 is represented in equations (1) and (2). Equation (3) to (7) show the detail contents of equation (1). Equations (8) to (14) show the detail contents of equation (2). Equations (15) to (21) represent that only one facility should be opened at each stage. Equations (22) to (27) represent that the treatment capacity of each stage is the same or greater than the previous one. Equations (28) to (42) show that the amount received from previous stage is the same as the treatment capacity at current stage. Equations (43) to (48) show that each decision variable should take a value of 0 or 1. Equation (49) refers to non-negativity.

$$\begin{aligned} \textit{Maximize } TR\_M2 = {} & TRM1\_1 + TRM1\_2 + TRM1\_3 + TRM1\_4 + TRM1\_5 \\ & + TRM2\_6 + TRM2\_7 + TRM2\_8 + TRM2\_9 + TRM2\_10 \end{aligned} \tag{50}$$

$$\begin{aligned} \textit{Minimize } TC\_M2 = {} & TFC\_M1 + TPC\_M1 + THC\_M2 + TCO\_M2 + IEC\_M1 \\ & + INC\_M1 + TTC\_M2 \end{aligned} \tag{51}$$

$$TRM2\_6 = \sum_{a}\sum_{h}\sum_{r} QN^{5}_{ahr} * VN_a \tag{52}$$

$$TRM2\_7 = \sum_{a}\sum_{i}\sum_{r} QN^{6}_{air} * VN_a \tag{53}$$

$$TRM2\_8 = \sum_{b}\sum_{l}\sum_{r} QM^{6}_{blr} * VN_a \tag{54}$$

$$TRM2\_9 = \sum_{b}\sum_{j}\sum_{k} QN^{7}_{bjk} * VN_{a} * \omega_{2} \tag{55}$$

$$TRM2\_10 = \sum_{s}\sum_{m}\sum_{h} QY^{5}_{smh} * VM_{s} \tag{56}$$

$$\begin{aligned} THC\_M2 = {} & \sum_{a}\sum_{h} HT_{ah} * (QN + QY^{5}_{smh}) * y^{1}_{h} * Ca^{1}_{h} + \\ & \sum_{a}\sum_{i} HD_{ai} * (QN^{2}_{aij} + QM^{4}_{bli}) * y^{2}_{i} * Ca^{2}_{i} + \\ & \sum_{a}\sum_{j} HL_{aj} * QN^{3}_{ajr} * y^{3}_{j} * Ca^{3}_{j} + \\ & \sum_{b}\sum_{k} HC_{bk} * (QN^{3}_{ajr} + QN^{6}_{air} + QN^{5}_{ahr} + QM^{6}_{blr}) * \beta_{1} * y^{4}_{k} * Ca^{5}_{k} + \\ & \sum_{b}\sum_{k}\sum_{l} RM_{bl} * QM^{1}_{bkl} * y^{5}_{l} * Ca^{6}_{l} + \\ & \sum_{s}\sum_{k}\sum_{m} RY_{sm} * QY^{1}_{skm} * y^{6}_{m} * Ca^{7}_{m} \end{aligned} \tag{57}$$

$$TCO\_M2 = \sum_{b}\sum_{k} CO_{bk} * (QN^{3}_{ajr} + QN^{6}_{air} + QN^{5}_{ahr} + QM^{6}_{blr}) * \beta_{1} * y^{4}_{k} * Ca^{5}_{k} \tag{58}$$

$$\begin{aligned} TTC\_M2 = {} & \sum_{a}\sum_{h}\sum_{i} TM^{1}_{hi} * QN^{1}_{ahi} + \sum_{a}\sum_{i}\sum_{j} TD^{1}_{ij} * QN^{2}_{aij} + \\ & \sum_{a}\sum_{j}\sum_{r} TE^{1}_{jr} * QN^{3}_{ajr} + \sum_{b}\sum_{k}\sum_{l} TC^{1}_{kl} * QM^{1}_{bkl} + \\ & \sum_{b}\sum_{k}\sum_{m} TC^{2}_{km} * QY^{1}_{bkm} + \sum_{b}\sum_{l}\sum_{n} TR^{1}_{ln} * QM^{2}_{bln} + \\ & \sum_{b}\sum_{l}\sum_{o} TR^{2}_{lo} * QM^{3}_{blo} + \sum_{s}\sum_{m}\sum_{v} TY^{1}_{mv} * QY^{2}_{smv} + \\ & \sum_{s}\sum_{m}\sum_{p} TY^{2}_{mp} * QY^{3}_{smp} + \sum_{s}\sum_{m}\sum_{q} TY^{4}_{mq} * QY^{4}_{smq} + \\ & \sum_{a}\sum_{h}\sum_{r} TM^{2}_{hr} * QN^{5}_{ahr} + \sum_{a}\sum_{i}\sum_{r} TD^{2}_{ir} * QN^{6}_{air} + \\ & \sum_{b}\sum_{l}\sum_{i} TR^{3}_{li} * QM^{4}_{bli} + \sum_{b}\sum_{l}\sum_{r} TR^{4}_{lr} * QM^{6}_{blr} + \\ & \sum_{b}\sum_{l}\sum_{m} TR^{5}_{lm} * QM^{5}_{blm} + \sum_{s}\sum_{m}\sum_{h} TY^{3}_{mh} * QY^{5}_{smh} \end{aligned} \tag{59}$$

Subject to

$$\sum_{r} Ca^{4}_{r} - (\sum_{k} Ca^{5}_{k} * y^{4}_{k} + \sum_{j} Ca^{3}_{j} * y^{3}_{j}) \geqq 0 \tag{60}$$

$$\sum_{l} Ca^{6}_{l} * y^{5}_{l} - (\sum_{n} Ca^{8}_{n} + \sum_{o} Ca^{9}_{o} + \sum_{i} Ca^{2}_{i} * y^{2}_{i} + \sum_{r} Ca^{4}_{r} + \sum_{m} Ca^{7}_{m} * y^{6}_{m}) = 0 \tag{61}$$

$$\sum_{m} Ca_{m}^{7} \ast y_{m}^{6} - (\sum_{v} Ca_{v}^{12} + \sum_{p} Ca_{p}^{10} + \sum_{q} Ca_{q}^{11} + \sum_{h} Ca_{h}^{1} \ast y_{h}^{1}) = 0 \tag{62}$$

$$QN = \sum_{a}\sum_{h}\sum_{i} QN_{ahi}^{1} + \sum_{s}\sum_{m}\sum_{h} QY_{smh}^{5} \qquad \forall\, h, i, m, h \tag{63}$$

$$QN \ast \delta_3 = \sum_{a}\sum_{h}\sum_{i} QN_{ahi}^{1} \tag{64}$$

$$QN \ast \delta_4 = \sum_{a}\sum_{j}\sum_{r} QN_{ajr}^{3} \tag{65}$$

$$(\sum_{a}\sum_{h}\sum_{i} QN_{ahi}^{1} + \sum_{b}\sum_{l}\sum_{i} QM_{bli}^{4}) \ast \delta_5 = \sum_{a}\sum_{i}\sum_{j} QN_{aij}^{2} \tag{66}$$

$$(\sum_{a}\sum_{h}\sum_{i} QN_{ahi}^{1} + \sum_{b}\sum_{l}\sum_{i} QM_{bli}^{4}) \ast \delta_5 \ast \delta_7 = \sum_{a}\sum_{h}\sum_{r} QN_{ahr}^{2} \tag{67}$$

$$(\sum_{a}\sum_{h}\sum_{i} QN_{ahi}^{1} + \sum_{b}\sum_{l}\sum_{i} QM_{bli}^{4}) \ast \delta_6 = \sum_{a}\sum_{i}\sum_{r} QN_{air}^{6} \tag{68}$$

$$(\sum_{a}\sum_{j}\sum_{r} QN_{ajr}^{3} + \sum_{a}\sum_{h}\sum_{r} QN_{ahr}^{5} + \sum_{a}\sum_{i}\sum_{r} QN_{air}^{6}) \ast \beta_1 \\ = \sum_{b}\sum_{r}\sum_{k} QN_{brk}^{7} \tag{69}$$

$$(\sum_{a}\sum_{j}\sum_{r} QN_{ajr}^{3} + \sum_{a}\sum_{h}\sum_{r} QN_{ahr}^{5} + \sum_{a}\sum_{i}\sum_{r} QN_{air}^{6}) \ast \beta_1 + \sum_{b}\sum_{r}\sum_{k} QN_{brk}^{7} \\ = Ca_{k}^{5} \ast y4_{k} \tag{70}$$

$$\left\{(\sum_{a}\sum_{j}\sum_{r} QN_{ajr}^{3} + \sum_{a}\sum_{h}\sum_{r} QN_{ahr}^{5} + \sum_{a}\sum_{i}\sum_{r} QN_{air}^{6}) \ast \beta_1 + \sum_{b}\sum_{r}\sum_{k} QN_{brk}^{7}\right\} \ast \gamma_1 = \\ \sum_{b}\sum_{k}\sum_{l} QM_{bkl}^{1} \tag{71}$$

$$\left\{(\sum_{a}\sum_{j}\sum_{r} QN_{ajr}^{3} + \sum_{a}\sum_{h}\sum_{r} QN_{ahr}^{5} + \sum_{a}\sum_{i}\sum_{r} QN_{air}^{6}) \ast \beta_1 + \sum_{b}\sum_{r}\sum_{k} QN_{brk}^{7}\right\} \ast \gamma_2 = \\ \sum_{b}\sum_{k}\sum_{m} QY_{bkm}^{1} \tag{72}$$

$$\sum_{b}\sum_{k}\sum_{l} QM_{bkl}^{1} = \sum_{b}\sum_{l}\sum_{n} QM_{bln}^{2} + \sum_{b}\sum_{l}\sum_{o} QM_{blo}^{3} + \\ \sum_{b}\sum_{l}\sum_{i} QM_{bli}^{4} + \sum_{b}\sum_{l}\sum_{m} QM_{blm}^{5} \tag{73}$$

$$\sum_{b}\sum_{k}\sum_{m} QY_{bkm}^{1} = \sum_{s}\sum_{m}\sum_{v} QY_{smv}^{2} + \sum_{s}\sum_{m}\sum_{p} QY_{smp}^{3} + \\ \sum_{s}\sum_{m}\sum_{q} QY_{smq}^{4} + \sum_{s}\sum_{m}\sum_{h} QY_{smh}^{5} \tag{74}$$

$$\left\{(\sum_{a}\sum_{j}\sum_{r} QN_{ajr}^{3} + \sum_{a}\sum_{h}\sum_{r} QN_{ahr}^{5} + \sum_{a}\sum_{i}\sum_{r} QN_{air}^{6}) \ast \beta_1 + \sum_{b}\sum_{r}\sum_{k} QN_{brk}^{7}\right\} \ast \gamma_2 \ast \delta_2 = \\ \sum_{s}\sum_{m}\sum_{h} QY_{smh}^{5} \tag{75}$$

The mathematical formulation for the M2 is attached from equations (50) to (75) on the basis of mathematical formulation of the M1. Equations (50) and (51) show the objective function of the M2. In the M2, the transportation route using normal delivery, direct delivery and direct shipment are proposed. Equations (53) to (54) show the increased source of revenue through direct delivery and direct shipment. Meanwhile, new transportation routes also increase the revenues and is represented in equations (55) and (56). Equations (57) to (59) show that the handling cost, collection cost and transportation cost for the M2. Equations (60) to (62) represent that the treatment capacity of each stage is the same or greater than the previous one in the M2. Equations (63) to (75) show that the amount received from previous stage is the same as the treatment capacity at current stage for the M2.

V. GA Approach

5.1 Introduction of GA

The term of genetic algorithm (GA) was firstly proposed by John Holland (1975). Simultaneously, the GA was extended to the area of functional optimization by De Jong (1975), and then improved upon by Goldberg (1985). Finally, an influential book ‘Genetic Algorithm in Search, Optimization, and Machine Learning’ (Goldberg, 1989) was published. Thus, the GA theory was established along with the sustained development and application.

The GA is a robust, stochastic, and powerful heuristic search method based on the mechanism of natural selection and evolution. In particularly, the GA is an effective method for solving complex, combinatorial, and optimal problems.

Before starting on the procedures of the GA, several definitions need to be decided. In keeping with the nature-selection analogy, the set of trial solutions are called ‘population’. Successive populations of trial solutions are called ‘generations’, or also called GA iterations. The members of the current generation are called ‘parent’, the members of the next generation are called ‘child’, subsequent generations are composed of children, produced through the selective reproduction of pairs of parents, the code form of a trial solution vector, which consist of genes called individuals or chromosome, the process of the positive number assigned to an individual representing a measure of goodness are fitness. In general, the procedure of the GA is represented as follows:

Step 1 : Representing by encoding the solution parameters as genes and creating a string of the genes to form a individual.
Step 2 : Initializing a starting population.
Step 3 : Evaluating and assigning fitness values to individuals in the population.
Step 4 : Performing reproduction of offspring using crossover operator.
Step 5 : Performing recombination and mutation to produce members of the offspring generation.
Step 6 : Representation by decoding and evaluating fitness value to the individuals.
Step 7 : Forming new generation by selection of good individuals.
Step 8 : Finding optimal solution.

The difference of the GA with conventional algorithms can be summarized as follows (Johnson et al. 1997):

- Operating on populations which are a group of trial solutions in parallel.
- Operating on individuals which are a process of coding of the function parameters
- Using the GA operators to explore the optimal solution which are crossover, mutation, evaluation, and selection.

The detail concepts of a general structure of the GA are showed in Figure 5-1 (Gen and Cheng, 1997).

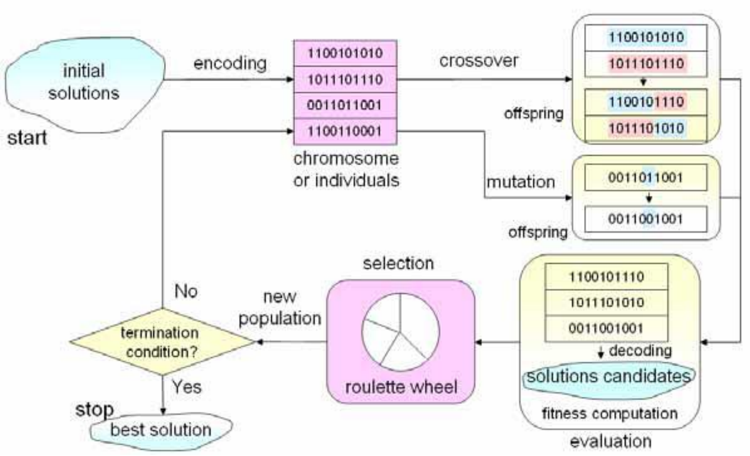


Figure 5-1. General structure of GA by Gen and Cheng (1997)

Let *P*(*t*) and *C*(*t*) be parents and offspring in current generation *t*, respectively. The general implementation procedure of the GA is described as follows.

```
procedure: Genetic algorithm
input: GA parameters
output: best solution
begin
  $t \leftarrow 0$;
  initialize P(t) by encoding routine;
  evaluate P(t) by decoding routine;
  while (not termination condition) do
    begin
      crossover P(t) to yield C(t);
      mutation P(t) to yield C(t);
      evaluate C(t) by decoding routine;
      select P(t+1) from P(t) and C(t);
```

```
        t ← t+1;
      end
    output best solution;
end
```

5.2 GA Approach for Implementing Mathematical Formulation

5.2.1 Genetic Representation

In order to apply any GA to a problem, the method of chromosomal representation should be defined. According to the kind of problems needed to be solved, the representation method can be characterized, such as flow-shop problems, optimization problems, job-shop scheduling problems, machine scheduling problems, transportation problems, and so on (Gen et al. 1997).

The representation of GA is divided into traditional representation and developed representation. One basic feature of traditional representation is that the work be transferred on coding space and solution space (Cheng et al. 1996). Evolution works on coding space by encoding, which is a mapping from the parameter space to the individual space using bit-string 0s and 1s. Evaluation works on solution space by decoding, which is a process of transferring the parameter space from bit-string to continuous, floating-point number. In tradition representation, the GA operates on a coding of the parameters, instead of the parameters themselves (Johnson et al. 1997).

Different representations are also possible. Non-string coding method is one of developed representation methods. In non-string coding method, the encoding and decoding between individuals and solutions are represented by natural numbers, not by binary code. The non-string coding method is effective when the individual is feasibility, legality, and keeping uniqueness of mapping (Cheng et al. 1996).

For the transportation problems, it can be characterized as a linear problem or nonlinear problem, and single objective problem or multiple objective problem according to the different objectives (Gen et al. 1997). For example, the matrix is the most nature representation of a solution for linear transportation problem. The allocation matrix of transportation problem can be written as follows:

$$X_p = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \tag{76}$$

where X_p denotes the *p-th* individual and xy_{ij} is the corresponding decision variable.

For solid transportation problem, a individual can be represented as a three-dimensional array and also equivalently represented as a matrix with mnK elements:

$$\left[x_{111}x_{211}\cdots x_{m11},\ \ldots,\ x_{1n1}x_{2n1}\cdots x_{mn1},\ \ldots,\ x_{11K}x_{21K}\cdots x_{m1K},\ \ldots,\ x_{1nK}x_{2nK}\cdots x_{mnK}\right] \tag{77}$$

where x_{ijk} is stage corresponding decision variables in the individual (Gen et al. 1997). In my study, real-numbers of facilities are utilized. The numbers represent the actual opened number of facilities at each stage. The detail contents of representation and initial populations in this study are showed in Figure 5-2.

	TM	DC	TD	CC	RM	RY	IN
P_1=	3	1	2	4	2	1	2

	TM	DC	TD	CC	RM	RY	IN
P_2=	2	2	4	1	3	2	1

Figure 5-2. The real-number representation of GA

Take the M1 as an example to explain the real-number representation, as mentioned above, there are seven facilities should be chosen at seven stages. At the stage of TM, there are eight locations to be chosen for the facility, if the location of number 3 is selected, the natural number 3 is be represented in TM space. Thus, the selected number of the DC, TD, CC, RM, RY, IN should be represented in each their space. Using this representation scheme, the initial population can be built as shown in Figure 5-3, when population size is 5.

	TM	DC	TD	CC	RM	RY	IN
P_1=	3	1	2	4	2	1	2
P_2=	2	2	4	1	3	2	1
P_3=	1	1	3	2	4	3	2
P_4=	4	3	3	2	1	4	3
P_5=	3	3	1	3	2	1	4

Figure 5-3. The initial population

Through real-number representation, the operation of the GA does not need to change the working space between encoding and decoding, and its search speed can be increased.

5.2.2 GA Operators and Detailed Implementation Procedure

There are two essential characteristics in the GA when the GA optimizes the functions of complex and huge network model. The first characteristic is the convergence ability when the local or global optimal solution locates the region of the optimal solution. The second characteristic is the exploration ability for new regions of the optimal solution in global search. The balance between these characteristics are crossover rate, mutation rate, crossover and mutation types (Srinivas et al. 1994).

1) Crossover Operator

The role of the crossover operator is to recombine two good “parent” solutions in order to produce better “offspring” solutions (Poon et al. 1995). The principle of the recombination operator is abstracted from the knowledge of natural genetics (Schaffer et al. 1995). Therefore, the points of crossover are to combine characteristics of both parent strings and offspring strings. Simultaneously, the validity of offspring solutions should be to make sure.

In a traditional crossover, the crossover operator starts from two strings of the population, a point selected randomly between 1 and string length-1 (Schaffer et al. 1995). Both strings are severed at a selected point and the segments of the right of this point are switched. The two starting strings and the resulting strings are usually called the parents and the offspring, respectively (Poon et al. 1995).

In the problems with global optimization, the crossover can be characterized as an arithmetical crossover, blend crossover, uni-modal normal distribution crossover, blend crossover, or direction-based crossover (Gen et al. 2000). For example, a blend crossover creates offspring randomly within a hyper-rectangular defined by the parent points (Eshelman et al. 1993). Consider a one-dimensional case; that is, a problem with just one variable. Suppose that the first parent has the value p_1, the second parent p_2, and that $p_2 > p_1$. Let $I = |p_1 - p_2|$ and $0 < \alpha, \beta < 1$; then an offspring is generated by randomly choosing a point within the interval

$$[p_1 - \alpha I, p_2 + \beta I] \tag{78}$$

It is usually specified as BLX-$\alpha-\beta$. Figure 5-4 illustrates the blend crossover.

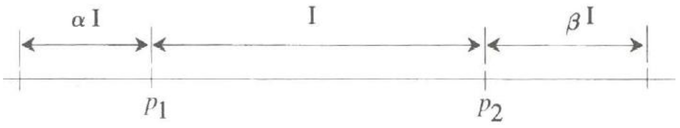
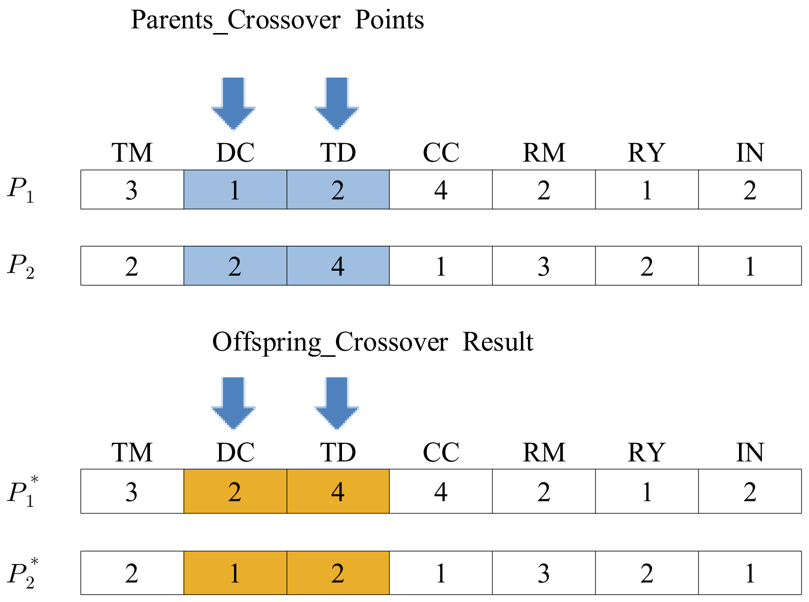


Figure 5-4. Blend crossover in a one-dimensional case.

In my study, the selected points of the locations of the facility in the CLSC network model is huge and complex. In order to recombining fast, two-point crossover operator and real number of locations are used. The two crossover points are selected at random, and the selected points are switched and new strings are produced. The action process is represented in Figure 5-5.



Parents_Crossover Points

	TM	DC	TD	CC	RM	RY	IN
P_1	3	1	2	4	2	1	2
P_2	2	2	4	1	3	2	1

Offspring_Crossover Result

	TM	DC	TD	CC	RM	RY	IN
P_1^*	3	2	4	4	2	1	2
P_2^*	2	1	2	1	3	2	1

Figure 5-5. Operation procedure using two-point crossover operator

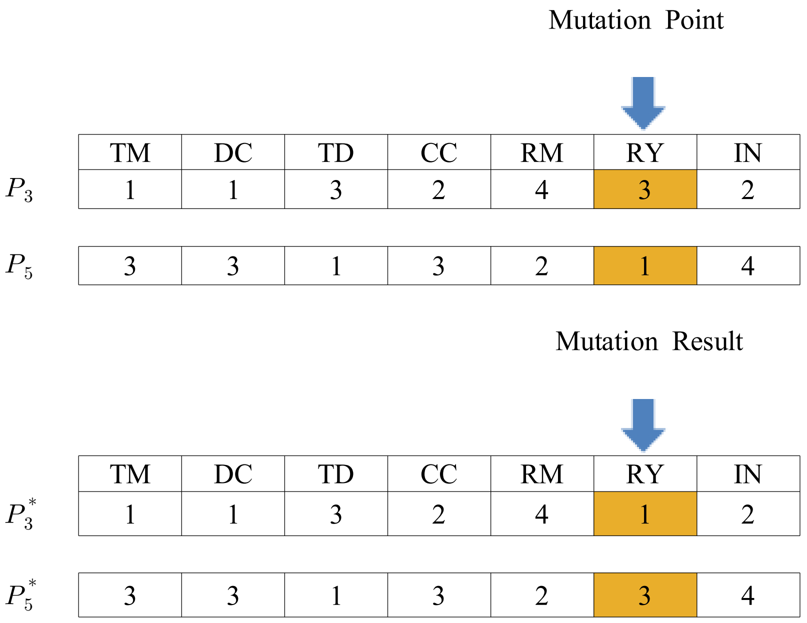
2) Mutation Operator

The role of mutation is to prevent the premature convergence of the optimal solutions (Srinivas et al. 1994). A mutation creates new individuals by modifying one or more existing individuals. Mutation operator increase the variability of the population in the process for searching optimal solution (Syarif et al. 2002). The mutation operator which produces spontaneous random changes in various individuals is used as the background operator. According to this kind of problem, various methods of mutation can be applied. In problems with global optimizations, the mutation can be characterized as a nonuniform mutation and directional (Gen et al. 2000). Take the method of nonuniform mutation for example; a method given by Michalewicz (1996). It is designed to fine-tune capabilities aimed at achieving high precision. For a given parent x, if the element x_k is selected for mutation, the resulting offspring is $x^{'} = (x_1,\ldots,x_k^{'},\ldots,x_n)$, where $x_k^{'}$ is randomly selected from the following two possible choices:

$$x_k^{'} = x_k + \triangle(t, x_k^U - x_k) \tag{79}$$

$$x_k^{'} = x_k - \triangle(t, x_k - x_k^L) \tag{80}$$

In my study, a one point mutation operator and the real number of locations are used. The two strings for mutation point are selected randomly, The mutation point with the real number of locations are switched with previous ones. The process of mutation is shown in Figure 5-6.



	TM	DC	TD	CC	RM	RY	IN
P_3	1	1	3	2	4	3	2
P_5	3	3	1	3	2	1	4

	TM	DC	TD	CC	RM	RY	IN
P_3^*	1	1	3	2	4	1	2
P_5^*	3	3	1	3	2	3	4

Figure 5-6. Operation procedure using one-point mutation operator

3) Evaluation

DeJong (1975) proposed the expected value model, and the contents are taken as a standard for comparison. The traditional model uses the average value of population to evaluate each individual and normalizes the value (DeJong, 1975; Holland, 1975). Evaluation is to associate each individual with a fitness value. The fitness value shows the degree of goodness by comparing to achieving an objective function. The higher fitness value of an individual is survival for the next generation.

So the role of evaluation and selection can not be ignored in the evolutionary process (Syarif et al. 2002).

The method of evaluation varies according to the kind of problem. For a network problem, the evaluation of weight value (fitness value) of routes is based on the communication latency along the routes. A delay message is sent at a specified interval to observe the delay along the route. Using the delay value obtained, evaluation of the weight value of routes can be calculated as follows:

$$eval(v_k) = \frac{1/D_k}{\sum_{i \in S} 1/D_k} \tag{81}$$

where $D_i = d_i / \sum_{j \in S} d_j$; d_j is the delay for route i and S is a set of routes of the same destination.

The equation implies that a smaller value of d_i generates a larger evaluation value. In the evaluation method, a route with a less communication latency is frequently employed in sending packets. For the scheduling problems, advanced transportation problems, and so on, various evaluation methods are used.

In my study, the value of the total cost at each stage should be compared. The initial population and offspring population are operated with crossover and mutation, and the sorting process is implemented according to the value of total cost at each stage. The first five individuals are chosen as a new combination from the low total cost to the high total cost. Thus a new fitness population is formed. The process of evaluation is shown in Figure 5-7.

	TM	DC	TD	CC	RM	RY	IN	Total Cost
P_1=	3	1	2	4	2	1	2	15320
P_2=	2	2	4	1	3	2	1	15280
P_3=	1	1	3	2	4	3	2	15310
P_4=	4	3	3	2	1	4	3	15290
P_5=	3	3	1	3	2	1	4	15305
P_1^*	3	2	4	4	2	1	2	15270
P_2^*	2	1	2	1	3	2	1	15315
P_3^*	1	1	3	2	4	1	2	15299
P_4^*	4	3	3	2	1	4	3	15311
P_5^*	3	3	1	3	2	3	4	15325

	TM	DC	TD	CC	RM	RY	IN	Total Cost
P_1^*	3	2	4	4	2	1	2	15270
P_2=	2	2	4	1	3	2	1	15280
P_4=	4	3	3	2	1	4	3	15290
P_3^*	1	1	3	2	4	1	2	15299
P_5=	3	3	1	3	2	1	4	15305
P_3=	1	1	3	2	4	3	2	15310
P_4^*	4	3	3	2	1	4	3	15311
P_2^*	2	1	2	1	3	2	1	15315
P_1=	3	1	2	4	2	1	2	15320
P_5^*	3	3	1	3	2	3	4	15325

Figure 5-7. The sorting process in my study.

4) Selection

As in nature, it is necessary to provide a driving mechanism for better individuals to survive. Trough selection activity, a new offspring of next generation is formed. Selection provides the driving force in a GA. With too much force, a genetic search will terminate prematurely; with too little force, the evolutionary progress will be slower than necessary. Typically, a lower selection pressure is indicated at the start of a genetic search in favor of a wider exploration of the search space, while a higher selection pressure is recommended at the end to narrow the search space. The selection directs the genetic search by promising regions in the search space. Over the past two decades, many selection methods have been proposed, examined, and compared, such as roulette wheel selection, $(\mu+\lambda)$ selection, tournament selection, and so on (Gen et al. 2000).

In my study, an elitist selection method is used. In this process, individual strings of the current population are compared to their fitness function values according to the empirical probability distribution in a mating pool; some individuals should be selected more than once, simultaneously, higher fitness value of individuals should be picked, and a low fitness of individuals should be eliminated (Bhandari et al. 1996).

For example, the objective function is to minimize total cost, the total cost of P_1^{**} compared to fitness value of total cost. If the total cost of P_1^{**} is smaller than the fitness value of total cost, the total cost of P_1^{**} is selected. Thus, the total cost of each individual should be compared to fitness value. If the value of each individual is superior to the fitness value, the value should be picked until termination. The selection process in my study is shown in Figure 5-8.

	TM	DC	TD	CC	RM	RY	IN	Total Cost
P_1^{**}	3	2	4	4	2	1	2	15270
$P_2^{**}=$	2	2	4	1	3	2	1	15280
$P_3^{**}=$	4	3	3	2	1	4	3	15290
P_4^{**}	1	1	3	2	4	1	2	15299
$P_5^{**}=$	3	3	1	3	2	1	4	15305

Figure 5-8. The selection process in my study.

The procedure of GA in my study is as follows:

```
Procedure: Genetic algorithm in my study
Input: GA parameters
Output: best solution
Begin
  initialize parent population by real-number of each stage;
  evaluate starting population;
  while (not termination condition) do
    apply crossover operator to parent population to yield offspring population;
```

```
        apply mutation operator to parent population to yield offspring population;
        evaluate offspring population;
        select next parent population from parent population and offspring population;
        parent population ← next parent population;
        end
    output best solution;
end
```

VI. Numerical Experiments

For numerical experiments, five scales and various scenarios for the M1 and the M2 are considered. There are two differences between Scenario 1 and 2. The first one is that the performance of Rev. and Co. will be verified by the result of each scale respectively in Scenario 1. The second one is that the performance of Rev., Co. and Rev./Co. will be verified by the result of five scales in one group in Scenario 2. Thus, through the result of each scale in Scenario 1 and that of five scales in one group in Scenario 2, the performances of M1 and M2 will be compared clearly. There are two differences between Scenario 3 and 4. The first one is the effect of Tech on the performance of the M1 and M2 along with changing of Tech value. The second one is the effect of scale size on the performance of Tech in the M1 and M2. Therefore, in Scenario 3, the effect of Tech on the performances of Rev., Co. and Rev./Co. will be verified. In order to verify the effect of scale size on the performance of Tech, Scenario 4 will be carried out under biggest size of Scale 5.

The data of unit fixed cost, unit production cost, unit handling cost, unit collection cost, unit investment cost, unit incineration cost, and unit transportation cost used in the M1 and the M2 are randomly generated by EXCEL. These data are shown in Appendixes 1 to 18. The distribution ratios of each stage in the M1 are calculated by the real data (KOTMA, 2017). The distribution ratios at the CC in the M2 are identical with that of the M1. The distribution ratios at the RM and the RY in the M2 are assigned maximally consistent with that of the M1 according to the real data (KOTMA, 2017). The distribution ratios for normal delivery, direct delivery and shipment are 0.8 and 0.2, respectively.

The performances of the M1 and the M2 are compared using the proposed GA approach, under the consideration of the five scales, various cases, and scenarios. The parameters for the proposed GA approach are that population size is 20, crossover rate 0.5. mutation rate 0.3 and total number of generations 1,000. The proposed GA approach is implemented under the following computation environment: Matlab R2015 under IBM compatible PC 3.40 GHZ processor (Inter Core i7-3770 CPU), 8GB and Window 7.

6.1 Case Study

Table 6-1 shows the five scales for the M1 and the M2. For example, In Scale 1, the number of the TM that can be considered is 2, which means that only one of the two TMs should be opened and the other is closed. the numbers of the DC, the TD, the CC, the RM, the RY and the IN are also interpreted as the same concept with the TM. However, The numbers of the EU, the DP, the EP, the DM, and the EM are fixed and always taken as 1.

Considering the numbers of each stage in Scale 1, total possible routes are 256(=2×2×4×2×2×2×2) and they can be easily solved using conventional approaches such as simulated annealing, hill climbing method, etc. However, when considering the numbers of each stage in Scale 5, total possible routes are 150,994,944(=16×16×24×16×16×16×6) and they cannot be easily solved using conventional approaches. Therefore, the optimization techniques such as GA approach with global search ability should be used for locating the global optimal solution.

Table 6-1. Five scales for the M1 and the M2.

Scale	TM	DC	TD	EU	CC	RM	RY	IN	DP	EP	DM	EM
1	2	2	4	1	2	2	2	2	1	1	1	1
2	4	4	8	1	4	4	4	3	1	1	1	1
3	8	8	16	1	8	8	8	4	1	1	1	1
4	12	12	20	1	12	12	12	5	1	1	1	1
5	16	16	24	1	16	16	16	6	1	1	1	1

According to real data from Korea Tire Manufacturers Association (KOTMA, 2017), the amount of new tires are 359,931 tons at the TM in the M1. The return rate is 85%, which is the percentage of used tires collected from the EU to the CC. Only normal delivery of transportation route is considered in the M1. The amount of used tires are divided into remanufacturing tires and recycling tires with γ_1% and γ_2% at the CC. The transportation ratio of γ_1% from the CC to the RM is 22.72%, the transportation ratio of γ_2% from the CC to the RY is 77.30%. The amount of remanufacturing tires are divided into θ_1% and θ_2% at the RM. The transportation ratio of θ_1% from the RM to the DP is 43.16%. The transportation ratio of θ_2% from the RM to the EP is 56.84%. The amount of recycling tires are divided into μ_1%, μ_2%, and μ_3% at the RY. The transportation ratio of μ_1% from the RY to the DM is 98.13%. The transportation ratio of μ_2% from the RY to the EM is 1.67%. The transportation ratio of μ_3% from the RY to the IN is 0.17%.

On the basis of the M1, the direct delivery and shipment are attached to the M2. For example, the amount of normal delivery and direct shipment is divided into with δ_3% and δ_4% at the TM, respectively. The ratio of normal delivery from the TM to the DC with δ_3% is 80%, the ratio of direct shipment from the TM to the EU with δ_4% is 20%. The amount of normal delivery and direct delivery is divided into δ_5% and δ_6% at the DC. The ratio of normal delivery from the DC to the TD with δ_5% is 80%, the ratio of direct delivery from the DC to the EU with δ_6% is

20%.

For a more accurate comparison of the M1 and the M2, we assume that the ratio is maximally consistent with the M1 in the RL of the M2. For example, the value of θ_1 is 0.4316 in the M1, the value of θ_1 is assumed as 0.4 in the M2.

Therefore, only normal delivery of transportation routes/types is considered in the M1. The amount of used tires are divided into remanufacturing tires and recycling tires with $\gamma_1\%$ and $\gamma_2\%$ at the CC. The amount of remanufacturing tires are divided into $\theta_1\%$ and $\theta_2\%$ at the RM. The amount of recycling tires are divided into $\mu_1\%, \mu_2\%$, and $\mu_3\%$ at the RY. The value of $\gamma_1\%, \gamma_2\%$, $\theta_1\%, \theta_2\%, \mu_1\%, \mu_2\%$,and $\mu_3\%$ is used with real data from Korea Tire Manufacturers Association (KOTMA, 2017). In the M2, the direct delivery and shipment of transportation routes/types are attached on basis of the M1. The stages of the TM and the RM are attached with the transportation routes/types of direct shipment. The stage of the DC is attached with the transportation routes/types of direct delivery.

In the FL of the M2, the ratios of normal delivery and direct delivery, shipment are fixed as 80% and 20% at the TM, the DC, and the TD, respectively. This means that the ratio of new tires sent from the TM to the DC has a taken value of 80%, the ratio of new tires sent from the TM to the EU has a taken value of 20%; the ratio of new tires sent from the DC to the TD has a taken value of 80%, and the ratio of new tires sent from the DC to the EU has a taken value of 20%.

In addition, in the M2, the amount of remanufacturing tires are divided into four parts. Besides $\theta_1\%$, $\theta_2\%$, the remanufacturing tires are also sent to the DC and the RY with $\theta_3\%$ and $\theta_4\%$, respectively. The amount of recycling tires are divided into four parts. Besides $\mu_1\%$, $\mu_2\%$, and $\mu_3\%$, the recycling tires are sent to the TM with $\delta_2\%$. The values of $\gamma_1\%$, $\gamma_2\%$, $\theta_1\%$, $\theta_2\%$, $\theta_3\%$, $\theta_4\%$, $\mu_1\%$, $\mu_2\%$, $\mu_3\%$, $\delta_2\%$ are maximally consistent with the M1. Meanwhile, the remanufactured and recycling tires are resold to the DP, the EP, the DC, the DM, and the EM at a normal price of 60%. At the TD, the tires which have passed the warranty period are sold to the CC at a normal price of 50%.

The distribution ratio of each stage for the M1 is calculated according to the real data (KOTMA, 2017). The data from δ_3 to δ_8 refers to the ratio of normal delivery, direct delivery and shipment in the M2, and the values are assigned. The ratio range of normal delivery can be changed from 0.95 to 0.7, changing with 0.5 as a unit. When comparing the performance of M1 and M2, the value of ratio for normal delivery is assigned with 0.8. An sensitivity analysis will be carried out with value changing from 0.95 to 0.7 later. For the rest data of distribution ratio in the M2, the values of γ_1 and γ_2 are calculated according to the real data. Because of attaching various transportation routes at stage of RM and RY in the M2, the situations of RM and RY are different to M1. Thus, the values from θ_1 to θ_5, μ_1 to μ_3, and δ_2 are assigned maximally consistent with real data. The detail contents are showed in Table 6-2.

Table 6-2. Distribution ratio of each stage for the M1 and the M2.

Ratio	M1	M2
δ_3	-	0.8
δ_4	-	0.2
δ_5	-	0.8
δ_6	-	0.2
δ_7	-	0.8
δ_8	-	0.2
γ_1	0.2272	0.2272
γ_2	0.7730	0.7730
θ_1	0.4316	0.4
θ_2	0.5684	0.5
θ_3	-	0.05
θ_4	-	0.03
θ_5	-	0.02
μ_1	0.9813	0.9
μ_2	0.0167	0.01
μ_3	0.0017	0.001
δ_2	-	0.089

Table 6-3 shows various scenarios for the M1 and the M2. The performance of the M1 and the M2 should be compared using various scenarios with distribution ratio at each stage shown in Table 6-2.

In scenario 1, the distribution ratio of each stage for the M1 and the M2, the performance of the M1 and the M2 are compared in terms of revenues (Rev.) and costs (Co.) under a scale of 1 to 5 with the same technological (Tech) coefficient value of 1. The results are represented in Figures 6-1, 6-2, 6-3, 6-4, and 6-5. In scenario 2, with distribution ratio of each stage for the M1 and the M2, the performances of the M1 and the M2 are compared in terms of the Rev., the Co., and the Rev./Co. under a scale of 1 to 5 with the same Tech value of 1. The results are represented in Figures 6-6, 6-7, and 6-8.

In scenario 3, with distribution ratio of each stage for the M1 and the M2, the performances of the M1 and the M2 are compared in terms of Rev., the Co., and the Rev./Co. under a scale of 1 with different Tech values of 1, 1.5, and 2. The results are represented in Figures 6-9, 6-10, and 6-11. In scenario 4, with the distribution ratio of each stage for the M1 and the M2, the performances of the M1 and the M2 are compared in terms of Rev. Co. and Rev./Co. under a scale of 5 with different Tech values of 1, 1.5, and 2. The results are represented in Figures 6-12, 6-13, and 6-14. The detail contents of scenario 1, 2, 3 and 4 are showed in Table 6-3.

Table 6-3. Various scenarios for M1 and M2

Scenario	Tech	Ratio	Scale	Performance
1	1	Table 6-2	1,2,3,4,5	Rev. Co.
2	1	Table 6-2	1,2,3,4,5	Rev. Co. Rev./Co.
3	1, 1.5, 2	Table 6-2	1	Rev. Co. Rev./Co.
4	1, 1.5, 2	Table 6-2	5	Rev. Co. Rev./Co.

The computation results of the M1 and the M2 with various scales are shown in Tables 6-4 and 6-5, respectively. The results are based on the average value of the 30 trials. Table 6-4 shows that the results of Rev., Co., and Rev./Co. for the M1 under the five scales. The results of the Rev. are identical in the five scales. The results of the Co. and the Rev./Co. have some changes in the five scales. Table 6-5 shows the results of Rev., Co., and Rev./Co. for the M2 under five scales. The results of the Rev. for M2 are also identical in the five scales. The results of the Co. are different in five scales for the M2. The results of Rev. and Co. of the M2 are all lower than the results of Rev. of the M1 in the five scales. However, the results of Rev./Co. of the M2 are higher than the results of the M1 in the five scales. Thus, same results with scenarios 1 and 2 can be confirmed.

Table 6-4. Computation results of the M1 along with various scales for scenarios 1 and 2.

	Scale 1	Scale 2	Scale 3	Scale 4	Scale 5
Rev.	12,753,134	12,753,134	12,753,134	12,753,134	12,753,134
Co.	39,925,528	39,361,372	39,925,528	39,545,294	39,549,845
Rev./ Co.	0.3194	0.3239	0.3190	0.3224	0.3224

Table 6-5. Computation results of the M2 along with various scales for scenarios 1 and 2.

	Scale 1	Scale 2	Scale 3	Scale 4	Scale 5
Rev.	12,626,116	12,626,116	12,626,116	12,626,116	12,626,116
Co.	35,709,009	35,166,795	35,709,009	35,230,962	35,242,920
Rev./ Co.	0.3536	0.3590	0.3536	0.3583	0.3582

Tables 6-4 and 6-5 can be represented by figure, simultaneously, scenarios 1 and 2 are displayed from Figure 6-1 to 6-8.

Scenario 1 is represented from Figure 6-1 to 6-5. The Figures show that the performance of the Rev. remains almost identical for the M1 and the M2 in all five sales. However, the performance of the Co. of the M2 is lower than that of the M1 in the five sales. All comparisons are carried out under equal conditions in terms of same Tech value. In the M1, the revenues are produced from five stages in terms of the EU, the DP, the EP, the DM, and the EM. The new tires are sold at the EU, and the used tires are sold at a normal price of 60% from the RM to the DP, and the EP; the recycling materials are sold at a normal price of 60% from the RY to the DM, and the EM. In the M2, the revenues are produced from six stages in terms of the EU, the CC, the DP, the EP, the DM, and the EM. Among those stages, except that the new tires are sold form the TD to the EU in terms of normal delivery, the new tires are also sold from the TM, the DC, and the RM to the EU at a normal price of 60% in terms of direct shipment and delivery. In addition, the tires that have passed the warranty period are sold at a normal price of 50% from the TD to the CC. In scenario 1, we can conclude that, although the total sales volume is increased because of attaching direct shipment and delivery in the M2, and the total quantities are limited, the total revenues are almost identical in the M1 and the M2. However, the total costs have been decreased in the M2 by attaching direct shipment and delivery.

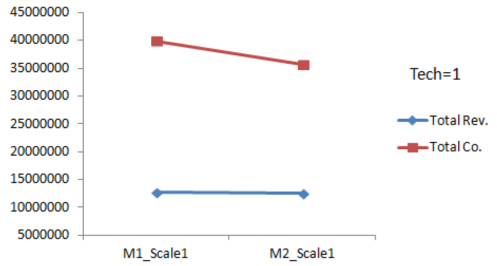


Figure 6-1. Scenario 1_Scale 1.

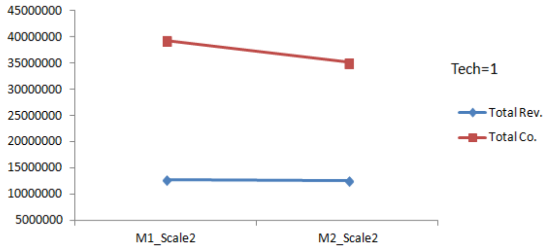


Figure 6-2. Scenario 1_Scale 2.

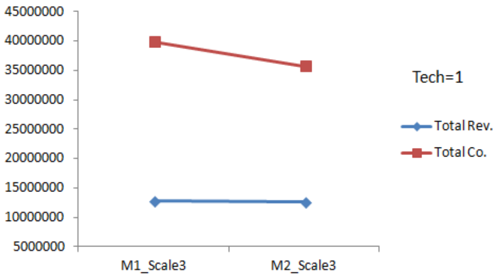


Figure 6-3. Scenario 1_Scale 3.

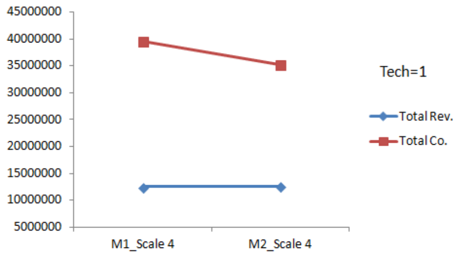


Figure 6-4. Scenario 1_Scale 4.

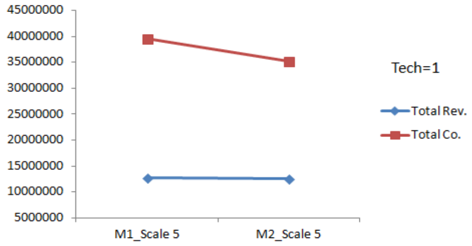


Figure 6-5. Scenario 1_Scale 5.

Figure 6-6 to 6-8 shows the results of scenario 2. Figure 6-6 displays the results of five scales in one figure and shows the performance of the Rev. of the M1 and M2. The total revenues of the M2 are lower than the M1. Figure 6-7 display the results of five scales in one figure and shows the performance of the Co. of the M1 and M2. The total costs of the M2 are lower than the M1. Figure 6-8 displays the results of five sales in one figure and shows that the performance of the Rev./Co. of the M1 and M2. The performance of the Rev./Co. of the M2 is higher than that of the M1. This means that because the direct delivery and shipment is attached to the M2, although the total revenues of the M2 are lower than the M1, the total costs of the M2 are also lower than the M1, but the results of the Rev./Co. of the M2 are almost identical with the M1.

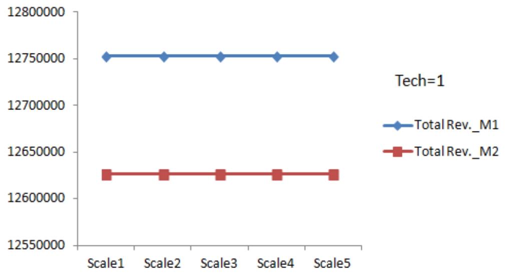


Figure 6-6. Scenario 2_Rev.

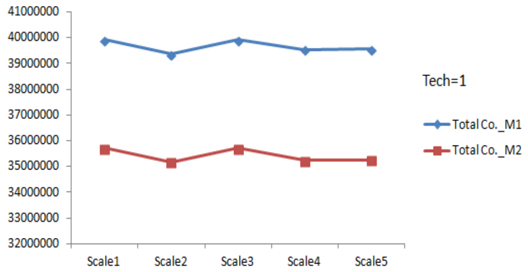


Figure 6-7. Scenario 2_Co.

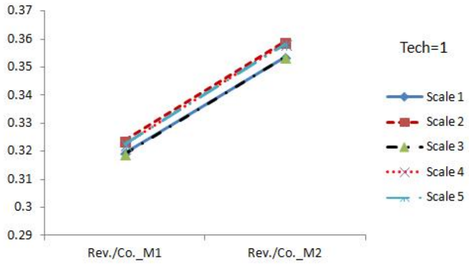


Figure 6-8. Scenario 2_Rev./Co.

Table 6-6 shows the computation results of the M1 with the Tech changing from 1 to 2 in Scale 1. The result of the Rev. is 12,753,134 when the Tech value is 1 in Scale 1. With the Tech value rising to 1.5, the result of the Rev. is rising to 19,129,700, an increase of 33.3%. With the Tech value rising to 2, the result of the Rev. is rising again to 25,506,267, the increase is 36.1%. However, compared with the increase in the Rev., the result of the Co. has not changed much. The result of the Co. is 39,925,528 when the Tech value is 1 in Scale 1. With the Tech value rising to 1.5, the result of the Co. is rising to 39,929,878, an increase of 0.010%. With the Tech value rising to 2, the result of the Co. is again to 39,934,228, an increase is also 0.010%.

Table 6-6. Computation results of the M1 along with various Tech under Scale 1

	Tech=1	Tech=1.5	Tech=2
Rev.	12,753,134	19,129,700	25,506,267
Co.	39,925,528	39,929,878	39,934,228
Rev./Co.	0.3194	0.4791	0.6387

Table 6-7 shows the computation results of the M2 with the Tech value changing from 1 to 2 in Scale 1. The result of the Rev. is 12,626,116 when the Tech value is 1 in Scale 1. With the Tech value rising to 1.5, the result of the Rev. is rising to 18,705,933, an increase of 32.5%. With the Tech value rising to 2, the result of the Rev. is rising again to 24,785,752, an increase of 24.5%. However, compared to the results of the Rev. of M1, the result of the Rev. of M2 are lower than the M1. Simultaneously, comparing with the increase in the Rev., the result of the Co. has not changed much. The result of the Co. is 35,709,009 when the Tech value is 1 in scale 1. With the Tech value rising to 1.5, the result of the Co. is rising to 35,713,359, an increase of 0.012%. With the Tech value rising to 2, the result of the Co. is rising again to 35,717,844, an increase of 0.012%. Therefore, the results are consistent with Scenario 3, as mentioned previously.

Table 6-7. Computation result of the M2 along with various Tech under Scale 1

	Tech=1	Tech=1.5	Tech=2
Rev.	12,626,116	18,705,933	24,785,752
Co.	35,709,009	35,713,359	35,717,844
Rev./Co.	0.3536	0.5238	0.6939

The same contents of Table 6-7 and Table 6-8 can be represented by figures. Figure 6-9 to 11 shows the results of Scenario 3. Figure 6-9 displays the results of the Rev./Co. of the M1 and the M2 along with the change of Tech value from 1 to 2. The results show that as Tech increased, the result of the Rev. has also increased for the M1 and the M2. Figure 6-10 shows that the performance of the Co. is similar no matter how tech changes. Figure 6-11 shows that as Tech value higher, the performance of the Rev./Co. is increased for the M1 and the M2. It means that higher Tech value has a significant effect on the performance of Rev./Co. In other words, higher quality used tires can produce higher revenues.

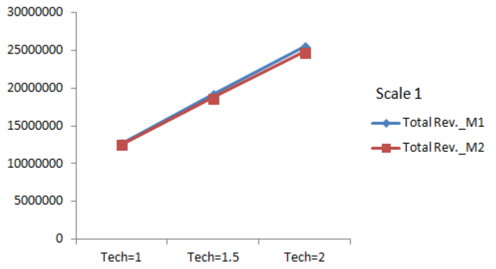


Figure 6-9. Scenario 3_Rev.

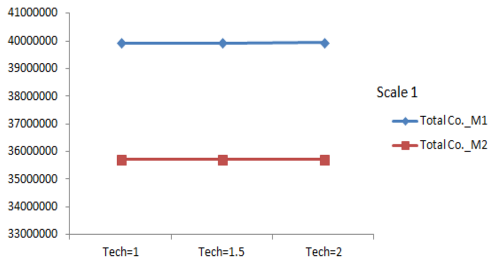


Figure 6-10. Scenario 3_Co.

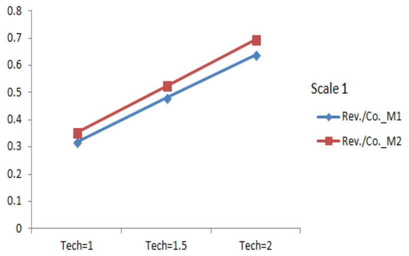


Figure 6-11. Scenario 3_Rev./Co.

Tables 6-8 and 6-9 show the computation results of the M1 and the M2 with the Tech value changing from 1 to 2 in scale 5. The scales and the comparison conditions are identical to Tables 6-6 and 6-7. The results are also similar with Tables 6-6 and 6-7. The detail contents are shown in Tables 6-8 and 6-9.

Table 6-8. Computation results of the M1 along with various Tech under Scale 5.

	Tech=1	Tech=1.5	Tech=2
Rev.	12,753,134	19,129,700	25,506,267
Co.	39,549,845	39,565,320	39,560,614
Rev./Co.	0.3224	0.4834	0.6447

Table 6-9. Computation results of the M2 along with various Tech under Scale 5.

	Tech=1	Tech=1.5	Tech=2
Rev.	12,626,116	18,705,933	24,785,752
Co.	35,242,920	35,235,501	35,242,399
Rev./Co.	0.3582	0.5308	0.7033

The same contents are represented by figures. Figures 6-12 to 6-14 show the results of scenario 4. Scenario 4 shows a similar result with scenario 3. In scenario 4, except the scale size, all the other conditions are same, the results show that as Tech value higher, the performance of the Rev. and the Rev./Co. has increased. So the higher quality of used tire has a significant effect on the performance of the Rev./Co..

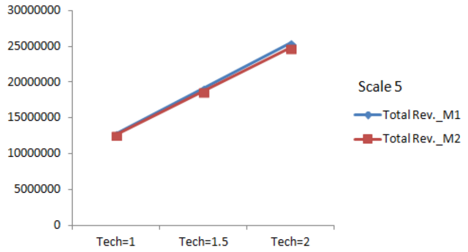


Figure 6-12. Scenario 4_Rev.

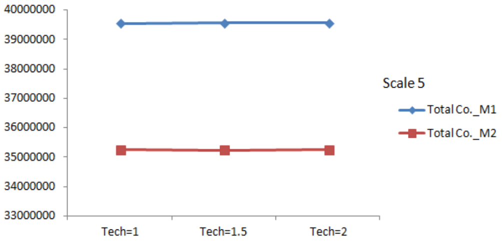


Figure 6-13. Scenario 4_Co.

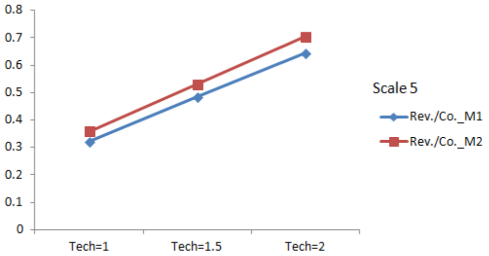


Figure 6-14. Scenario 4_Rev./Co.

In conclusion, for each scale, the results of the Rev. of the M1 are almost identical to the M2. The results of the Co. of the M2 are lower than the M1, and the results of the Rev./Co. of the M2 are higher than the M1. The Tech value has no significant effect on the results of the Co. of the M1 and the M2. However, it has a significant effect on the results of the Rev. of the M1 and the M2. The results show that the higher quality used tires have a positive effect on the results of the Rev. and the Rev./Co. Based on the scenario 1, 2, 3, 4, we conclude that the M2 is more efficient than M1. Finally, the computational results of the best solution of the M2 is 35,229,866, the location and allocation decision of the M2 is shown in Table 6-10. The opened number of facility at each stage is shown in Table 6-10. Simultaneously, the computation results of the M2 along with transportation quantity are shown in Figure 6-15.

Table 6-10 Location and allocation decision for the M2 in Scale 5 along with best solution.

Stage	TM	DC	TD	CC	RM	RY	IN
No.	9	9	7	7	9	3	6

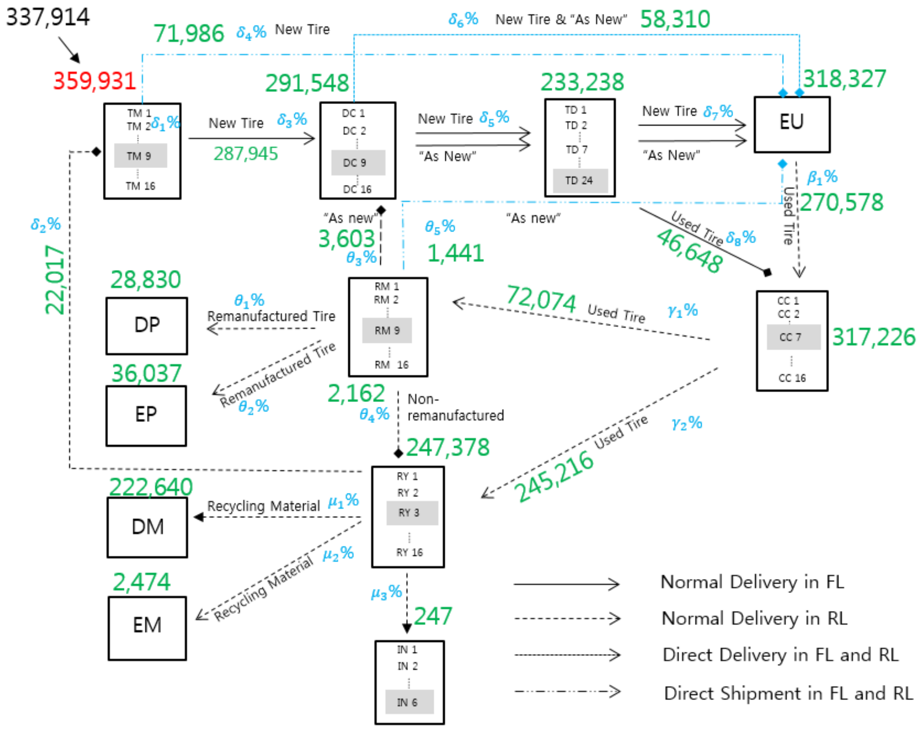


Figure 6-15. Computation result of the M2 along with transportation quantity

In Figure 6-15, the quantity of transportation from the TM is fixed at 359,931 tons. The quantity of transportation from the TM to the DC with 80% of the total is 287,945 tons in terms of normal delivery. The quantity of transportation from the TM to the EU is 71,986 tons with 20% of the total in terms of direct shipment. At the DC, the remanufactured tires are always transported from the RM to the DC, and the quality is identical to the new tires. The received transportation quantity at the DC is divided into two parts. One part is received from the TM, which is 287,945 tons. The other part is received from the RM, which is 3,603 tons. Thus, the transportation quantity of the DC is 291,548 tons, which is the sum of 287,945 and 3,603. The quantity of transportation from the DC to the TD is 233,238 tons with 80% of the total of 291,548 tons. The quantity of transportation from the DC to the EU is 58,310 tons, with 20% of the total of 291,548 tons in terms of direct delivery. At the EU, the received quantity is divided into four parts. The first part is transported from the TD, and the transportation quantity is 186,590 tons, with 80% of the total of 238,238 tons. The second part is transported from the TM, and the transportation quantity is 71,986 tons, with 20% of the total of 359,931 tons in terms of direct shipment. The third part is transported from the DC, and the transportation quantity is 58,310 tons, with 20% of the total of 291,548 tons in terms of direct delivery. The fourth part is transported from the RM, and the transportation quantity is 1,441 tons, with 2% of the total of 72,074 tons. Thus, the sum of those four parts is 318,327 tons at the EU.

At the CC, the transportation quantity is divided into two parts: one part is transported from the EU, and the quantity of transportation from the EU is 270,578 tons, with 85% of the total of 318,327 tons. The other part is transported from the TD, and the quantity of transportation from the TD is 46,648 tons, with 20% of the total of 233,238 tons. Therefore, the transportation quantity of the CC is 317,226 tons which is the sum of the two parts. The quantity of transportation from the CC to the RM is 72,074 tons, with 22.72% of the total of 317,226 tons. The quantity of transportation from the CC to the RY is 245,216 tons with 77.30% of the total of 317,226 tons.

At the RM, the total transportation quantity is 72,074 tons and divided into five parts. The first part is transported to the DP, and the quantity of transportation is 28,830 tons with 40% of the total. The second part is transported to the EP, and the quantity of transportation is 36,037 tons with 50% of the total. The third part is transported to the DC, and the quantity of transportation is 3,603 tons, with 5% of the total. The fourth part is transported to the EU, and the quantity of transportation is 1,441 tons, with 2% of the total. The five part is transported to the RY, and the quantity of transportation is 2,162 tons with 3% of the total.

At the RY, the transportation quantity is transported from the RM with 2,162 tons and from the CC with 245,216 tons, thus the total transportation quantity transported to the next stage is the sum of the two parts. The total transportation quantity is 247,378 tons, and transported to four stages. The first one is the DM, and the quantity of transportation is 222,640 tons, with 90% of the total. The second one is the EM, and the quantity of transportation is 2,474 tons, with 1% of the total. The third one is the IN, and the quantity of transportation is 247 tons, with 0.1% of the total. The fourth one is the TM, and the quantity of transportation is 22,017 tons, with 8.9% of the total. Therefore, a part of the raw materials can be supplied from the RY, with 22,017 tons. So compared to the M1, only 337,914 tons need to be produced at the TM.

A brief summary of the section 6.1 is as follows. The numerical example is carried out through a case study using real data in the Korean tire industry. Five scales are considered for the M1 and the M2. The distribution ratios of each stage are used in the M1 and the M2. Various scenarios are represented within the five scales and distribution ratios of each stage.

The M1 is compared to the M2 through scenario 1 to 4. Scenarios 1 and 2 represent the result of the Rev. the Co. and the Rev./Co. in five scales with Tech = 1. The computation results of scenarios 1 and 2 show that the result of the Rev. is similar at both the M1 and M2. The result of the Co. of the M1 is higher than the M2. The result of the Rev./Co. of the M1 is lower than the M2.

Scenarios 3 and 4 represent the result of the Rev. the Co. and the Rev./Co. with changing of the Tech value in scales 1 and 5, respectively. The computation results of scenarios 3 and 4 show that the result of the Co. of the M1 is higher than the M2 with a changing Tech value from 1 to 2 both in scale 1 and scale 5. The result of the Rev. and the Rev./Co. represents that with the increase of the Tech value, the result of the Rev. and the Rev./Co. increases both in the M1 and the M2. Therefore, we can conclude that the M2 is a more efficient CLCS network model than the M1. The efficiency improvement of the M2 is influenced on the following several points:

- Transportation routes using direct delivery and shipment can increase the flexibility of the CLSC network model. Therefore, various treatment methods are applied to the M2 more frequently.
- The technology coefficient which can be represented by the value of Tech has a significant influence on the performances of the M1 and the M2.
- Since the limitation of treatment capacity is adapted to the M2, additional 22,017 tons raw materials are produced inside of the M2, and they can reduce the production cost at the TM.
- The amount of incineration materials is reduced from 410 tons to 247 tons in the M2.
- The location and allocation decisions of each stage are optimized.

6.2 Sensitivity Analysis

In section 6.1, the distribution ratios for normal delivery, direct delivery and shipment were assigned as 0.8 and 0.2, respectively. The ratios of treatment method at the RM and the RY in terms of remanufacturing, recycling, and waste disposal were applied to the M1 with the real date (KOTMA, 2017). However, the M2 has a different network structure when compared with the M1, so the ratios are assigned to the M2 as maximally the same as those of the M1 according to the real data (KOTMA, 2017). For sensitivity analysis, to verify the effect of ratio regulation on the performance of the CLSC network model, the ratios for normal delivery, direct delivery and shipment are considered with various value. The ratios of treatment method at the CC, the RM and the RY are assigned with various value in this section.

Among various cases, the ratio regulation is divided into two parts. The first part is that the ratio is regulated in treatment methods in terms of remanufacturing, recycling, and waste disposal. The second part is that the ratio is regulated in transportation routes/types in terms of normal delivery, direct delivery and shipment.

A sensitivity analysis of the M2 will be carried out by changing the ratio regulation in terms of transportation routes/types and treatment methods. In cases 1, 2, 3 and 4, the ratio of transportation routes/types is changed in terms of normal delivery, direct delivery and shipment. In cases 5, 6 and 7, the amount of transportation from the RM and the RY to each stage should be changed. In cases 8, 9 10, 11 and 12, the amount of transportation from the CC to next stage should be changed. The detail contents are showed in Table 6-11.

Table 6-11. Various cases

	Case1	Case2	Case3	Case4	Case5	Case6	Case7	Case8	Case9	Case10	Case11	Case12
δ_3	0.95	0.9	0.85	0.7	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
δ_4	0.05	0.1	0.15	0.3	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
δ_5	0.95	0.9	0.85	0.7	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
δ_6	0.05	0.1	0.15	0.3	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
δ_7	0.95	0.9	0.85	0.7	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
δ_8	0.05	0.1	0.15	0.3	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
γ_1	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.3	0.4	0.5	0.7	0.8
γ_2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.7	0.6	0.5	0.3	0.2
θ_1	0.4	0.4	0.4	0.4	0.3	0.5	0.6	0.4	0.4	0.4	0.4	0.4
θ_2	0.4	0.4	0.4	0.4	0.3	0.2	0.2	0.4	0.4	0.4	0.4	0.4
θ_3	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
θ_4	0.05	0.05	0.05	0.05	0.1	0.1	0.05	0.05	0.05	0.05	0.05	0.05
θ_5	0.05	0.05	0.05	0.05	0.1	0.1	0.05	0.05	0.05	0.05	0.05	0.05
μ_1	0.4	0.4	0.4	0.4	0.3	0.5	0.6	0.4	0.4	0.4	0.4	0.4
μ_2	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4
μ_3	0.1	0.1	0.1	0.1	0.2	0.1	0.05	0.1	0.1	0.1	0.1	0.1
μ_4	0.1	0.1	0.1	0.1	0.2	0.1	0.05	0.1	0.1	0.1	0.1	0.1

Table 6-12 shows the various scenarios for the sensitivity analysis. Under the situation of scale 5 and same Tech value, the performances of the Rev. the Co. and the Rev./Co. are compared by changing the transportation routes/types from case 1 to 4, as shown in Figure 6-15 and 6-16. In scenario 6, the performances of the Rev. the Co. and the Rev./Co. are compared to the changing of transportation method from case 5 to 7, and showed in Figure 6-17 and 6-18. In scenario 7, the performances of the Rev. the Co. and the Rev./Co. are compared with changing of transportation methods from case 8 to case 12 and showed in Figure 6-19 and 6-20.

In Scenario 5 from case 1 to case 4, the effect of ratios change of normal delivery, direct delivery and shipment on the performance of CLSC network model will be verified. In Scenario 6 from case 5 to 7, the effect of remanufacturing and recycling activities on the performance of CLSC network model will be verified when ratios are changing. In Scenario 7 from case 8 to 12, the effect of collection situations of remanufacturable and recyclable tires on performance of CLSC network model will be verified when ratios are changing.

Table 6-12. Various scenarios for sensitivity analysis of M2

Scenario	Tech	Case	Scale	Performance
5	1	1,2,3,4	5	Rev. Co. Rev./Co.
6	1	5,6,7	5	Rev. Co. Rev./Co.
7	1	8,9,10,11,12	5	Rev. Co. Rev./Co.

Table 6-13 shows the computation results of scenario 5 with the same Tech value from Case 1 to 4 in Scale 5. The result of the Rev. is 12,159,638. With the case changing from 2 to 4, the result of the Rev. is in turns 12,060,678, 11,984,978, and 11,877,402. Simultaneously, The results of the Co. and Rev./Co. are shown in Table 6-13. The result of the Co. is 38,738,164 in Case 1, it is decreasing to 34,528,511 in Case 4, an decrease of 10.86%. The result of Rev./Co. is 0.3139 in Case 1, it is 0.3439 in Case 4, an increase of 9.5%

Table 6-13. Computation results of scenario 5.

	Case 1	Case 2	Case 3	Case 4
Rev.	12,159,638	12,060,678	11,984,978	11,877,402
Co.	38,738,164	37,407,175	36,337,188	34,528,511
Rev./Co.	0.3139	0.3224	0.3298	0.3439

The same contents are represented by figures. Figure 6-16 shows that the performance of the Rev. stays consistent by increasing the amount of direct delivery and direct shipment in cases 1, 2, 3, and 4. However, the performance of the Co. is decreasing under the same situations.

Figure 6-17 shows that the performance of the Rev./Co. is increasing in cases 1, 2, 3, 4. So through scenario 5, we can conclude that the direct delivery and shipment has a positive effect on performance of the Rev./Co.

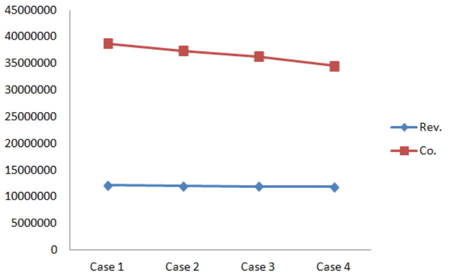


Figure 6-16. Scenario 5_Rev. & Co.

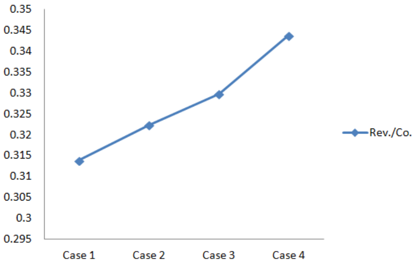


Figure 6-17. Scenario 5_Rev./Co.

Table 6-14 shows the computation results of scenario 6 with the same Tech value from Case 5 to 7 in Scale 5. The result of the Rev. is in turns 12,060,648, 12,159,638, 11,984,978 from Case 5 to 6. The result of the Co. is 37,407,175 in Case 5, it is rising to 38,738,164 in Case 6, and declining to 36,337,188 in Case 7. The result of Rev./Co. is 0.3224 in Case 1, it is declining to

0.3139 in Case 6, and rising up to 0.3298 in Case 7.

Table 6-14. Computation results of scenario 6.

	Case 5	Case 6	Case 7
Rev.	12,060,648	12,159,638	11,984,978
Co.	37,407,175	38,738,164	36,337,188
Rev./Co.	0.3224	0.3139	0.3298

The same contents are represented by figures. Figure 6-18 shows that the performance of the Co. is decreasing with the changing of the ratio of transportation from the RM and the RY to each next stage in cases 5, 6, and 7. The performance of the Rev. keeps almost consistent in case 5, 6, and 7. Figure 6-19 shows that the performance of the Rev./Co. is declining at beginning and rising up on late.

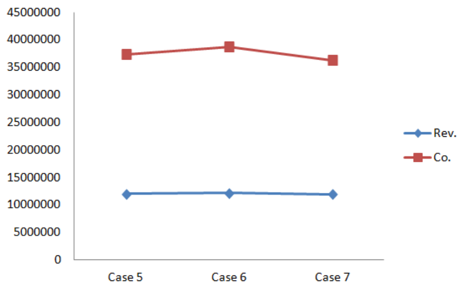


Figure 6-18. Scenario 6_Rev. & Co.

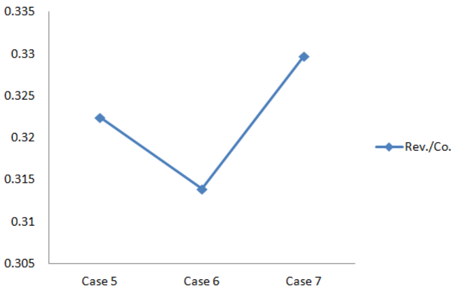


Figure 6-19. Scenario 6_Rev./Co.

Table 6-15 shows the computation results of scenario 7 with the same Tech value from Case 8 to 12 in Scale 5. The results of the Co. and Rev. keep almost consistent from Cases 8 to 12. The result of Rev./Co. is 0.3223 in Case 8, it is declining to 0.3046 in Case 12, an decrease of 5.49%.

Table 6-15. Computation results of scenario 7.

	Case 8	Case 9	Case 10	Case 11	Case 12
Rev.	12,559,879	12,760,001	12,359,757	11,959,514	11,759,393
Co.	38,969,387	39,065,058	38,884,722	38,690,610	38,594,115
Rev./Co.	0.3223	0.3266	0.3178	0.3090	0.3046

The same contents are represented by figures. Figure 6-20 shows that the performance of the Co. and the Rev. has subtle changes with the changes of ratio of transportation from the CC to the RM and the RY in case 8, 9, 10, 11, and 12.

Figure 6-21 shows that the performance of the Rev./Co. is increasing from case 8 to case 9, and then declining from case 9 to case 12.

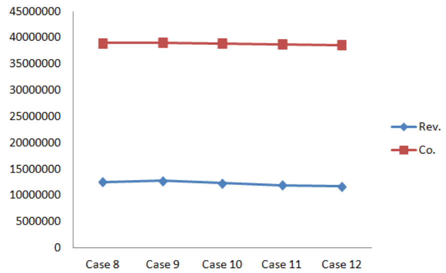


Figure 6-20. Scenario 7_Rev. & Co.

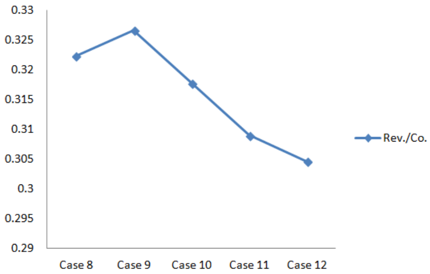


Figure 6-21. Scenario 7_Rev./Co.

A sensitivity analysis is applied to the M2 by regulating the distribution ratio. The application of ratio regulation is divided into two parts. One part is applied into the transportation routes/types. The ratio regulation is applied into normal delivery and direct delivery and shipment at the TM, DC, and RM stage. The other one part is applied into treatment method in the RL at stage of the CC, the RM, and the RY. The computation results are represented in scenarios 5, 6, and 7.

The computation results show that the ratio regulation has no significant effect on the performance of the Rev. in scenarios 5, 6, and 7. Along with the ratio of direct delivery and shipment increasing in scenarios 5, 6, and 7, the computation result of the Co. decreases, and the result of the Rev./Co. increases, which means that the direct delivery and shipment has a significant effect on the performance of the M2.

By contrast, there are not distinct regularity in the result of the Co. and the Rev./Co. when the ratio is regulated at stage of the CC, the RM, and the RY. So the application of ratio regulation of treatment method has no significant effect on the performance of the Rev./Co.

Based on the computation result using various sensitive analyses, the following summary can be reached.

- Direct delivery and shipment has a significant influence on the performance of Rev. and Rev./Co.
- The ratio regulations for remanufacturable products and recycable materials have highly effect on the performance of Rev. rather than that of Co.
- The ratio regulations for remanufactured products and recycable materials have highly effect on the performance of Co. rather than that of Rev.

VII. Conclusions

The term of logistics was used in military terms before the 1950s (Ballou, 1978). Around 1950s, logistics firstly was changed to “transformation” (Heskett et al. 1964). American Production and Inventory Control Society (APICS, 1990) defined the supply chain, and the basis supply chain consists of suppliers, manufacturers, distributors, retailers, and customers (Chopra et al. 2001). RL was realized, starting from remanufacturing. The early research of the RL, which was sponsored by U.S. military, focused on the relationship and coordination between each stage (Guide, 1996; Guide et al. 1998). Contrary to expectations, in Europe, The RL was subjected to legislation via European Union directives on end-of-life product. A CLSC network model is developed when companies taken attention to minimize the return costs and disposal costs (Stock et al. 2002). Daniel et al. (2009) defined the conception of the CLSC network model as a system which maximizes value creation over the entire life cycle by the design, control, and operation.

The focusing points for the CLSC network model of this literatures are numerous. Along with the evolution of the CLSC network model, research has moved from OR-based problems to profitability and maximizing value. There are several methods to achieve the profitability and maximizing value. Those methods consist of six characteristics as follows: treatment methods, transportation routes/types, limitation of treatment capacity, ratio regulations, technology coefficients, Location and allocation decisions.

The objective of this paper is to design an efficient CLSC network model along with an application of various strategies considering the six characteristics. A mathematical formulation is built. To find the optimal solution of minimization costs and maximization revenue, a GA method is used.

In the numerical experiments, two CLSC network models are compared. According to the data of Korea Tire Manufacturers Association (KOTMA, 2017), we display the structure of the CLSC network model in the Korean Tire industry by the M1. Meanwhile, an improved CLSC network model of the M2 is proposed to offset the weakness of the M1. Various stages are included in the M1 and the M2. For the FL, the TM, DC, TD, EU have been considered. For the RL, the CC, RM, RY, DP, EP, DM, EM, and IN have been considered. The difference is that the M1 only uses normal delivery, but the M2 attaches by direct shipment and direct delivery.

For the stages of the RM and the RY, the treatment methods of remanufacturing, recycling, and waste disposal are considered. With the capacity of each stage limited, the ratio regulation of treatment method and transportation routes/types are considered. The treatment methods are regulated in terms of the ratio of remanufacturing, recycling, and waste disposal. The transportation routes/types are regulated in terms of the ratio of normal delivery, direct delivery and shipment.

The Tech is considered to indicate the high quality and normal quality of used tires. Based on those situations, for the M1 and the M2, the objective function of mathematical formulations are to minimize total costs and maximize total revenues. The total costs are consist of fixed costs, production costs, handling costs, collection costs, investment costs for environmental protection, incineration costs, and transportation costs. The total revenues consist of sales of new tires, used tires and recycling materials. The mathematical formulations are implemented using a GA approach. Meanwhile, the decision of location and allocation are optimized.

In numerical experiments, five scales and four scenarios have been presented to compare the performances of the M1 and the M2. Under the same situations, the performance of the Rev. of the M1 is almost identical to the M2. The performance of the Co. of the M1 is lower than the M2. However, the performance of the Rev./Co. of the M2 is higher than the M1. The performance of the Rev./Co. of M2 is higher than the M1 along with the increasing technological coefficients. This means that high quality of used tires have a significant effect on the performance of the M2. Simultaneously, the computational results show that the M2 with normal delivery, direct delivery and direct shipment is more efficient than the M1 with normal delivery alone. In addition, the ratio of treatment methods and transportation routes/types are both regulated.

The results show that the ratio regulation has no significant effect on the performance of the Rev., but the ratio regulation has a significant effect on the performance of the Co., and the Rev./Co. So various treatment methods, transportation routes/types, ratio regulations, and technological coefficients are efficient strategies for the proposed CLSC network model of the M2. In the M1, 359,931 tons raw materials were used at TM. However, through implementing the M2, a part of the raw materials can be supplied from the RY with 22,017 tons. So compared with the M1, only 337,914 tons need to be used at the TM.

In the future study, i) larger scales and more various scenarios will be considered, ii) various hybrid approaches using Tabu search, Cuckoo search, and particle swarm optimization will be used to compare the performance of the GA, iii) the environmental effect will be taken into consideration, and iv) more practical data taken from real world will be used, for reinforcing the performance of the M2.

References

Amin, S. H. and Zhang, G. (2012), A proposed mathematical model for closed-loop network configuration based on product lift cycle, *International Journal of Advanced Manufacturing Technology*, 58(5):791-801.

Amin, S. H. and Zhang, G. (2013), A three-stage model for closed-loop supply chain configuration under uncertainty, *International Journal of Production Research*, 51(5): 1405-1425.

Amin, S. H., Zhang, G. and Akhtar, P. (2017), Effects of uncertainty on a tire closed loop supply chain network, *Expert Systems With Applications*, 73:82-91.

ANIP. (2012). *National association of the tire industry*. Reciclanip. Available at: www.reciclanip.com.br/?cont=ecopontos_oquesao, accessed 2012.06.15.

Aras, N., Boyaci, T. and Verter, V. (2004), The effect of categorizing returned products in remanufacturing, *IIE Transactions*, 36:319‑331.

Baker, J. E. (1985), Adaptive selection methods for genetic algorithms, *Proceeding of The First International Conference on Genetic Algorithms and Their Applications*.

Ballou, R. (1978), *Basic Business Logistics*, Prentice-Hall, Englewood Cliffs, NJ.

Bhandari, D., Murthy, C. A. and Sankar K, P. (1996), Genetic algorithm with elitist model and its convergence, *International Journal of Pattern Recognition and Artificial Intelligence*, 10(6): 731-747.

Bloemhof-Ruwaard, J. M., Van Wassenhove, L. N., Gabel, H. and Weaver, P. (1996), An environmental life cycle optimization model for the European pulp and paper industry, *Omega* 24:615‑629.

Charlle S. (2017), A policy development model for reducing bullwhips in hybrid production-distribution systems, *International Journal of Production Economics*, 190:67-79.

Chen, Y. T., Chan, F. T. S., and Chung, S. H. (2015), An integrated closed-loop supply chain model with location and allocation problem and product recycling decisions, *International Journal of Production Research*, 53(10):3120-3140.

Chen, Y, W., Wang, L. C., Wang, A. and Chen, T. L. (2017), A particle swarm approach for optimizing a multi-stage closed loop supply chain for the solar cell industry, *Robotics and Computer-Integrated Manufacturing*,43:111-123.

Cheng, R. W., Gen, M. and Tsujimura, Y. (1996), A tutorial survey of job-shop scheduling problems using genetic algorithm ‑ I. representation, *Computer & Industrial Engineering*, 30(4):983-997.

Chopra, S. and Meindl, P. (2001), *Supply Chain Management: Strategy, Planning, and Operation*, Prentice-Hall, Upper Saddle River, NJ.

Collins, K. J., Jensen, A. C., Mallinson, J. J., Roenelle, V. and Smith, I. P. (2002), Environmental impact assessment of a scrap tyre artificial reef, *ICES Journal of Marine Science*, 59:S243-S249, DOI:10.1006/jmsc.2002.1297.

Debanné, J. G. (1975), A regional techno-economic energy supply-distribution-demand model for North America, *Computers and Operations Research*, 2(3-4):153-193.

De Jong, K. A. (1975), An analysis of the behavior of a class of genetic adaptive systems, Doctoral Dissertation, *Dissertation Abstracts International*, (36):10, 5140B.

Eshelman, L and Schaffer, J. (1993), Real-coded genetic algorithms and interval-schemata, in Whitely, L. (Ed.), *Foundations of Genetic Algorithm*, 2:187-202, Morgan Kanufmann Publisher, San Francisco.

Fleischmann, M., Beullens , P., Bloemhof-Ruwaard, J. M. and Van Wassenhove, L. N. (2001), The impact of product recovery on logistics network design, *Production and Operations Management*, 10(2):156-173.

Fleischmann, M., Van Nunen, J. and Gräve, B. (2003), Integrating closed-loop supply chains and spare-parts management at IBM, *Interfaces*, 33:44‑56.

Gan, **S. S.**, Pujawan, I. N. and Widodo, B. (2017), Pricing decision for new and remanufactured product in a closed-loop supply chain with separate sales-channel, *International Journal of Production Economics*, 190:120-132.

Galbreth, M. and Blackburn,J. D. (2006), Optimal acquisition and sorting policies for remanufacturing, *Production Operations Management*, 15:384‑392.

Gen, M. and Cheng, R. (1997), *Genetic Algorithms and Engineering Design*, John-Wiley & Sons, New York.

Gen, M. and Cheng, R. (2000), *Genetic Algorithms and Engineering Optimization*, John-Wiley & Sons, New York.

Guide, Jr. V. D. R. (1996), Scheduling using drum-buffer-rope in a remanufacturing environment, *International Journal of Production Research*, 34:1081‑1091.

Guide, Jr. V. D. R. and Srivastava, R. (1998), Inventory buffers in recoverable manufacturing, *Journal of Operations Management*, 16:551‑568.

Guide, Jr. V. D. R., and Van Wassenhove, L. N. (2001), Managing product returns for remanufacturing, *Production Operations Management*, 10:142‑155.

Guide, Jr. V. D. R. and Van Wassenhove, L. N. (2002), Closed-loop supply chains. In A. Klose, (Ed.), *Quantitative approaches to distribution logistics and supply chain management*, 47‑60 Springer.

Guide, Jr. V. D. R., and Van Wassenhove, L. N. (2003a), Special section on closed-loop supply chains, *Interfaces*, 33(6):1-2.

Guide, Jr. V. D. R., and Van Wassenhove, L. N. (2003b), *Business Aspects of Closed-Loop Supply Chains*, Carnegie Mellon University Press, Pittsburgh.

Guide, Jr. V. D. R. and Van Wassenhove, L. N. (2006), Feature issue on closed-loop supply chains, *Production Operations Management*, 15:3-4.

Guide, Jr. V. D. R. and Van Wassenhove, L. N. (2009), The evolution of closed-loop supply chain research, *Operations Research*, 57(1):10-18.

Goldberg, D. E. (1989), *Genetic Algorithms in Search, Optimization and Machine Learning*, Addison-Wesley Publishing Company.

Habib, M. (2011), *Supply Chain Management*, INTECH, DOI: 10.5772/755. www.intechopen.com.

Hasani, A., Zegordi, S. H. and Nikbakhsh, E. (2012), Robust closed-loop supply chain network design for perishable goods in agile manufacturing under uncertainty, *International Journal of Production Research*, 50(16):4649-4669.

Hasani, A., Zegordi, S. H. and Nikbakhsh, E. (2015), Robust closed-loop global supply chain network design under uncertainty: The case of the medical device industry, *International Journal of Production Research*, 53(5):1596-1624.

Heskett, J., Ivie, R. and Glaskowsky, N. (1964), *Business Logistics, Management of Physical Supply and Distribution*, the Ronald Press Company, New York, NY.

Holland, J. H. (1975), *Adaptation in Natural and Artificial Systems*. University of Michigan Press, Ann Arbor.

Holland, C. P. (1995), *Adaptation in nature and artificial systems: an introductory analysis with applications to biology , control, and artificial intelligence*, University of Michigan Press, Ann Arbor.

Jamrus, T., Chien, Ch. F., Gen, M. and Sethanan, K. (2015), Multistage production distribution under uncertain demands with integrated discrete particle swarm optimization and extended priority-based hybrid genetic algorithm, *Fuzzy Optimization & Decision Making*, 14(3):265-287.

Jayaraman, V., Guide, V. D. R. and Srivastava, R. (1999), A closed-loop logistics model for remanufacturing, *Journal of the Operational Research Society* 50(5): 497-508.

Jindal, A. and Sangwan, K. S. (2014), Closed-loop supply chain network design and optimization using fuzzy mixed integer linear programming model, *International Journal of Production Research*, 52(14):4156-4173.

John, T. Mentzer., William DeWitt., James S. Keebler., Soonhong Min., Nancy W. Nix., Carlo D. Smith and Zach G. Zacharia. (2001), Defining supply chain management*, Journal of Business Logistics, 22(2):1-15.*

Johnson, J. M. and Rahmat-Samii, V. (1997), Genetic algorithm in engineering electromagnetics, *IEEE Antennas and Propagation Magazine*, 39(4):7-21.

Kannan, G., Sasikumar, P. and Devika, K. (2010), A genetic algorithm approach for solving a closed loop supply chain model: A case of battery recycling, *Applied Mathematical Modelling*, 34(3):665-670.

Kelvin Chiang, W. Y., Chhajed, D. and Hess, J. D. (2003), Direct marketing, indirect profits: a strategic analysis of dual-channel supply chain design, *Management Science*, 49(1):1-20.

Keyvanshokooh, E., S. M.and Kabir, E. (2016), Hybrid robust and stochastic optimization for closed-loop supply chain network design using accelerated Benders decomposition, *European Journal of Operational Research*, 249(1):76-92.

Krikke, H., Bloemhof-Ruwaard, J. and Van Wassenhove, L. N. (2003), Concurrent product and closed-loop supply chain design with an application to refrigerators, *International Journal of Production Research*, 41(16):3689-3719.

KOTMA. (2017), *Korea Tire Manufacturers Association*. www.kotma.or.kr. accessed 2017.09.05.

Lund, R. T. (1984), *Remanufacturing The Experience of the United States and Implications for Developing Countries*. World Bank, Washington, D.C.

Lund, R. T. (1996), *The Remanufacturing Industry: Hidden Giant*. Boston University, Boston.

Michalewicz, Z. (1996), *Genetic Algorithm + Data Structure = Evolution Programs*, 3rd edition, Spring-Verlag, New York.

Min, H. and Ko, H. J. (2008), The dynamic design of a reverse logistics network from the perspective of third-party logistics service providers, *International Journal of Production Economics*, 113(1):176-192.

Mitra, S. (2012), Inventory Management in a Two-echelon Closed-loop Supply Chain with Correlated Demands and Returns, *Computers and Operations Research*, 2(3-4):153-193.

Morris, R. M. (1980), Feed coversion efficiency and the efficiency of the UK food chain, *Agriculture Systems*, 5(4):267-278.

Oliver, R. K. and Webber, M. D. (1992), Supply-chain management: logistics catches up with strategy, in Christopher, M. (Ed.), *Logistics: The Strategic Issues*, Chapman & Hall, London.

Özceylan, E. and Paksoy, P. (2013), A mixed integer programming model for a closed-loop supply chain network, *International Journal of Production Research*, 51(5):718-734.

Özceylan, E., Demirel, N., Çetinkaya, C. and Demirel, E. (2017), *Computers and Industrial Engineering*. DOI: http://dx.doi.org/10.1016/j.cie.2016.12.022.

Pedram, A., Yusoff, N. B., Udoncy, O. E., Mahat, A. B., Pedram, P. and Babalola, A. (2017), Integrated forward and reverse supply chain: A tire case study, *Waste Management*, 60:460-470

Pishvaee, M. S., Jolai, F. and Razmi, J. (2009), A stochastic optimization model for integrated forward/reverse logistics network design, *Journal of Manufacturing Systems*, 28(4):107-114.

Pishvaee, M. S., Jolai, F. and Torabi, S. A. (2011), A robust optimization approach to closed-loop supply chain network design under uncertainty. *Applied Mathematical Modelling*, 35(2):637-649.

Poon, P. W. and Carter, J. N. (1995), Genetic algorithm crossover operators for ordering applications, *Computers & Operations Research*, 22(1):135-147.

Ramezani, M., Kimiagari, A. M., Karimi, B. and Hejazi, T. H. (2014), Closed-loop supply chain network design under a fuzzy environment, *Knowledge-Based Systems*, 59: 108-120.

Realff, M. J., Ammons, J. C. and Newtom, D. J. (2004), Robust reverse production system design for carpet recycling, *IIE Transactions*, 36(8):767-776.

Reeves, C.R. (1995), A genetic algorithm for flowshop sequencing, *Computer & Operations Research*, 22(1):5-13.

Sasikumar, P., Kannan, G. and Haq, A. N. (2010), A multi-echelon reverse logistics network design for product recovery-a case of truck tire remanufacturing, *International Journal of Advanced Manufacturing Technology*, 49:1223-1234.

Sasikumar, P. and Haq, A. N. (2011), Integration of closed loop distribution supply chain network and 3PRLP selection for the case of battery recycling, *International Journal of Production Research*, 49(11):3363-3385.

Spengler, T., Stolting, W. and Ploog, M. (2004), *Recovery planning in closed loopsupply chain: An activity analysis based approach*, Dyckhoff, H., Lackes, R. and Reese, J. (Eds) Supply chain management and reverse logistics, Springer, 61‑89.

Stock, J., Speh, T. and Shear, H. (2002), Many happy (product) returns, *Harvard Business Review,* 80(7):16‑17.

Soleimani, H.and Kannan, G. (2015), A hybrid partical swarm optimization and genetic algorithm for closed-loop supply chain network design in large-scale networks, *Applied Mathematical Modelling*, 39(14):3990-4012.

Srinivas, M. and Patnaik, L. M. (1994), Adaptive probabilities of crossover and mutation in genetic algorithms, *IEEE Transaction on Systems, Mans and Cybernetics*, 24(4), 656-667.

Subulan, K., Tasan, A. S.and Baykasoglu, A. (2015), Designing an environmentally conscious tire closed-loop supply chain network with multiple recovery options using interactive fuzzy goal programming, *Applied Mathematical Modelling*, 39:2661-2702.

Tedeschi, B. (2000), Big companies go slowely in devising net strategy, *New York Times*.

Üser, H., Easwaran, G., AkÇali, E. and Çetinkaya, S. (2007), Benders decomposition with alternative multiple cuts for a multi-product closed-loop supply chain network design model, *Naval Research Logistics*, 54(8):890-907.

Van Der Laan, E., Salomon, M., Dekker,R. and Van Wassenhove, L. N. (1999), Inventory control in hybrid systems with remanufacturing, *Management Science,* 45:733‑747.

Wang, H. F, and Hsu, H. W. (2010), A closed-loop logistic model with a spannning tree based genetic algorithm, *Computers and Operations Research*, 37(2):376-389.

World Tires, (2014), *Industry Study 3105,* The Freedonia Group.

Yadav, P., Miller, D., Schmidt, C. and Drake, R. (2003), McGriff Treading Company implements service contracts under shared savings, *Interfaces*, 33:18‑29.

Zeballos, L. J., Méndez, C. A., Barbosa-Povoa, A. P. and Novais, A. Q. (2014), Multi-period design and planning of closed-loop supply chains with uncertain supply and demand, Multi-period design and planning of closed-loop supply chains with uncertain supply and demand, *Computers and Chemical Engineering*, 66:151-164.

Appendix

<Appendix 1> Transportation cost from TM to DC of M1 and M2 for Scale 5

	DC1	DC2	DC3	DC4	DC5	DC6	DC7	DC8	DC9	DC10	DC11	DC12	DC13	DC14	DC15	DC16
TM1	2.7	2.2	2.5	2.8	2.2	2.3	2.2	2.1	2.2	2.3	2.5	2.6	2.2	2.3	2.5	2.6
TM2	2.3	2.1	2.4	2.7	2.4	2.1	2.1	2.3	2.5	2.4	2.7	2.1	2.5	2.4	2.7	2.1
TM3	2.5	2.3	2.8	2.4	2.6	2.6	2.3	2.5	2.1	2.3	2.1	2.5	2.1	2.3	2.1	2.5
TM4	2.4	2.7	2.5	2.1	2.8	2.4	2.5	2.4	2.8	2.7	2.5	2.7	2.8	2.7	2.5	2.7
TM5	2.3	2.2	2.3	2.5	2.2	2.8	2.6	2.6	2.6	2.2	2.3	2.5	2.6	2.2	2.3	2.5
TM6	2.1	2.5	2.6	2.1	2.1	2.5	2.4	2.8	2.5	2.3	2.4	2.7	2.5	2.3	2.4	2.7
TM7	2.5	2.4	2.7	2.7	2.3	2.2	2.1	2.4	2.4	2.1	2.1	2.9	2.4	2.1	2.1	2.9
TM8	2.8	2.7	2.4	2.6	2.6	2.4	2.2	2.1	2.2	2.5	2.8	2.1	2.2	2.5	2.8	2.1
TM9	2.1	2.5	2.6	2.1	2.1	2.5	2.4	2.8	2.2	2.3	2.5	2.6	2.2	2.3	2.5	2.6
TM10	2.5	2.4	2.7	2.7	2.3	2.2	2.1	2.4	2.5	2.4	2.7	2.1	2.5	2.4	2.7	2.1
TM11	2.1	2.5	2.6	2.1	2.1	2.5	2.4	2.8	2.1	2.3	2.1	2.5	2.1	2.3	2.1	2.5
TM12	2.5	2.4	2.7	2.7	2.3	2.2	2.1	2.4	2.8	2.7	2.5	2.7	2.8	2.7	2.5	2.7
TM13	2.7	2.2	2.5	2.8	2.2	2.3	2.2	2.1	2.2	2.3	2.5	2.6	2.2	2.3	2.5	2.6
TM14	2.3	2.1	2.4	2.7	2.4	2.1	2.1	2.3	2.5	2.4	2.7	2.1	2.5	2.4	2.7	2.1
TM15	2.5	2.3	2.8	2.4	2.6	2.6	2.3	2.5	2.1	2.3	2.1	2.5	2.1	2.3	2.1	2.5
TM16	2.4	2.7	2.5	2.1	2.8	2.4	2.5	2.4	2.8	2.7	2.5	2.7	2.8	2.7	2.5	2.7
DC10	2.5	2.4	2.7	2.1	2.3	2.4	2.7	2.9	2.8	2.6	2.3	2.5	2.5	2.1	2.3	2.3
DC11	2.1	2.3	2.1	2.5	2.5	2.6	2.8	2.4	2.1	2.8	2.5	2.2	2.4	2.2	2.5	2.5
DC12	2.8	2.7	2.5	2.7	2.4	2.5	2.2	2.3	2.2	2.4	2.6	2.3	2.8	2.5	2.8	2.1
DC13	2.2	2.3	2.5	2.6	2.2	2.4	2.1	2.6	2.3	2.1	2.2	2.6	2.3	2.4	2.1	2.2
DC14	2.5	2.4	2.7	2.1	2.3	2.4	2.7	2.9	2.8	2.6	2.3	2.5	2.5	2.1	2.3	2.3
DC15	2.1	2.3	2.1	2.5	2.5	2.6	2.8	2.4	2.1	2.8	2.5	2.2	2.4	2.2	2.5	2.5
DC16	2.8	2.7	2.5	2.7	2.4	2.5	2.2	2.3	2.2	2.4	2.6	2.3	2.8	2.5	2.8	2.1

<Appendix 2> Transportation cost from TM to EU of M2 for Scale 5

	EU
TM1	2.5
TM2	2.8
TM3	2.4
TM4	2.1
TM5	2.3
TM6	2.5
TM7	2.8
TM8	2.6
TM9	2.6
TM10	2.5
TM11	2.4
TM12	2.2
TM13	2.5
TM14	2.7
TM15	2.6
TM16	2.1
DC10	2.5
DC11	2.4
DC12	2.8
DC13	2.3
DC14	2.5
DC15	2.4
DC16	2.8

<Appendix 3> Transportation cost from DC to TD of M1 and M2 for Scale 5

	TD1	TD2	TD3	TD4	TD5	TD6	TD7	TD8	TD9	TD10	TD11	TD12	TD13	TD14	TD15	TD16	TD17	TD18	TD19	TD20	TD21	TD22	TD23	TD24
DC1	2.2	2.3	2.5	2.6	2.2	2.4	2.1	2.6	2.3	2.1	2.2	2.6	2.3	2.4	2.1	2.2	2.3	2.4	2.1	2.2	2.1	2.2	2.3	2.4
DC2	2.5	2.4	2.7	2.1	2.3	2.4	2.7	2.9	2.8	2.6	2.3	2.5	2.5	2.1	2.3	2.3	2.5	2.1	2.3	2.3	2.3	2.3	2.5	2.1
DC3	2.1	2.3	2.1	2.5	2.5	2.6	2.8	2.4	2.1	2.8	2.5	2.2	2.4	2.2	2.5	2.5	2.4	2.2	2.5	2.5	2.5	2.5	2.4	2.2
DC4	2.8	2.7	2.5	2.7	2.4	2.5	2.2	2.3	2.2	2.4	2.6	2.3	2.8	2.5	2.8	2.1	2.8	2.5	2.8	2.1	2.8	2.1	2.8	2.5
DC5	2.6	2.2	2.3	2.5	2.3	2.2	2.3	2.5	2.5	2.6	2.8	2.4	2.9	2.6	2.6	2.6	2.9	2.6	2.6	2.6	2.6	2.6	2.9	2.6
DC6	2.5	2.3	2.4	2.7	2.2	2.1	2.5	2.4	2.4	2.7	2.4	2.9	2.1	2.8	2.4	2.9	2.1	2.8	2.4	2.9	2.4	2.9	2.1	2.8
DC7	2.4	2.1	2.1	2.9	2.4	2.6	2.7	2.3	2.3	2.5	2.1	2.7	2.2	2.4	2.5	2.5	2.2	2.4	2.5	2.5	2.5	2.5	2.2	2.4
DC8	2.2	2.5	2.8	2.1	2.7	2.4	2.3	2.9	2.1	2.4	2.6	2.5	2.5	2.2	2.1	2.8	2.5	2.2	2.1	2.8	2.1	2.8	2.5	2.2
DC9	2.2	2.3	2.5	2.6	2.2	2.4	2.1	2.6	2.3	2.1	2.2	2.6	2.3	2.4	2.1	2.2	2.3	2.4	2.1	2.2	2.1	2.2	2.3	2.4
DC10	2.5	2.4	2.7	2.1	2.3	2.4	2.7	2.9	2.8	2.6	2.3	2.5	2.5	2.1	2.3	2.3	2.5	2.1	2.3	2.3	2.3	2.3	2.5	2.1
DC11	2.1	2.3	2.1	2.5	2.5	2.6	2.8	2.4	2.1	2.8	2.5	2.2	2.4	2.2	2.5	2.5	2.4	2.2	2.5	2.5	2.5	2.5	2.4	2.2
DC12	2.8	2.7	2.5	2.7	2.4	2.5	2.2	2.3	2.2	2.4	2.6	2.3	2.8	2.5	2.8	2.1	2.8	2.5	2.8	2.1	2.8	2.1	2.8	2.5
DC13	2.2	2.3	2.5	2.6	2.2	2.4	2.1	2.6	2.3	2.1	2.2	2.6	2.3	2.4	2.1	2.2	2.3	2.4	2.1	2.2	2.1	2.2	2.3	2.4
DC14	2.5	2.4	2.7	2.1	2.3	2.4	2.7	2.9	2.8	2.6	2.3	2.5	2.5	2.1	2.3	2.3	2.5	2.1	2.3	2.3	2.3	2.3	2.5	2.1
DC15	2.1	2.3	2.1	2.5	2.5	2.6	2.8	2.4	2.1	2.8	2.5	2.2	2.4	2.2	2.5	2.5	2.4	2.2	2.5	2.5	2.5	2.5	2.4	2.2
DC16	2.8	2.7	2.5	2.7	2.4	2.5	2.2	2.3	2.2	2.4	2.6	2.3	2.8	2.5	2.8	2.1	2.8	2.5	2.8	2.1	2.8	2.1	2.8	2.5

<Appendix 4> Transportation cost from DC to EU of M2 for Scale 5

	EU
DC1	2.6
DC2	3.2
DC3	2.4
DC4	2.1
DC5	2.3
DC6	2.2
DC7	2.6
DC8	2.9
DC9	2.2
DC10	2.3
DC11	2.1
DC12	2.6
DC13	2.1
DC14	2.1
DC15	2.3
DC16	2.5

<Appendix 5> Transportation cost from TD to EU of M1 and M2 for Scale 5

	EU
TD1	2.6
TD2	2.2
TD3	2.4
TD4	2.1
TD5	2.4
TD6	2.9
TD7	2.3
TD8	2.7
TD9	2.2
TD10	2.3
TD11	2.6
TD12	2.7
TD13	2.3
TD14	2.7
TD15	3.2
TD16	3.1
TD17	3.6
TD18	2.1
TD19	2.5
TD20	2.2
TD21	2.7
TD22	2.3
TD23	2.5
TD24	2.4

<Appendix 6> Transportation cost from TD to CC of M2 for Scale 5

	CC1	CC2	CC3	CC4	CC5	CC6	CC7	CC8	CC9	CC10	CC11	CC12	CC13	CC14	CC15	CC16
TD1	2.1	2.7	2.2	2.3	2.1	2.2	2.3	2.2	2.7	2.2	2.3	2.1	2.2	2.7	2.2	2.3
TD2	2.3	2.6	2.4	2.4	2.3	2.4	2.6	2.3	2.6	2.4	2.4	2.3	2.3	2.6	2.4	2.4
TD3	2.4	2.4	2.8	2.7	2.6	2.5	2.5	2.1	2.4	2.8	2.7	2.6	2.1	2.4	2.8	2.7
TD4	2.9	2.8	2.6	2.6	2.4	2.8	2.4	2.5	2.8	2.6	2.6	2.4	2.5	2.8	2.6	2.6
TD5	2.3	2.5	2.5	2.4	2.1	2.7	2.3	2.6	2.5	2.5	2.4	2.1	2.6	2.5	2.5	2.4
TD6	2.5	2.4	2.4	2.1	2.2	2.4	2.7	2.4	2.4	2.4	2.1	2.2	2.4	2.4	2.4	2.1
TD7	2.9	2.2	2.1	2.5	2.5	2.3	2.5	2.5	2.2	2.1	2.5	2.5	2.5	2.2	2.1	2.5
TD8	2.6	2.6	2.9	2.7	2.6	2.6	2.4	2.6	2.6	2.9	2.7	2.6	2.6	2.6	2.9	2.7
TD9	2.3	2.3	2.2	2.6	2.8	2.5	2.1	2.8	2.3	2.2	2.6	2.8	2.8	2.3	2.2	2.6
TD10	2.5	2.1	2.4	2.1	2.4	2.4	2.2	2.7	2.1	2.4	2.1	2.4	2.7	2.1	2.4	2.1
TD11	2.9	2.5	2.5	2.2	2.6	2.8	2.3	2.4	2.5	2.5	2.2	2.6	2.4	2.5	2.5	2.2
TD12	2.6	2.6	2.6	2.3	2.8	2.3	2.5	2.6	2.6	2.6	2.3	2.8	2.6	2.6	2.6	2.3
TD13	2.7	2.7	2.7	2.4	2.7	2.2	2.6	2.1	2.7	2.7	2.4	2.7	2.1	2.7	2.7	2.4
TD14	2.1	2.6	2.9	2.9	2.5	2.5	2.7	2.2	2.6	2.9	2.9	2.5	2.2	2.6	2.9	2.9
TD15	3.1	2.4	2.4	2.6	2.1	2.5	2.4	2.1	2.4	2.4	2.6	2.1	2.1	2.4	2.4	2.6
TD16	2.8	2.3	2.6	2.2	2.3	2.4	2.2	2.5	2.3	2.6	2.2	2.3	2.5	2.3	2.6	2.2
TD17	2.9	2.5	2.5	2.2	2.6	2.8	2.3	2.4	2.5	2.5	2.2	2.6	2.4	2.5	2.5	2.2
TD18	2.6	2.6	2.6	2.3	2.8	2.3	2.5	2.6	2.6	2.6	2.3	2.8	2.6	2.6	2.6	2.3
TD19	2.7	2.7	2.7	2.4	2.7	2.2	2.6	2.1	2.7	2.7	2.4	2.7	2.1	2.7	2.7	2.4
TD20	2.1	2.6	2.9	2.9	2.5	2.5	2.7	2.2	2.6	2.9	2.9	2.5	2.2	2.6	2.9	2.9
TD21	2.9	2.5	2.5	2.2	2.6	2.8	2.3	2.4	2.5	2.5	2.2	2.6	2.4	2.5	2.5	2.2
TD22	2.6	2.6	2.6	2.3	2.8	2.3	2.5	2.6	2.6	2.6	2.3	2.8	2.6	2.6	2.6	2.3
TD23	2.7	2.7	2.7	2.4	2.7	2.2	2.6	2.1	2.7	2.7	2.4	2.7	2.1	2.7	2.7	2.4
TD24	2.1	2.6	2.9	2.9	2.5	2.5	2.7	2.2	2.6	2.9	2.9	2.5	2.2	2.6	2.9	2.9

<Appendix 7> Transportation cost from EU to CC of M1 and M2 for Scale 5

	CC1	CC2	CC3	CC4	CC5	CC6	CC7	CC8	CC9	CC10	CC11	CC12	CC13	CC14	CC15	CC16
EU	2.1	2.5	2.6	2.4	2.6	2.8	2.1	2.2	2.5	2.4	2.7	2.1	2.7	2.8	2.7	2.5

<Appendix 8> Transportation cost from CC to RM of M1 and M2 for Scale 5

	RM1	RM2	RM3	RM4	RM5	RM6	RM7	RM8	RM9	RM10	RM11	RM12	RM13	RM14	RM15	RM16
CC1	2.4	2.2	2.4	2.3	2.2	2.9	2.8	2.5	2.7	2.2	2.3	2.5	2.3	2.2	2.9	2.8
CC2	2.1	2.6	2.6	2.1	2.1	2.5	2.6	2.6	2.6	2.4	2.5	2.6	2.1	2.1	2.5	2.6
CC3	2.5	2.1	2.8	2.4	2.5	2.4	2.4	2.1	2.5	2.1	2.4	2.4	2.4	2.5	2.4	2.4
CC4	2.4	2.3	2.4	2.7	2.6	2.6	2.2	2.2	2.3	2.9	2.8	2.8	2.7	2.6	2.6	2.2
CC5	2.5	2.1	2.2	2.5	2.8	2.8	2.3	2.3	2.2	2.6	2.9	2.7	2.5	2.8	2.8	2.3
CC6	2.4	2.5	2.3	2.4	2.4	2.4	2.7	2.1	2.3	2.8	2.2	2.4	2.4	2.4	2.4	2.7
CC7	2.9	2.6	2.4	2.6	2.1	2.3	2.4	2.4	2.1	2.9	2.6	2.6	2.6	2.1	2.3	2.4
CC8	2.7	2.8	2.6	2.7	2.2	2.1	2.6	2.6	2.2	2.7	2.1	2.5	2.7	2.2	2.1	2.6
CC9	2.1	2.2	2.3	2.9	2.8	2.8	2.5	2.8	2.6	2.3	2.7	2.4	2.9	2.8	2.8	2.5
CC10	2.4	2.3	2.2	2.6	2.9	2.7	2.4	2.4	2.4	2.2	2.6	2.6	2.6	2.9	2.7	2.4
CC11	2.6	2.5	2.3	2.8	2.2	2.4	2.2	2.5	2.3	2.4	2.5	2.7	2.8	2.2	2.4	2.2
CC12	2.7	2.6	2.1	2.9	2.6	2.6	2.6	2.6	2.1	2.2	2.3	2.9	2.9	2.6	2.6	2.6
CC13	2.1	2.6	2.6	2.1	2.1	2.5	2.6	2.6	2.6	2.4	2.5	2.6	2.1	2.1	2.5	2.6
CC14	2.5	2.1	2.8	2.4	2.5	2.4	2.4	2.1	2.5	2.1	2.4	2.4	2.4	2.5	2.4	2.4
CC15	2.4	2.3	2.4	2.7	2.6	2.6	2.2	2.2	2.3	2.9	2.8	2.8	2.7	2.6	2.6	2.2
CC16	2.5	2.1	2.2	2.5	2.8	2.8	2.3	2.3	2.2	2.6	2.9	2.7	2.5	2.8	2.8	2.3

<Appendix 9> Transportation cost from CC to RY of M1 and M2 for Scale 5

	RC1	RC2	RC3	RC4	RC5	RC6	RC7	RC8	RC9	RC10	RC11	RC12	RC13	RC14	RC15	RC16
CC1	2.6	2.3	2.7	2.2	2.3	2.5	2.3	2.1	2.6	2.3	2.7	2.2	2.5	2.3	2.1	2.6
CC2	2.4	2.2	2.6	2.4	2.5	2.6	2.1	2.5	2.4	2.2	2.6	2.4	2.6	2.1	2.5	2.4
CC3	2.3	2.4	2.5	2.1	2.4	2.4	2.1	2.6	2.3	2.4	2.5	2.1	2.4	2.1	2.6	2.3
CC4	2.1	2.2	2.3	2.9	2.8	2.8	2.5	2.8	2.1	2.2	2.3	2.9	2.8	2.5	2.8	2.1
CC5	2.4	2.3	2.2	2.6	2.9	2.7	2.4	2.4	2.4	2.3	2.2	2.6	2.7	2.4	2.4	2.4
CC6	2.6	2.5	2.3	2.8	2.2	2.4	2.2	2.5	2.6	2.5	2.3	2.8	2.4	2.2	2.5	2.6
CC7	2.7	2.6	2.1	2.9	2.6	2.6	2.6	2.6	2.7	2.6	2.1	2.9	2.6	2.6	2.6	2.7
CC8	2.9	2.1	2.2	2.7	2.1	2.5	2.7	2.1	2.9	2.1	2.2	2.7	2.5	2.7	2.1	2.9
CC9	2.4	2.3	2.2	2.6	2.9	2.7	2.4	2.4	2.4	2.2	2.6	2.6	2.7	2.4	2.4	2.4
CC10	2.6	2.5	2.3	2.8	2.2	2.4	2.2	2.5	2.3	2.4	2.5	2.7	2.4	2.2	2.5	2.3
CC11	2.7	2.6	2.1	2.9	2.6	2.6	2.6	2.6	2.1	2.2	2.3	2.9	2.6	2.6	2.6	2.1
CC12	2.1	2.2	2.3	2.9	2.8	2.8	2.5	2.8	2.6	2.3	2.7	2.4	2.8	2.5	2.8	2.6
CC13	2.6	2.5	2.3	2.8	2.2	2.4	2.2	2.5	2.3	2.4	2.5	2.7	2.4	2.2	2.5	2.3
CC14	2.7	2.6	2.1	2.9	2.6	2.6	2.6	2.6	2.1	2.2	2.3	2.9	2.6	2.6	2.6	2.1
CC15	2.1	2.6	2.6	2.1	2.1	2.5	2.6	2.6	2.6	2.4	2.5	2.6	2.5	2.6	2.6	2.6
CC16	2.5	2.1	2.8	2.4	2.5	2.4	2.4	2.1	2.5	2.1	2.4	2.4	2.4	2.4	2.1	2.5

<Appendix 10> Transportation cost from RM to DP of M1 and M2 for Scale 5

	DP
RM1	2.3
RM2	2.6
RM3	2.4
RM4	2.7
RM5	2.3
RM6	2.2
RM7	2.1
RM8	2.5
RM9	2.1
RM10	2.4
RM11	2.6
RM12	2.7
RM13	2.3
RM14	2.2
RM15	2.1
RM16	2.5

<Appendix 11> Transportation cost from RM to EP of M1 and M2 for Scale 5

	EP
RM1	2.5
RM2	2.1
RM3	2.3
RM4	2.4
RM5	2.2
RM6	2.3
RM7	2.5
RM8	2.7
RM9	2.2
RM10	2.3
RM11	2.5
RM12	2.6
RM13	2.2
RM14	2.3
RM15	2.5
RM16	2.7

<Appendix 12> Transportation cost from RM to DC of M2 for Scale 5

	DC1	DC2	DC3	DC4	DC5	DC6	DC7	DC8	DC9	DC10	DC11	DC12	DC13	DC14	DC15	DC16
RM1	2.3	2.2	2.2	2.5	2.3	2.1	2.3	2.4	2.7	2.2	2.3	2.5	2.4	2.7	2.2	2.3
RM2	2.8	2.4	2.3	2.6	2.1	2.3	2.6	2.5	2.6	2.4	2.5	2.6	2.5	2.6	2.4	2.5
RM3	2.2	2.6	2.4	2.8	2.5	2.4	2.4	2.9	2.5	2.1	2.4	2.4	2.9	2.5	2.1	2.4
RM4	2.6	2.1	2.6	2.1	2.6	2.6	2.8	2.6	2.3	2.9	2.8	2.8	2.6	2.3	2.9	2.8
RM5	2.2	2.3	2.3	2.2	2.8	2.5	2.7	2.3	2.2	2.6	2.9	2.7	2.3	2.2	2.6	2.9
RM6	2.1	2.5	2.1	2.3	2.4	2.2	2.2	2.1	2.3	2.8	2.2	2.4	2.1	2.3	2.8	2.2
RM7	2.3	2.6	2.2	2.4	2.3	2.4	2.6	2.3	2.1	2.9	2.6	2.6	2.3	2.1	2.9	2.6
RM8	2.6	2.4	2.5	2.5	2.2	2.6	2.4	2.5	2.2	2.7	2.1	2.5	2.5	2.2	2.7	2.1
RM9	2.6	2.3	2.7	2.2	2.3	2.5	2.3	2.1	2.6	2.3	2.7	2.4	2.1	2.6	2.3	2.7
RM10	2.4	2.2	2.6	2.4	2.5	2.6	2.1	2.5	2.4	2.2	2.6	2.6	2.5	2.4	2.2	2.6
RM11	2.3	2.4	2.5	2.1	2.4	2.4	2.1	2.6	2.3	2.4	2.5	2.7	2.6	2.3	2.4	2.5
RM12	2.1	2.2	2.3	2.9	2.8	2.8	2.5	2.8	2.1	2.2	2.3	2.9	2.8	2.1	2.2	2.3
RM13	2.3	2.6	2.2	2.4	2.3	2.4	2.6	2.3	2.1	2.9	2.6	2.6	2.3	2.1	2.9	2.6
RM14	2.6	2.4	2.5	2.5	2.2	2.6	2.4	2.5	2.2	2.7	2.1	2.5	2.5	2.2	2.7	2.1
RM15	2.6	2.3	2.7	2.2	2.3	2.5	2.3	2.1	2.6	2.3	2.7	2.4	2.1	2.6	2.3	2.7
RM16	2.4	2.2	2.6	2.4	2.5	2.6	2.1	2.5	2.4	2.2	2.6	2.6	2.5	2.4	2.2	2.6

<Appendix 13> Transportation cost from RM to RY of M2 for Scale 5

	RC1	RC2	RC3	RC4	RC5	RC6	RC7	RC8	RC9	RC10	RC11	RC12	RC13	RC14	RC15	RC16
RM1	2.5	2.2	2.2	2.2	2.3	2.7	2.9	2.6	2.1	2.6	2.3	2.7	2.5	2.2	2.2	2.2
RM2	2.6	2.3	2.4	2.1	2.5	2.4	2.8	2.1	2.5	2.4	2.2	2.6	2.6	2.3	2.4	2.1
RM3	2.5	2.6	2.7	2.6	2.4	2.9	2.7	2.3	2.6	2.3	2.4	2.5	2.5	2.6	2.7	2.6
RM4	2.1	2.5	2.6	2.8	2.6	2.8	2.2	2.8	2.8	2.1	2.2	2.3	2.1	2.5	2.6	2.8
RM5	2.3	2.2	2.3	2.5	2.3	2.6	2.9	2.4	2.4	2.4	2.3	2.2	2.3	2.2	2.3	2.5
RM6	2.6	2.3	2.6	2.4	2.9	2.5	2.7	2.5	2.5	2.6	2.5	2.3	2.6	2.3	2.6	2.4
RM7	2.7	2.4	2.4	2.3	2.1	2.6	2.4	2.6	2.6	2.7	2.6	2.1	2.7	2.4	2.4	2.3
RM8	2.9	2.8	2.5	2.1	2.2	2.4	2.1	2.7	2.1	2.9	2.1	2.2	2.9	2.8	2.5	2.1
RM9	2.3	2.2	2.3	2.5	2.3	2.6	2.9	2.4	2.4	2.4	2.2	2.6	2.3	2.2	2.3	2.5
RM10	2.6	2.3	2.6	2.4	2.9	2.5	2.7	2.5	2.5	2.3	2.4	2.5	2.6	2.3	2.6	2.4
RM11	2.7	2.4	2.4	2.3	2.1	2.6	2.4	2.6	2.6	2.1	2.2	2.3	2.7	2.4	2.4	2.3
RM12	2.9	2.8	2.5	2.1	2.2	2.4	2.1	2.7	2.8	2.6	2.3	2.7	2.9	2.8	2.5	2.1
RM13	2.7	2.3	2.2	2.3	2.5	2.3	2.6	2.9	2.4	2.4	2.4	2.2	2.6	2.3	2.2	2.3
RM14	2.6	2.6	2.3	2.6	2.4	2.9	2.5	2.7	2.5	2.5	2.3	2.4	2.5	2.6	2.3	2.6
RM15	2.5	2.7	2.4	2.4	2.3	2.1	2.6	2.4	2.6	2.6	2.1	2.2	2.3	2.7	2.4	2.4
RM16	2.3	2.9	2.8	2.5	2.1	2.2	2.4	2.1	2.7	2.8	2.6	2.3	2.7	2.9	2.8	2.5

<Appendix 14> Transportation cost from RM to EU of M2 for Scale 5

	EU
RM1	2.6
RM2	2.4
RM3	2.1
RM4	2.2
RM5	2.3
RM6	2.1
RM7	2.6
RM8	2.1
RM9	2.3
RM10	2.5
RM11	2.4
RM12	2.6
RM13	2.3
RM14	2.6
RM15	2.4
RM16	2.5

<Appendix 15> Transportation cost from RY to DM of M1 and M2 for Scale 5

	DM
RC1	2.7
RC2	2.2
RC3	2.3
RC4	2.5
RC5	2.3
RC6	2.1
RC7	2.6
RC8	2.4
RC9	2.9
RC10	2.4
RC11	2.6
RC12	2.7
RC13	2.3
RC14	2.2
RC15	2.1
RC16	2.5

<Appendix 16> Transportation cost from RY to EM of M1 and M2 for Scale 5

	EM
RC1	2.5
RC2	2.4
RC3	2.2
RC4	2.6
RC5	2.2
RC6	2.3
RC7	2.1
RC8	2.6
RC9	2.1
RC10	2.3
RC11	2.5
RC12	2.6
RC13	2.2
RC14	2.3
RC15	2.5
RC16	2.7

<Appendix 17> Transportation cost from RY to IN of M1 and M2 for Scale 5

	IC1	IC2	IC3	IC4	IC5	IC6
RC1	2.2	2.3	2.2	2.5	2.2	2.2
RC2	2.6	2.1	2.4	2.4	2.4	2.4
RC3	2.9	2.4	2.7	2.3	2.1	2.1
RC4	2.4	2.5	2.6	2.9	2.9	2.9
RC5	2.1	2.3	2.5	2.6	2.6	2.6
RC6	2.3	2.1	2.5	2.4	2.8	2.8
RC7	2.5	2.6	2.3	2.7	2.9	2.9
RC8	2.7	2.4	2.7	2.5	2.7	2.7
RC9	2.2	2.7	2.1	2.5	2.6	2.3
RC10	2.2	2.6	2.9	2.7	2.7	2.2
RC11	2.3	2.8	2.2	2.4	2.9	2.4
RC12	2.1	2.9	2.6	2.6	2.4	2.2
RC13	2.9	2.1	2.2	2.7	2.1	2.4
RC14	2.4	2.3	2.2	2.6	2.9	2.1
RC15	2.6	2.5	2.3	2.8	2.2	2.9
RC16	2.7	2.6	2.1	2.9	2.6	2.6

<Appendix 18> Transportation cost from RY to TM of M2 for Scale 5

	TM1	TM2	TM3	TM4	TM5	TM6	TM7	TM8	TM9	TM10	TM11	TM12	TM13	TM14	TM15	TM16
RC1	2.5	2.4	2.2	2.5	2.3	2.1	2.2	2.8	2.6	2.3	2.7	2.6	2.2	2.5	2.2	2.2
RC2	2.1	2.2	2.3	2.4	2.1	2.2	2.6	2.5	2.4	2.2	2.6	2.4	2.4	2.4	2.4	2.4
RC3	2.5	2.5	2.4	2.7	2.5	2.6	2.4	2.7	2.3	2.4	2.5	2.1	2.7	2.3	2.1	2.1
RC4	2.1	2.1	2.6	2.6	2.6	2.8	2.5	2.6	2.1	2.2	2.3	2.2	2.6	2.9	2.9	2.9
RC5	2.2	2.4	2.3	2.2	2.4	2.7	2.2	2.4	2.4	2.3	2.2	2.3	2.5	2.6	2.6	2.6
RC6	2.3	2.7	2.5	2.1	2.1	2.5	2.1	2.3	2.6	2.5	2.3	2.1	2.5	2.4	2.8	2.8
RC7	2.5	2.6	2.4	2.4	2.2	2.4	2.8	2.8	2.7	2.6	2.1	2.6	2.3	2.7	2.9	2.9
RC8	2.6	2.5	2.3	2.6	2.8	2.3	2.9	2.7	2.9	2.1	2.2	2.1	2.7	2.5	2.7	2.7
RC9	2.5	2.2	2.2	2.2	2.3	2.7	2.9	2.6	2.4	2.2	2.6	2.3	2.1	2.5	2.6	2.3
RC10	2.6	2.3	2.4	2.1	2.5	2.4	2.8	2.1	2.3	2.4	2.5	2.5	2.9	2.7	2.7	2.2
RC11	2.5	2.6	2.7	2.6	2.4	2.9	2.7	2.3	2.1	2.2	2.3	2.4	2.2	2.4	2.9	2.4
RC12	2.1	2.5	2.6	2.8	2.6	2.8	2.2	2.8	2.6	2.3	2.7	2.6	2.6	2.6	2.4	2.2
RC13	2.6	2.5	2.3	2.6	2.8	2.3	2.9	2.7	2.9	2.1	2.2	2.1	2.2	2.7	2.1	2.4
RC14	2.5	2.2	2.2	2.2	2.3	2.7	2.9	2.6	2.4	2.2	2.6	2.3	2.2	2.6	2.9	2.1
RC15	2.6	2.3	2.4	2.1	2.5	2.4	2.8	2.1	2.3	2.4	2.5	2.5	2.3	2.8	2.2	2.9
RC16	2.5	2.6	2.7	2.6	2.4	2.9	2.7	2.3	2.1	2.2	2.3	2.4	2.1	2.9	2.6	2.6

Research Accomplishments (연구실적)

International Journals Papers

- Chen, X., Anudari, C. and Yun, Y. S., Integrated Logistics Network Optimization Using Hybrid Genetic Algorithm, *New Physics: Sea Mulli*, 67(5):628-637, 2017.06.

International Proceedings Papers

- Chen, X., Anudari, C. and Yun, Y. S., Design of Closed-Loop Supply Chain Model with Various Transportation Methods. *The 18th Asia Pacific Industrial Engineering & Management Systems Conference(APIEMS2017)*, Yogyakarta, Indonesia, Dec. 03-06, 2017

- Chen, X., Anudari, C. and Yun, Y. S., Design of Closed-Loop Supply Chain Model with Efficient Operation Strategy. *The 11th International Conference on Management Science and Engineering Management(ICMSEM2017)*, Kanazawa, Japanese, Jul. 28-31, 2017

- Yun, Y. S., Anudari, C., Chen, X. and Gen, M., Optimization of Closed-Loop Supply Chain Model with Part and Module Inventory Centers. *The 11th International Conference on Management Science and Engineering Management(ICMSEM2017)*, Kanazawa, Japanese, Jul. 28-31, 2017

- Gen, M., Chen, X., Anudari, C. and Yun, Y. S., Optimization of Integrated Logistics Network Model with Location and Allocation Problems, *The International Symposium on Innovation in Information Technology and Applications (ISIITA2017)*, pp. 116-118, Da Nang, Vietnam, Jan. 10-13, 2017

- Chen, X, Anudari. C. and Yun, Y. S. Closed-Loop Supply Chain Design for Production System using Part and Module, *Proceedings of the Asia Pacific Industrial Engineering & Management Systems Conference, Taipei, Taiwan, 2016, 12*

- Yun, Y. S., Anudari, C.,Chen, X. amd Gen. M. Integrated Supply Chain Design Problem with Various Handling Processes, *Proceedings of the Asia Pacific Industrial Engineering & Management Systems Conference, Taipei, Taiwan, 2016, 12*

- Yun, Y. S., Anudari, C.,Chen, X. and Hwang, R. K. Closed-loop supply chain network model with product recovery, reselling and waste disposal, The 46th International

Conference on Computers and Industrial Engineering, Tianjin, China, pp. 1-10, 2016.10

■ Chen, X., Anudari, C. Yun, Y. S. and Gen, M. Closed-loop supply chain network model with module manufacture and recovery process, The 46th International Conference on Computers and Industrial Engineering, Tianjin, China, pp. 1-10, 2016.10

Domestic Journal Papers

■ 윤영수, 추룬수크아누다리, 진성, 폐쇄루프공급망모델최적화를위한적응형혼합형유전알고리즘접근법, 한국산업정보학회논문지, 22(2): 79-90, 2017.04

■ 윤영수, 추룬수크아누다리, 진성, 폐쇄루프공급망모델을이용한혼합형유전알고리즘접근법, 한국산업정보학회논문지, 21(4): 31-41, 2016.08

■ 윤영수, 진성, 역물류네트워크를이용한생활폐기물처리효율화방안-D광역시를중심으로, 한국산업정보학회논문지, 20(2): 97-111, 2015.04

Domestic Proceedings Papers

■ 윤영수, 추룬수크 아누다리, 진성, 유전알고리즘과 타부서치를 이용한 폐쇄루프물류네트워크 모델 최적화, 2017 한국산업정보학회 추계학술대회, 2017.11

■ 진성, 추룬수크 아누다리, 윤영수, 중국 WEEE시장에서 재사용 및 재활용 물류네트워크의 효율적인 운용전략, 2017 한국산업정보학회 춘계학술대회, pp. 129-1137, 2017.06

■ 윤영수, 추룬수크 아누다리, 진성, 회수제품의 다양한 특성을 고려한 통합형 공급망 설계, 2016 한국산업정보학회 추계학술대회, pp. 146-149, 2016.11

■ 윤영수, 추룬수크 아누다리, 진성, 폐쇄루프 공급망 모델을 이용한 다양한 접근법의 수행도 비교, 2016 한국산업정보학회 춘계학술대회, pp. 5-11, 2016.06

■ Xing, C., Anudari, C. and Yun Y. S. Integrated Supply chain Design Problem with Various Suppliers, 2016 한국산업정보학회 춘계학술대회, pp. 55-60, 2016.06

■ 진성, 아누다리, 윤영수, Optimization of Closed-Loop Supply Chain Model with Modular Production System, 2016 SCM춘계발표대회, pp. 1-7, 2016.06

■ 윤영수, 진성, 아누다리, 통합형/비통합형역물류네트워크분석-유전알고리즘접근법, 한국산업정보학회2015년도춘계학술대회, pp.127-130, 2015.06

■ 진성, 아누다리, 윤영수, Internationalization strategy of Korea new venture firms in China, 한국산업정보학회2015년도춘계학술대회, pp.131-135, 2015.06

Awards(수상경력)

■ Best Student Paper Award Certificate

수여기관: The 18th Asia Pacific Industrial Engineering and Management Systems C Conference

수여일자: 2017.12.05.

내 용: APIEMS 2017

논문제목: Design of Closed-Loop Supply Chain Model with Various Transportation Methods

■ 최우수논문상 수상

수여기관: 한국산업정보학회

수여일자: 2016.06.24.

내 용: 한국산업정보학회2016년도 춘계학술대회

논문제목: 폐쇄루프 공급망 모델을 이용한 다양한 접근법의 수행도 비교

■ 우수논문상 수상

수여기관: 한국산업정보학회

수여일자: 2015.06.19.

내 용: 한국산업정보학회2015년도 춘계학술대회

논문제목: Internationalization Strategy of Korea new venture firms in China