

THE EFFECTS OF DIFFERENT KINDS OF RETURN ON AN  
INTEGRATED CHANCE-CONSTRAINED STOCHASTIC MOBILE  
PHONE CLOSED-LOOP SUPPLY CHAIN CONFIGURATION AND  
SUPPLIER SELECTION

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## ABSTRACT

### **The effects of different kinds of returns on an integrated chance-constrained stochastic mobile phone closed-loop supply chain configuration and supplier selection**

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One of the important concerns in the world is E-waste. Ending up e-waste in the landfill and inappropriate disposing of it are hazardous to the environment. The goal of this research is to design and optimize a multi-period, multi-product, multi-echelon, and multi-customer Closed-Loop Supply Chain (CLSC) network for a mobile phone network considering different types of product returns. Commercial, end of life, and end-of-use returns are well-known in practice. In this research, a multi-objective mixed-integer linear programming formulation with stochastic demand and return is proposed to maximize the total profit in the mobile phone CLSC network, alongside maximizing the weights of eligible suppliers which are estimated based on a fuzzy method for efficient supplier selection and order allocation. Chance-constraint programming is applied in order to deal with the stochastic demand and return. Moreover, distance method and  $\varepsilon$ -constraint technique are employed to solve the proposed multi-objective problem. The application of the proposed mathematical model is illustrated in Toronto, Canada using real maps.

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# Table of Contents

Author’s Declaration.....	ii
Abstract.....	iii
Acknowledgments.....	iv
Table of Contents.....	v
List of Tables.....	vii
List of Figures.....	viii
List of Acronyms.....	ix

## CHAPTER 1. INTRODUCTION

1.1. Introduction.....	1
1.2. Forward Supply Chain.....	1
1.3. Reverse Logistics (RL).....	1
1.4. Importance of Closed-Loop Supply Chain (CLSC).....	1
1.5. Different types of returns of products.....	2
1.6. Electronic waste recycling.....	3
1.6.1. Importance of mobile phone recycling.....	4
1.6.2. Different types of mobile phones.....	4
1.6.3. Recyclable materials of mobile phones.....	4
1.7. Aim and research contribution.....	5
1.8. Research objective.....	7
1.9. Solution methodologies.....	7
1.10. Organization of the thesis.....	10

## CHAPTER 2. REVIEW OF LITERATURE

2.1. Introduction.....	11
2.2. Deterministic models in CLSC.....	11
2.3. Supplier selection and order allocation.....	13
2.4. Stochastic programming in CLSC.....	15
2.5. Multi-objective models in CLSC.....	17

**CHAPTER 3. THE EFFECTS OF DIFFERENT KINDS OF RETURNS ON A MOBILE PHONE CLOSED-LOOP SUPPLY CHAIN NETWORK**

3.1. Introduction.....20  
3.2. Network explanation.....20  
3.3. Optimization model .....22  
3.4. Application of the proposed model and solution approach .....28  
3.5. Sensitivity analysis.....30  
3.6. Conclusions.....34

**CHAPTER 4. AN INTEGRATED CHANCE-CONSTRAINED STOCHASTIC MODEL FOR A MOBILE PHONE CLOSED-LOOP SUPPLY CHAIN NETWORK WITH SUPPLIER SELECTION**

4.1. Introduction.....36  
4.2. Problem definition .....37  
4.2.1. Supplier evaluation .....38  
4.2.2. Mathematical model .....44  
4.3. Chance-constraint programming.....45  
4.4. Solution Approach .....47  
4.4.1.  $\epsilon$ -constrained method and results .....48  
4.4.2. Distance method and results .....48  
4.5. The Value Path Approach (VPA) .....50  
4.6. Sensitivity analysis.....51  
4.7. Conclusions.....52

**CHAPTER 5. CONCLUSIONS AND FUTURE RESEARCH**

5.1. Research contributions.....54  
5.2. Conclusions.....54  
5.3. Future research.....55

REFERENCES .....57

## LIST OF TABLES

### CHAPTER 2

Table 2.1. Review of some papers in CLSC.....	18
---	----

### CHAPTER 3

Table 3.1. Values of some parameters defined to solve the mathematical model .....	29
Table 3.2. Some values of the model for $i = j = t = 1, s = 3, m = 2, r = 12, k = 18, l = 13, d = 6, g = 5, x = 1$ .....	29

### CHAPTER 4

Table 4.1. Weights of categories.....	42
Table 4.2. Weights of criteria .....	42
Table 4.3. Evaluation of supplier 1 for material 1 .....	42
Table 4.4. Final score for supplier 1 according to material 1 .....	43
Table 4.5. Weight of supplier $s$ according to material $j$ .....	43
Table 4.6. Values of some parameters defined to solve the mathematical model .....	47
Table 4.7. Values of objective functions obtained by $\varepsilon$ -constraint method.....	48
Table 4.8. Values of objective functions obtained by distance method.....	49
Table 4.9. Results of Value Path Approach (VPA) .....	50
Table 4.10. Some values of the model for $i = j = t = 1, s = 3, m = 2, r = 12, k = 18, l = 13, d = 6, g = 5, x = 1, \varepsilon = 825,000$ .....	51

## LIST OF FIGURES

### CHAPTER 1

Fig. 1.1. Service flow in Closed-Loop Supply Chain Management (CLSCM) .....	1
Fig. 1.2. Closed-Loop Supply Chain model for remanufacturing .....	2
Fig. 1.3. Materials in mobile phone .....	5
Fig. 1.4. A trapezoidal fuzzy number .....	9

### CHAPTER 3

Fig. 3.1. A closed-loop supply chain of mobile phone including recycling and reselling .....	21
Fig. 3.2. Toronto wards .....	28
Fig. 3.3. Flow through the CLSC network based on the results .....	31
Fig. 3.4. The changes of the profit due to the demand changes.....	32
Fig. 3.5. Flow through the new CLSC network (a) based on the results .....	32
Fig. 3.6. Flow through the new CLSC network (b) based on the results.....	33
Fig. 3.7. Flow through the new CLSC network (c) based on the results .....	34

### CHAPTER 4

Fig. 4.1. The various steps of the solution approach .....	37
Fig. 4.2. A linguistic scale for providing experience level .....	39
Fig. 4.3. Supplier selection framework in mobile phone CLSC network.....	40
Fig. 4.4. Linguistic scale .....	40
Fig. 4.5. The Value Path Approach (VPA).....	50
Fig. 4.6. The optimal mobile CLSC network.....	51
Fig. 4.7. The changes of the profit due to the change in $\alpha$ .....	52

## **LIST OF ACRONYMS**

Analytic Hierarchy Process (AHP)

Application Programming Interfaces (APIs)

Chance-Constrained Programming (CCP)

Closed-Loop Supply Chain (CLSC)

Closed-Loop Supply Chain Management (CLSCM)

Data Envelopment Analysis (DEA)

End-Of-Life (EOL)

End-Of-Life Electronics (EOLE)

End-Of-Use (EOU)

Enterprise Resource Planning (ERP)

Fully Fuzzy Programming (FFP)

Fuzzy Weighted Average (FWA)

House of Quality (HOQ)

Multi-Attribute Decision-Making (MADM)

Ontario Electronic Stewardship (OES)

Operating Systems (OS)

Quality Function Deployment (QFD)

Returnable Transport Items (RTIs)

Reverse Logistics (RL)

Trapezoidal fuzzy number (TFN)

Value Path Approach (VPA)

Waste Electrical and Electronic Equipment (WEEE)

# CHAPTER 1

## 1.1. Introduction

Closed-Loop Supply Chain (CLSC) plays a crucial role in both industrial and environmental aspects. According to Fig.1.1, the CLSC can be explained as the combination of design, examination, and control of a network for maximization of the values of the returned products via recovery options such as recycling (Guide and Wassenhove, 2009). CLSC contains forward supply chain and reverse logistics.



Fig. 1.1. Service flow in Closed-Loop Supply Chain Management (CLSCM)

## 1.2. Forward Supply Chain

The forward supply chain considers supplier, manufacturer, and retailer. The main objective of forward supply chain is to convert raw components to specific products with managerial insight in order to satisfy demand and minimize the total cost (Cooper et al., 1997).

## 1.3. Reverse Logistics (RL)

Reverse Logistics (RL) includes drop-off and recycling centres which are responsible for gathering, recycling, and disposing of the used products. By increasing concerns regarding the environment and green issues, reverse logistics has received many attentions. Reverse logistics consists of the procedure of organizing, enforcing, and controlling the entering flow and repository of secondary products and associated information unlike the classic supply chain orders in order to fulfill the desire of recovering and appropriate disposal (Fleischmann, 2001).

## 1.4. Importance of Closed-Loop Supply Chain (CLSC)

Product waste, especially e-waste, has become a crucial problem worldwide during the last years. Remanufacturing the usable parts of products and recycling unusable components are a solution concerning minimizing waste and benefiting the resources properly to achieve better

sustainability. Closed-Loop Supply Chain (CLSC) includes a procedure of taking back products from customers to be reused, remanufactured, or recycled. Considering forward and reverse supply chains together results in creation of closed-loop supply chain (Govindan et al., 2015). CLSC management is the design, control, and function of a system to maximize value generation over the whole life cycle of a product with dynamic recovery of value from various types and volumes of returns over the time (Guide et al., 2003). Comprehending the fundamental parameters of CLSC is significant for substitute of traditional operations management by state-of-the-art CLSC procedure. Fig. 1.2 indicates the general scope of CLSC management process.

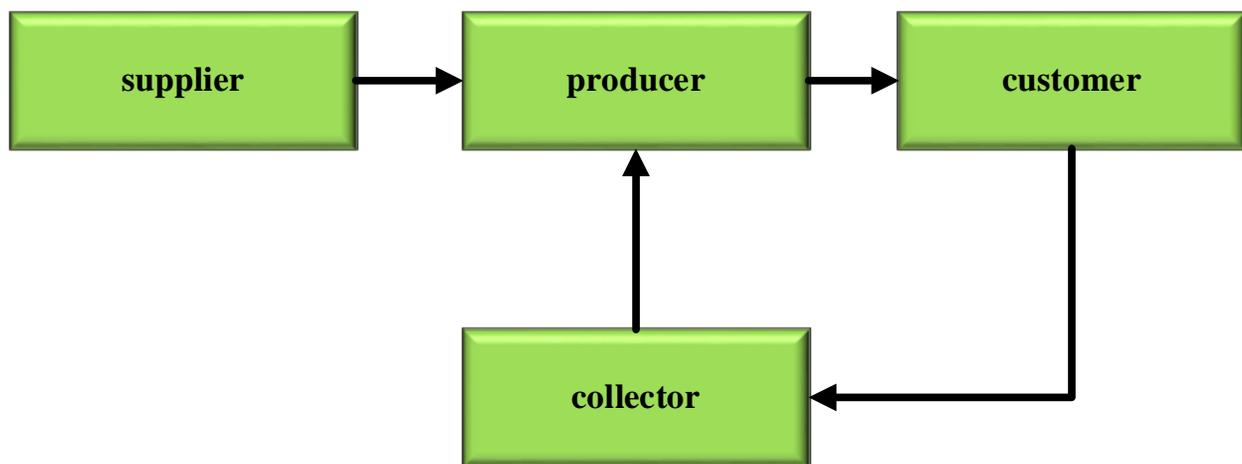


Fig. 1.2. Closed-Loop Supply Chain model for remanufacturing

Remanufacturing of returned products in CLSC makes profit. In Supply Chain Management (SCM), the objective is to maximize the profit or to minimize the cost, while both financial and environmental aspects are considered in CLSC. In this thesis, the objective is to design a mobile phone CLSC in Toronto, Canada. Ontario Electronic Stewardship (OES) is responsible for collecting End-Of-Life Electronics (EOLE) and recycling them. EOL electronics are dropped off at OES authorized collection centres. Provincial data and statistics related to electronic devices can be found in their website.

### 1.5. Different types of returns of products

According to Guide and Wassenhove (2009), various types of returns can be presented. If the product is returned to the retailer by the customer within a specific timeframe such as 30, 60, or

90 days after purchase, it can be considered as a commercial return. End-Of-Use (EOU) returns are the replacement of a practical product by a technological upgrade. End-of life returns are available when the product becomes technically obsolete or no longer contains any utility for the current user. The mobile phone can be mentioned as an example. In North America, a mobile phone is refundable within 30 days after purchase which is considered as a commercial return. Moreover, 80% of customers are allowed to upgrade their mobile phones which still works very well, so that their previous mobile phone will be recognized as an end-of-use product return. Furthermore, several mobile phone users abandon their devices because it is technically out-of-date or all service providers don't support the device anymore, and it becomes an end-of-life return.

The quality of commercial and EOU products is nearly the same as new products so that they can be resold to the second customers. Therefore, second customers will be encouraged to purchase a used product with a lower price as compared to a new product (John et al., 2017; Batarfi et al., 2017). The EOL products are collected by drop-off centres. After sufficient investigations, all reusable materials such as metal, glass, and plastics will be returned to be processed into new products. Unproductive items will be shipped to disposal centres to reduce the environmental pollution.

## **1.6. Electronic waste recycling**

According to development of technology and increasing use of electronic products, electronic waste has become one of the most important concerns in the world (Geyer and Blass, 2010). As stated in Statistics Canada (2014), the overall amount of electronic waste generated in Canada in 2014 is estimated about 83,377 tones. Inappropriate discarding electronic devices or ending up in landfills will become hazardous due to dispersing their chemical components into soil and water reservoirs. While by recycling unusable electronics not only they will be kept out of landfills, but also it prevents them being illegally handled or exported by unreliable recyclers. Moreover, important materials that can be returned into the manufacturing supply chain will be recovered. In many countries, severe legislation and different incentives are established to guarantee take back products to reduce waste. For example, in 2003 the Waste Electrical and Electronic Equipment or WEEE directive (Directive 2002/96/EC) turned into a European law, emphasizing

on collecting, recycling, and remanufacturing of different types of electrical products (Georgiadis and Besiou, 2010).

### **1.6.1. Importance of mobile phone recycling**

Mobile phone closed-loop supply chain management is much more essential than other EOL products, since not only it encounters recycling and manufacturing recoverable materials like glass, plastics, and precious metals (Cao et al., 2016), but also hazardous elements like nickel, lead, and mercury are required to be disposed of in order to protect both the health and safety of people and the environment (Oguchi, 2013; Yu and Solvang, 2016). Therefore, designing and planning CLSC networks for mobile phone is important. Most of the components of a mobile phone are recyclable. Particularly, 40% of Plastics, 15% of Glasses and Ceramics, and 15% of Coppers can be recycled (Mobile Phone Partnership Initiative, 2008; Noman and Amin, 2017). According to U.S. Environmental Protection Agency (2017), 35,274 lbs of Copper, 75 lbs of Gold, 772 lbs of Silver, 33 lbs of Palladium are extracted due to recycling each 1 million mobile phones.

### **1.6.2. Different types of mobile phones**

Mobile phones can be considered as two general groups: feature phones and smartphones (Noman and Amin, 2017). Fundamental operations of a mobile phone including calling, sending and receiving messages, accessing internet, playing music, camera, etc. are provided by a feature phone. The price of these phones is usually low. However, mobile phones with progressive calculation capacities are smartphones which is performed on mobile Operating Systems (OS). The OS provides complicated Application Programming Interfaces (APIs) so that other applications can be performed perfectly on the mobile phone. Typically, smartphones are known with large screens and touchscreen feature.

### **1.6.3. Recyclable materials of mobile phones**

Some key physical components of mobile phones including battery, charger, camera, and display are able to be disassembled and remanufactured easily. However, 500 to 1,000 components used to manufacture a mobile phone are made of various materials (Life Cycle

Environmental Issues of Mobile Phones, 2005). Different types of metals such as Gold and Silver are utilized in a mobile phone. About 20% to 35% of the components of a mobile phone cannot be returned to the manufacturing process when the mobile phone is disassembled and cut into smaller pieces. Various substances used in producing a mobile phone are shown in Fig. 1.3.

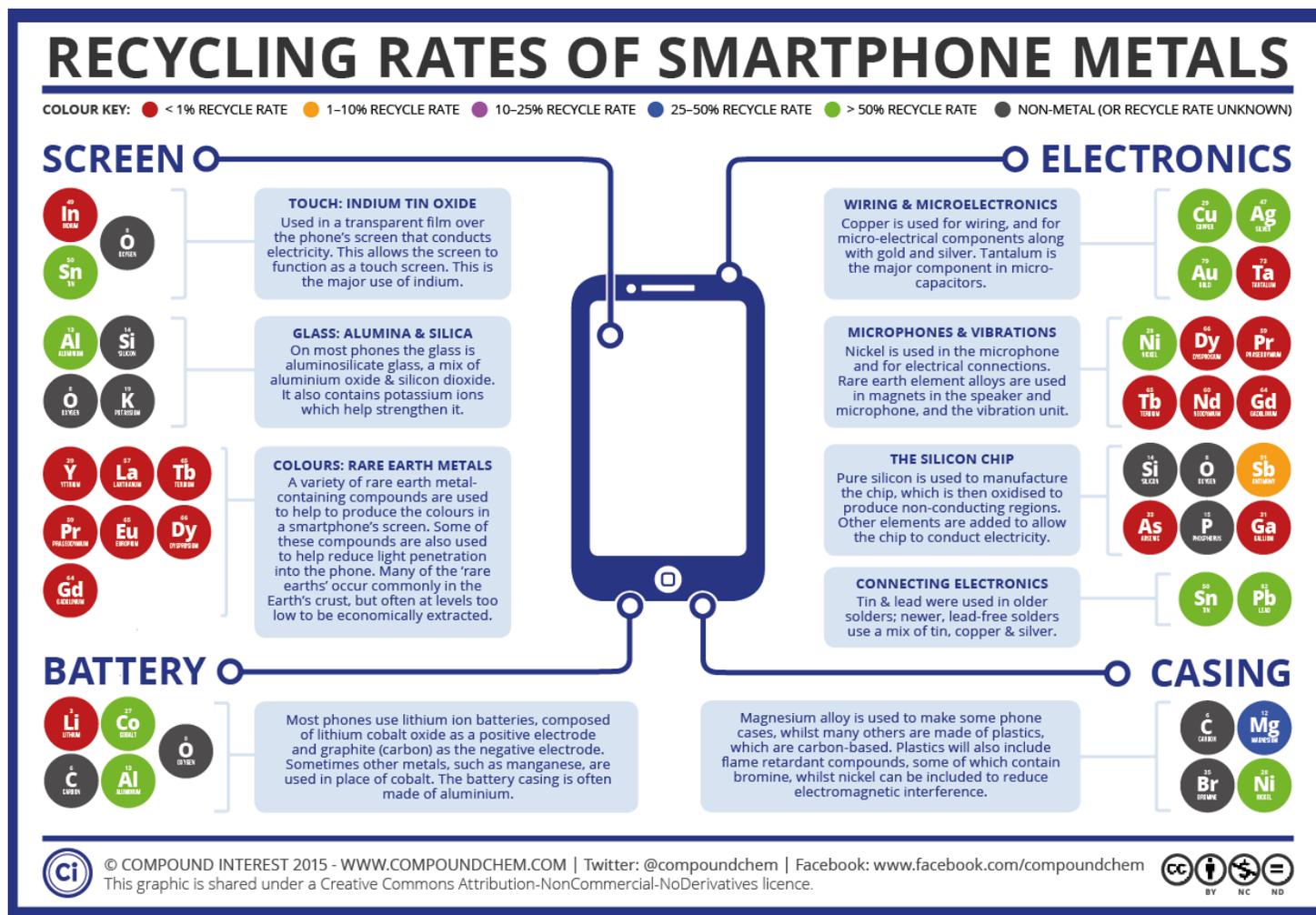


Fig. 1.3. Materials in mobile phone, [URL:http://www.compoundchem.com/2015/09/15/recycling-phone-elements/](http://www.compoundchem.com/2015/09/15/recycling-phone-elements/)

### 1.7. Aim and research contribution

In this research, different types of product return, as well as various selling prices based on quality, are considered, which has been ignored in many supply chain investigations. Mobile phone industry is an example in which different types of product returns are outstanding. In order to perform supplier selection and order allocation, a method is applied by which both qualitative and quantitative criteria will be ranked. Moreover, a multi-objective mixed-integer linear

programming formulation is provided to optimize and configure a CLSC network for mobile phone industry considering three types of returned products including commercial, EOU, and EOL, separately and their associated selling prices to make the model more applicable in the real world of mobile phones. Indeed, reselling of repaired and reconditioned products to the second customers is calculated in the model which has been ignored in many studies. The aim of this research is maximizing the total profit in the network alongside minimizing defect rate as well as maximizing the weights of suppliers where the demands of first and second customers and the rate of returned products are assumed to be stochastic. Utilizing chance-constrained programming, the deterministic equivalent of the stochastic constraints are acquired. The mathematical model comprises multiple products, multiple periods, suppliers, manufacturers, retailers, second and first customers, drop-off, consolidation, and disposal centres. Real data are applied to this model according to Statistics Canada in 2011. Using Google maps, the distances between various facilities are obtained. To my knowledge, in this study, supplier selection and order allocation are applied to a mobile phone CLSC network configuration and optimization in Toronto for the first time.

The main research contributions of this study in CLSC field are as follows:

- Development of a mathematical formulation to configure a CLSC network for mobile phone recovery and recycling in a multi-period and multi-product situation with considering different types of returned products in Toronto, Canada.
- Investigating reselling, commercial, and EOU returned products to the second customers with different selling prices.
- Applying chance-constrained programming to deal with stochastic sources in the CLSC network such as demand and rate of returned products.
- Developing a fuzzy method to estimate the quantitative and qualitative weights for supplier selection and order allocation in the proposed model.
- Providing real distances in the proposed multi-echelon model using Google maps.

## 1.8. Research objective

The objective of this study is to configure a closed-loop supply chain network for mobile phone and to provide some methodologies in order to consider the following issues:

**Uncertainty:** Various parameters including cost, demand, and return are considered as non-deterministic parameters in several mathematical models. Therefore, some causes of uncertainty are examined.

**Multi-objectives:** In mobile phone CLSC, not only it is essential to minimize the total cost or maximize the total profit, but also it is necessary to consider green impacts of facilities. Providing a balance between these two objectives has become as a challenge for organizations. Incorporation of supplier selection strategies, not only can profoundly reduce the total cost, but also can yield a tactical key regarding raised carbon footprint issue of the suppliers (Govindan et al., 2014). Consequently, proposing multi-objective models and developing proper solution methodologies become very important.

## 1.9. Solution methodologies

In this section, some outstanding approaches which have been applied in this study are investigated.

**Mixed-integer linear programming:** Minimizing or maximizing a linear function subject to linear constraints is defined as a mixed-integer linear programming. Variables can be determined as either nonnegative or integer. Binary variables can be mentioned as an example of integer variables which are defined as 0 or 1 (Amin, 2012).

**Multi-objective programming:** several goals can be examined in multi-objective programming while in mono-objective programming, only one aim can be considered. For example, in closed-loop supply chain management, the total profit can be maximized alongside with the minimization of carbon footprint. There is no single solution optimizing each objective for a multi-objective optimization problem. Therefore, there will be conflict among objective functions, and resulting a number of Pareto optimal solutions. Finding an optimal set of Pareto

solutions, or assessing the trade-offs in satisfying the different objectives, or providing a single solution in order to satisfy the subjective desires of a human decision-maker (DM) can be the goal (Collette and Siarry, 2003).

**Stochastic programming:** Stochastic programming can be applied in mathematical optimization models in which uncertainty is considered. Minimization of the total expected cost or maximization of the total expected profit of a network are the main objectives of many stochastic models.

**Theory of fuzzy:** The fuzzy sets theory was originally introduced by Zadeh (1965). The fuzzy sets theory can be considered as a theory of scaled approach, a theory in which everything is based on grade or everything has elasticity (Zimmermann, 2001). Fuzzy sets theory allows the step-by-step evaluation of the membership of factors in a set; this is provided with the aid of a membership function defined in the real unit interval  $[0, 1]$ .

Trapezoidal fuzzy number (TFN) is one of the most known fuzzy numbers. This TFN, also known as membership function, is convex i.e. the level begins at zero, increases to a maximum, and then drops to zero again. A trapezoidal fuzzy number  $A = (a, b, c, d)$  is a fuzzy set on  $\mathbb{R}$  with the membership function given by

$$\mu_A(x) = \begin{cases} \frac{x-a}{b-a} & \text{if } x \in [a, b) \\ 1 & \text{if } x \in [b, c] \\ \frac{d-x}{d-c} & \text{if } x \in (c, d] \\ 0 & \text{otherwise} \end{cases} \quad (1.1)$$

where  $a \leq b \leq c \leq d$  as shown in Fig. 1.4.

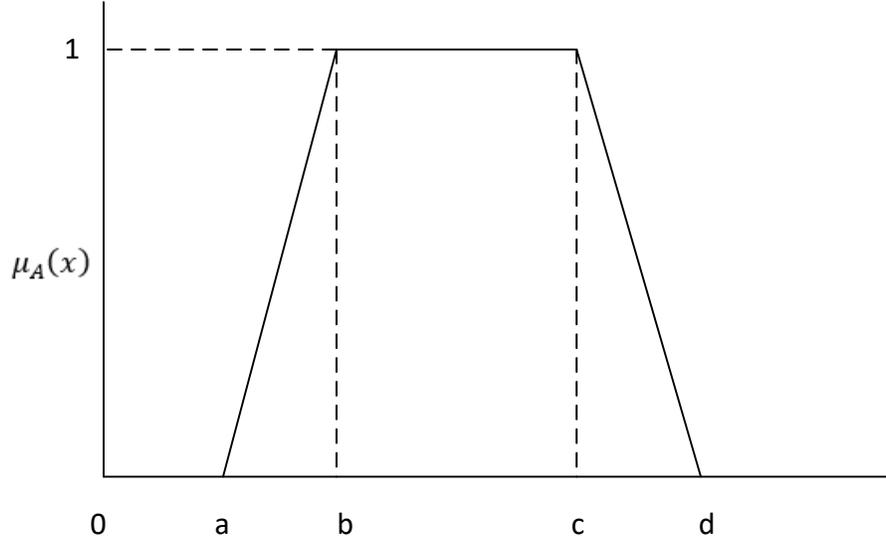


Fig. 1. 4. A trapezoidal fuzzy number

**Chance-constrained programming:** A lot of methodologies can be taken into account to deal with stochastic parameters in optimization models. One of the methods that has been used in many studies is Chance-Constrained Programming (CCP) proposed by Charnes et al. (1990). Assume a mathematical programming with stochastic parameters as follows:

$$\begin{cases} \max f(x) \\ \text{subject to:} \\ g_j(x, \xi) \leq 0, j = 1, 2, \dots, p \end{cases} \quad (1.2)$$

where  $x$  and  $\xi$  are a decision vector and a stochastic vector, respectively.  $f(x)$  is a non-stochastic objective function and  $g_j(x, \xi)$  is a stochastic constraint. A stochastic decision problem can be also written as follows (Liu, 1999):

$$\begin{cases} \max f(x) \\ \text{subject to:} \\ \Pr\{\xi | g_j(x, \xi) \leq 0\} \geq \alpha_j, j = 1, 2, \dots, p \end{cases} \quad (1.3)$$

where  $\alpha_j$  is a predetermined confidence level to the respective stochastic constraint and  $\Pr\{.\}$  indicates the probability of the event in  $\{.\}$ . The stochastic constraint is required to be converted to its deterministic equivalent.

**Supplier selection and order allocation:** Supplier selection is defined as A multi-criteria decision problem that has both subjective and objective parameters (Amin and Razmi, 2009). Nowadays, a crucial decision is to select the most appropriate supplier. Several criteria such as durability and being state-of-the-art possess a higher level of importance in CLSC network especially when we are dealing with the mobile phone industry.

### **1.10. Organization of the thesis**

This thesis is organized as follows: literature review is provided in Chapter 2. Then in Chapter 3, a deterministic facility location model for mobile phone closed-loop supply chain network is defined, and its mathematical formulation is presented. Chapter 4 is assigned to extending the model to a stochastic one, then a supplier selection and order allocation methodology is discussed. Moreover, the distance method along with  $\varepsilon$ -constraint method are introduced to determine solutions for the proposed multi-objective model. Finally, Chapter 5 contains conclusions and future works.

## CHAPTER 2. REVIEW OF LITERATURE

### 2.1. Introduction

In this chapter, various papers and approaches in the field of RL and CLSC and supplier selection are reviewed. Stochastic programming, supplier selection method, deterministic CLSC networks, MILP, and different types of returns are the main covered parameters. Consequently, studies related to deterministic CLSC configurations are presented in Section 2.2. Next, Section 2.3 is assigned to investigation of some papers including supplier selection and order allocation. The application of stochastic programming in CLSC is provided in Section 2.4. In Section 2.5 multi-objective models in CLSC are discussed.

### 2.2. Deterministic models in CLSC

Plenty of studies in the field of CLSC design and planning can be mentioned, in which different attitudes of network configuration are considered. In most of these studies, a general network is designed, while some CLSC networks are arranged and analyzed for precise products. Kannan et al. (2009) proposed a multi-echelon inventory allocation closed-loop supply chain configuration considering built-to-order situation. They applied genetic algorithm along with particle swarm optimization to their model. Lee et al. (2009) configured a CLSC network without considering any specific product. They utilized a heuristic approach for the proposed mathematical model. They determined the optimum quantities of disassembly and operating centres considering only one supplier in their network. Cho et al. (2017) provided a mixed-integer nonlinear programming formulation to analyze EOL options of computer parts in order to maximize the total profit related to computer remanufacturing considering multiple production periods. They proposed ant colony and genetic search algorithms because the problem was NP-hard. Efficiency of time and energy has been analyzed in the CLSC model proposed by Kadambala et al. (2017). They provided a multi-objective programming network to optimize customer surplus and profit, in addition to minimizing applied energy. Xu et al. (2017) provided an innovative comprehensive reverse supply chain. Various uncertainties including waste collection, carbon emission, and exchange rate and transportation cost have been considered in their work. Soleimani and Kannan (2015) developed a new solution methodology to deal with a deterministic, multi-period situation for multiple products. They regarded large-scale examples

in their analyses to have reliable performance. The new proposed hybrid algorithm has been evaluated using CPLEX and MATLAB.

Very few papers have focused on the mobile phones CLSC network, especially in Canada. It should be mentioned that without considering a specific product, it would be hard to apply the proposed model and transfer it from theory to practice (Soleimani and Kannan, 2015). Optimization methods and simulation were combined by Franke et al. (2006) to make an integrated solution methodology for reproducing mobile phones. An environmental assessment method was executed by Huisman (2004) regarding recycling the mobile phones. Guide et al. (2005) contributed some statistics about a remanufacturing mobile phone company in U.S. Ponce-Cueto et al. (2011) analyzed a reverse logistics system for the mobile phone industry in Spain, and investigated the efficient factors included in this part. Their results illustrate that the issues in the system arise from the low recovery quantity through the legitimate networks, extensive increasing secondary markets because of the potential values of the mobile phones, and irregular logistics and supply chain networks for the returned mobile phones. Velmurugan (2016) investigated a mobile phones remanufacturing considering health and environmental impacts. In the study of Argenta et al. (2017), recovery the parts of mobile phones such as LCD screens was examined. Noman and Amin (2017) investigated various important characteristics of reverse logistics and recycling of mobile phone in Canada emphasizing on British Columbia, Ontario, and Nova Scotia. Jayant et al. (2014) considered an integrated decision analysis method consisting of TOPSIS and AHP to opt the best mobile phone service provider in an RL system. The performance of a reverse logistics firm has been measured by an agent-based modeling technique provided by Pandian (2015). The different agents considered in this network are collector agent, sorting-cum-reuse agent, supplier agent, recycler agent, distributor agent, and remanufacturing agent. These agents act independently, and their individual performances are measured.

Not only it is essential to consider multiple-products to design a CLSC network for its economic efficiency, but also various types of returns and quality levels of the returned products should be regarded. Multi-product scheme has been utilized in many papers (e.g., Salema et al., 2006; Lee and Dong, 2008; Amin and Zhang, 2013; Ramezani et al., 2013; Soleimani and Kannan, 2015; Amin et al., 2017), however a very few studies include the different classes of

returns and their quality levels (e.g., Dat et al., 2012; Alumur et al., 2012). The important point is that various recovery choices such as recycling, remanufacturing, and repairing should be considered in the design and analysis of a CLSC network (John et al., 2017). Amin and Zhang (2012a) developed a mixed-integer formulation to optimize a general network considering commercial, EOU, and EOL returns. In their paper, it is assumed that commercial returns go to the repair site, whereas EOU and EOL returns are disassembled. John et al. (2017) presented an integer programming mathematical model to design a multi-product and multi-echelon reverse logistics for two electronic products including digital cameras and mobile phones. Different recovery options and the cost of grading in collection centre have been considered in their model. Ignoring multi-period in input parameters are the most important drawbacks of both aforementioned works. In addition, it has been assumed that EOU or commercial returns are directed toward collection centres or repair sites whereas, in reality, EOU and commercial returned mobile phones are returned to the retailers. Besides, EOL products are shipped to the collection and drop-off centres for further inspections.

### **2.3. Supplier selection and order allocation**

There are many publications in the field of supplier selection and order allocation. An integrated decision model was provided by Ordoobadi (2010) in which AHP and the Taguchi loss function are utilized. In fact, the weights regarding the importance of tangible and intangible decision criteria are estimated using AHP, while suppliers are ranked by calculating the weighted Taguchi loss scores. An integration of ANP, TOPSIS, and LP was provided by Lin et al. (2011) in order to rank the suppliers for the application of Enterprise Resource Planning (ERP) system. Supplier selection and order allocation along with inventory management were considered by Mendoza and Ventura (2012). Two models were proposed by them. The order quantities were determined using the first model, while this quantity was restricted to be of equal size by the second model. Shirkouhi et al. (2013) proposed a multi-objective linear network according to a fuzzy concept with two phases. The various objectives of the proposed model were minimizing the cost and defect rate as well as emphasizing on omitting lateness of the jobs. Amid et al. (2011) proposed a fuzzy model with the aim of supplier selection in order to achieve the lowest purchasing cost and best service and quality level. The weighted max-min approach is utilized to solve this model while the weights were calculated by AHP. Amin and Zhang (2012b)

considered three groups of qualitative and quantitative criteria including supplier-relevant, part-relevant, and process-relevant, and developed an integrated mixed-integer programming model for designing a CLSC network as well as supplier selection and order allocation. They utilized fuzzy method in order to assess the suppliers. Shaw et al. (2012) examined a supplier selection fuzzy optimization model. They considered a multi-objective model comprising of minimizing the cost, late delivery performance, rejection rate, and greenhouse effect of goods. A fuzzy multi-criteria optimization model for supplier selection and purchasing order allocation according to different economic and environmental criteria in order to minimize the purchasing cost is presented by Kannan et al. (2013). Dweiri et al. (2016) utilized AHP in an automotive industry and applied a decision-making approach in order to select suppliers. Many studies used Quality Function Deployment (QFD) which is defined as a procedure for investigating and analyzing the voice of customers and converting it into the engineering concepts. Bevilacqua et al. (2006) utilized fuzzy QFD for selecting the suppliers without considering order allocation. The research of Amin and Razmi (2009) was conducted in the field of service corporation integrating three levels of supplier selection including supplier selection, assessment, and improvement. QFD was utilized to determine the best internet service provider. A fuzzy methodology was also proposed to take into account the inaccuracy of human assumptions. A novel solution methodology for supplier selection and order allocation was proposed by Scott et al. (2015) in which AHP, QFD, and chance-constraint programming were combined. Yazdani et al. (2017) utilized a QFD model to determine the connections between several criteria and customer requirement based on a relationship matrix. Babbar and Amin (2017) presented a model for supplier selection and order allocation considering both qualitative and quantitative environmental criteria. They proposed a two-stage QFD in order to examine all suppliers comprehensively. One of the most popular methods for supplier selection is Data Envelopment Analysis (DEA). A methodology was presented by Weber et al. (2000) to select proper vendors. They achieved the optimal solutions of a multi-objective supplier selection problem by adjusting the weights of the quantity of suppliers and the weights of objective functions. Then, the results of objective functions related to achieved optimal solutions were considered as inputs of DEA model in order to provide the number of suppliers. As the result, the average of DEA efficiency score was maximized. A hybrid methodology including DEA, decision tree, and neural network was developed by Wu (2009) in which the application of DEA was to categorizing suppliers into efficient and

inefficient classes. Jafari-Songhori et al. (2011) developed an integration of DEA and multi-objective mixed-integer programming model to perform supplier selection at first, and order allocation alone. Karsak and Dursun (2014) exploited an imprecise DEA for supplier selection, in which the weights of criteria of suppliers are calculated using Fuzzy Weighted Average (FWA) applying the data from the House of Quality (HOQ) and supplier rankings according to supplier evaluation criteria. Kumar et al. (2014) applied Green DEA approach for supplier selection among all suppliers who fulfill the emission standards and poses high environmental efficiency. A multi-objective DEA model based on type-2 fuzzy sets theory was proposed by Zhou et al. (2016) so that the most proper sustainable suppliers were assessed and chosen. Moheb-Alizadeh and Handfield (2017) utilized a bi-objective DEA to assess the efficiency and sustainability of suppliers in a multi-objective mixed-integer non-linear programming network.

#### **2.4. Stochastic programming in CLSC**

Stochastic programming is utilized in closed-loop supply chain design to deal with sources of uncertainties such as demand, cost, return, etc. Uncertainty in demand is the most important one. Inaccurate prediction of demand or demand volatility is described as demand uncertainty. Hence, considering uncertain demand in both functional and research aspects is important (Davis, 1993; Zhang and Ma, 2009; Peidro et al., 2009). A stochastic closed-loop supply chain network considering uncertain demand and return was proposed by Inderfurth (2005). Moreover, an additional parameter was defined in their model with the aim of measuring the uncertainty in quality. A stochastic model for configuration of a CLSC network consisting of both supply and return channels was provided by Listes (2007). Their solution approach was a decomposition methodology according to branch-and-cut method. Lieckens and Vandaele (2007) developed a mixed-integer nonlinear programming network considering stochastic lead time and queuing theory. However, multi-product scenario is ignored in their work. Paksoy et al. (2011) presented an optimization model in order to evaluate the environmental factors and efficiency in a multi-product CLSC network. Stochastic programming was applied to examine the trade-off solution in a realistic network. Amin and Zhang (2013) proposed a three-stage model. They applied a new Quality Function Deployment (QFD) model to evaluate various facilities including suppliers, refurbishing sites, etc. In addition, they proposed a closed-loop supply chain network using a stochastic mixed-integer nonlinear programming model. They consider the demand as the

uncertain parameter. Kenne et al. (2012) introduced a manufacturing/remanufacturing policy within a CLSC network. Their objective was to minimize the total cost of holding and blocking for manufacturing and remanufacturing goods. The optimal control theory was applied to develop the optimality conditions according to stochastic dynamic programming. Kim et al. (2014) developed a two-stage closed-loop supply chain in which manufactured products are shipped from supplier to the buyer using Returnable Transport Items (RTIs) so that empty RTIs are gathered at the buyer point and sent back to the supplier. They assumed that the return time of RTIs is stochastic. Mitra (2012) considered the inventory management issue in closed-loop supply chains and proposed deterministic and stochastic two-echelon models in which demand and return are correlated with respect to generalized cost structures. Their results illustrated that in spite of a reduction in the variability of the demand in case of the higher rate of return and the higher correlation between demand and return, the cost is not essentially saved. However, the costs movement will be dependent on some parameters of the network. Vahdani and Mohammadi (2015) developed a bi-objective optimization model with the objective of decreasing the total cost and waiting time in the line. Their solution approach was a hybrid methodology with respect to stochastic programming and robust optimization to cope with the uncertainty in the model. Francie et al. (2015) proposed a CLSC for a printer cartridge with the application of stochastic programming. Their goal was to minimize the total cost induced by customer waiting and holding inventories according to finished and returned products. Jeihoonian et al. (2016) developed a two-stage stochastic programming model in order to configure a closed-loop supply chain network which is in accordance with modular structured products. In their model, the quality level of the return stream was uncertain. An accelerated L-shaped algorithm is utilized in their work to deal with the stochastic program. Keyvanshokoo et al. (2016) proposed a novel hybrid robust-stochastic programming methodology in which stochastic scenarios were applied for transportation expenses and polyhedral uncertainty sets for demand and return. The proposed model was solved using an accelerated stochastic Benders decomposition algorithm. Feitó-Cespón et al. (2017) combined stochastic and multi-criteria modeling in order to investigate different objectives to consider the uncertainty in a maintainable supply chain network. Uncertainties had the minimum effect on decision-making, and the provided solution was evaluated utilizing a performance indicator. Haddadsisakht and Ryan (2018) developed a three-stage hybrid robust/stochastic program considering the combination of

probabilistic scenarios for the amount of demands and returns along with the uncertainty sets for the carbon tax rates. They provided the bender cuts according to the novel duality developments for robust linear programming.

## **2.5. Multi-objective models in CLSC**

Nowadays according to the importance of environmental issues, in addition to the objectives related to the cost or profit, the objectives of green factors has attained a lot of attentions. Hence, multi-objective and aim programming models and closed-loop supply chain networks are developed. Krikke et al. (2003) considered both the design structure of the logistics network and the design structure of a product, i.e. modularity, reparability, and recyclability in their proposed quantitative model for decision-making support. Linear-energy and waste functions are utilized to estimate the environmental impacts. Real R and D data of a Japanese consumer electronics company for refrigerators was applied to their closed-loop supply chain network. The three objective functions are minimization of the total costs along with energy consumption and residual waste. Uster et al. (2007) configured a multi-product CLSC network for the purpose of locating the collection centres and remanufacturing sites with respect to coordination of the forward and reverse flows in the system. Their objective was to minimize the operating transportation and fixed expenses of facility locations. Benders decomposition methodology was their approach to solve the model. Pishvae et al. (2010) proposed a bi-objective mixed-integer programming model. Their goal was to maximize the total cost as well as to maximize the responsiveness of a logistics network. Their solution approach to deal with the bi-objective model was a memetic algorithm. Das and Posinasetti (2015) developed multi-product CLSC network formulating a mathematical model considering the environmental issues. Maximization of the profit along with optimization of consumed energy and harmful emission were their objectives. They utilized goal programming to solve the proposed multi-objective model. Özkır and Başlıgil (2013) introduced a CLSC network with three objective formulations. They aimed to maximize satisfaction level of trade with regard to maximizing satisfaction degrees of customers and maximizing the total profit of the network. Tosarkani and Amin (2018a) designed a CLSC network for a battery recycling system. They provided a multi-component, multi-echelon, multi-product, and multi-period model under imprecise information. An FFP method has been applied for this model. This network was realistic based on real distances and real

information related to Vancouver, Canada. Besides, by expanding the mathematical model to the multi-objective, green factors regarding manufacturers and battery recovery centres have been considered. Ghassemi et al. (2018) developed an integrated framework including a Multi-Attribute Decision-Making (MADM) method and a multi-objective formulation to provide the material flow of parts and products among various facilities in a CLSC network.

Table 2.1 represents the analysis of several papers in the literature. Some keywords such as reverse logistics, mobile phone, different types of return, CLSC, etc. have been used to search papers. www.sciencedirect.com, Taylor and Francis, and Google Scholar have been utilized to find papers.

Table 2.1.  
Review of some papers in CLSC

References	Uncertainty	Type of Products	Multi-Period	objectives			Real Locations	All Types of Product Return
				Cost/profit	Supplier selection	Green factors		
Pishvae and Razmi (2012)	Input data	-	-	√	-	√	√	-
Amin et al. (2017)	Demand, return	Tire	√	√	-	-	√	-
Vahdani and Mohammadi (2015)	Cost and capacity	-	-	√	-	-	-	-
Cardoso et al. (2013)	Demand	-	√	√	-	-	-	-
Soleimani and Kannan (2015)	-	Hospital Furniture	√	√	-	-	-	-
Xu et al. (2017)	Waste collection level	-	√	√	-	-	-	-
Amin and Zhang (2013)	Decision-making process	-	√	√	√	-	-	-
Subulan et al. (2015)	-	Tire	√	√	-	√	√	-
Mohajeri and Fallah (2016)	Recovery rate, landfilling rate, demand	Laptop industry	-	√	-	-	√	-
References	Uncertainty	Type of Products	Multi-Period	objectives			Real Locations	All Types of Product Return
Ramezani et al. (2014)	All parameters	-	√	√	-	-	-	-
Jeihoonian et al. (2017)	Quality of returned products	-	-	√	-	-	-	-

Özceylan et al. (2017)	-	Automotive Industry	√	√	-	-	√	-
John et al. (2017)	-	Mobile Phone and Camera	-	√	-	-	√	-
Moghadam (2015)	Customers' demand, suppliers' capacity, returned products	-	-	-	√	-	-	-
Das and Posinasetti (2015)	-	-	-	√	-	√	-	-
Garg et al. (2015)	-	-	-	√	-	√	√	-
Zeballos et al. (2014)	Supply and demand	-	√	√	-	-	-	-
Dutta et al. (2016)	Demand	-	√	√	-	-	-	-
Shakourloo et al. (2016)	-	-	-	√	√	-	-	-
Chen et al. (2017)	-	Solar energy	-	√	-	√	-	-
Pham and Yenradee (2017)	Demand, location-production opening cost, setup cost	Toothbrush	√	√	-	-	-	-
Ruimin et al. (2016)	Demand, cost parameters	-	-	√	-	√	√	-
Talaei et al. (2016)	Demand, variable cost	-	-	√	-	-	-	-
Feitó-Cespón et al. (2017)	demand and waste generation	-	-	√	-	-	-	-
Moheb-Alizadeh and Handfield (2017)	Demand	-	√	√	√	-	-	-
Tosarkani and Amin (2018a)	All parameter and decision variables	Battery	√	√	-	√	√	-
Babbar and Amin (2018)	Demand and unit costs	beverages	√	√	√	√	-	-
My model		Mobile Phone	√				√	√

## **CHAPTER 3. THE EFFECTS OF DIFFERENT KINDS OF RETURNS ON A MOBILE PHONE CLOSED-LOOP SUPPLY CHAIN NETWORK**

### **3.1. Introduction**

In this chapter, a deterministic model for mobile phone industry is provided. A multi-period, multi-product, multi-echelon, and multi-customer Closed-Loop Supply Chain (CLSC) network for a mobile phone network is designed and optimized considering different types of product returns. The aim of this study is to determine the number and location of suppliers, manufacturers, retailers, and drop-off centres as well as the amount of materials and products that are required to be purchased or produced, respectively in order to maximize the total profit of the CLSC network. Different types of returns, as well as various selling prices, are considered in the proposed model.

In the following sections, at first, the mobile phone CLSC network is analyzed in Section 3.2. Then, a mathematical model related to the proposed model is described in Section 3.3. Section 3.4, is assigned to explaining several assumptions about the amount of demand and return and the location of demand markets as well as the solution of the proposed model. Various sensitivity analyses and their related discussions are provided in Section 3.5. Finally, this chapter is summarized in Section 3.6.

### **3.2. Network explanation**

Fig. 3.1 shows a closed-loop supply chain network for mobile phone recycling and reselling considering multi-materials and multi-products in multiple periods. The provided network includes suppliers, manufacturers, retailers, first and second customers, drop-off centres, consolidation centres, and disposal centres. Manufacturers purchase the main materials of mobile phone from suppliers and generate four categories of products. Then, the outputs are transported to the retailers. It is required that the retailers satisfy the demands of both first and second customers by storing the least possible aggregating inventory to decrease related costs.

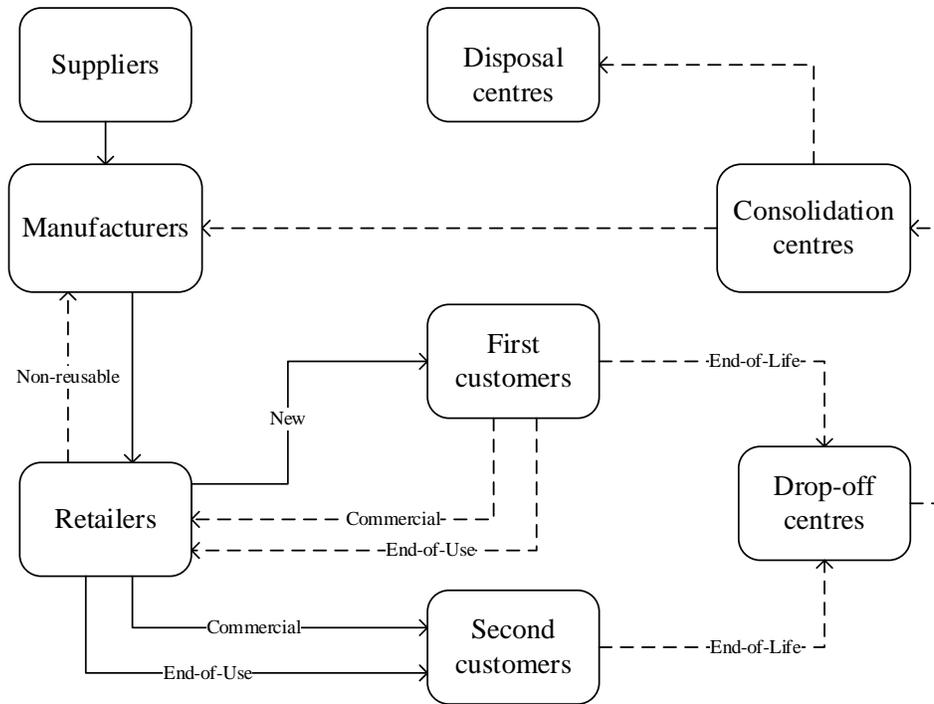


Fig. 3.1. A closed-loop supply chain of mobile phone including recycling and reselling

First customers purchase new mobile phones from retailers. Some of them can be returned to the retailers as commercial or EOU, whereas some others are directed toward drop-off centres (EOL). The mobile phones returned to the retailer are resold to the second customers with a lower price. EOL mobile phones are shipped to consolidation centres from drop-off centres for more investigations and decomposition to the main materials. Some of these materials can be recycled and forwarded to the manufacturers for further consumption, while unusable components are shipped to the disposal centres. In this problem, the manufacturer manages the network. In the other words, the network has been designed for the manufacturer.

In this work, it is emphasized to clarify the following issues: Which suppliers are appropriate for providing materials? Which locations should be selected for manufacturers? Which retailers should be opened? Which drop-off centres must be responsible for collecting EOL products? Which consolidation centres are suitable for decomposing of mobile phones? How many materials should be purchased from selected suppliers? How many products are transported between various facilities?

### 3.3. Optimization model

A mixed-integer linear programming formulation is provided which deals with the problem of mobile phone CLSC. Different components of the mathematical model are defined in this section.

#### Sets

$M$	set of manufacturers (1 ... $m$ ... $M$ )
$S$	set of suppliers (1 ... $s$ ... $S$ )
$R$	set of retailers (1 ... $r$ ... $R$ )
$K$	set of first customers (1 ... $k$ ... $K$ )
$L$	set of second customers (1 ... $l$ ... $L$ )
$D$	set of drop-off centres (1 ... $d$ ... $D$ )
$X$	set of disposal centres (1 ... $x$ ... $X$ )
$I$	set of products (1 ... $i$ ... $I$ )
$J$	set of materials (1 ... $j$ ... $J$ )
$G$	set of consolidation centres (1 ... $g$ ... $G$ )
$T$	set of periods (1 ... $t$ ... $T$ )

#### Parameters

$fa_m$	fixed-cost of manufacturer $m$
$fb_s$	fixed-cost of supplier $s$
$fc_r$	fixed-cost of retailer $r$
$fd_d$	fixed-cost of drop-off centre $d$
$fe_g$	fixed-cost of consolidation centre $g$
$Ac_{kit}$	demand of product $i$ by first customer $k$ in period $t$
$As_{lit}$	demand of product $i$ by second customer $l$ in period $t$
$P_i^n$	unit price of selling new product $i$
$P_i^u$	unit price of selling used return product $i$
$P_i^c$	unit price of selling commercial return product $i$
$ka_{smt}$	unit transportation cost from supplier $s$ to manufacturer $m$ in period $t$
$kb_{mrt}$	unit transportation cost from manufacturer $m$ to retailer $r$ in period $t$

$kc_{rmt}$	unit transportation cost from retailer $r$ to manufacturer $m$ in period $t$
$kd_{dgt}$	unit transportation cost from drop-off centre $d$ to consolidation centre $g$ in period $t$
$ke_{gmt}$	unit transportation cost from consolidation centre $g$ to manufacturer $m$ in period $t$
$kf_{gxt}$	unit transportation cost from consolidation centre $g$ to disposal centre $x$ in period $t$
$\omega_{sjt}$	unit price of raw material $j$ from supplier $s$ in period $t$
$\mu_{mit}$	unit production cost of product $i$ made by manufacturer $m$ in period $t$
$\gamma_{git}$	unit decomposition cost of product $i$ by consolidation centre $g$ in period $t$
$dw_{rit}$	unit inspection cost of returned product $i$ by retailer $r$ in period $t$
$dh_{xjt}$	unit disposal cost of material $j$ by disposal centre $x$ in period $t$
$\theta_{sm}$	the distance between supplier $s$ and manufacturer $m$
$\theta_{mr}$	the distance between manufacturer $m$ and retailer $r$
$\theta_{dg}$	the distance between drop-off centre $d$ and consolidation centre $g$
$\theta_{gm}$	the distance between consolidation centre $g$ and manufacturer $m$
$\theta_{gx}$	the distance between consolidation centre $g$ and disposal centre $x$
$zc_{kit}$	end-of-life returned product $i$ from first customer $k$ in period $t$
$zs_{lit}$	end-of-life returned product $i$ from second customer $l$ in period $t$
$\tau c_{kit}$	percentage of commercial returned product $i$ from customer $k$ in period $t$
$\tau u_{kit}$	percentage of end-of-use returned product $i$ from customer $k$ in period $t$
$\tau l_{rit}$	percentage of unusable product $i$ from retailer $r$ in period $t$
$\sigma_{it}$	unit penalty cost of product $i$ in period $t$
$\eta_j$	unit cost saving of material $j$ owing to product decomposition
$\beta_{ij}$	material $j$ used to produce product $i$
$\rho_i$	unit inventory cost of product $i$
$\varepsilon_j$	disposal fraction of the material $j$
$mcap_{mj}$	inventory capacity of manufacturer $m$ for material $j$
$rcap_{ri}$	inventory capacity of retailer $r$ for product $i$
$dcap_{di}$	inventory capacity of drop-off centre $d$ for product $i$
$gcap_{gi}$	inventory capacity of consolidation centre $g$ for product $i$
$scap_{sj}$	inventory capacity of supplier $s$ for material $j$

## Decision Variables

$a_{rkit}^n$	quantity of new product $i$ sold by retailer $r$ to first customer $k$ in period $t$
$a_{rlit}^u$	quantity of used product $i$ sold by retailer $r$ to second customer $l$ in period $t$
$a_{rlit}^c$	quantity of commercial return $i$ sold by retailer $r$ to second customer $l$ in period $t$
$q_{smjt}$	quantity of raw material $j$ shipped from supplier $s$ to manufacturer $m$ in period $t$
$a_{mrit}$	quantity of product $i$ from manufacturer $m$ to retailer $r$ in period $t$
$b_{krit}^c$	quantity of commercial return product $i$ from first customer $k$ to retailer $r$ in period $t$
$b_{krit}^u$	quantity of used product $i$ from first customer $k$ to retailer $r$ in period $t$
$a_{rmit}^l$	quantity of unusable product $i$ from retailer $r$ to manufacturer $m$ in period $t$
$ef_{kdit}$	quantity of product $i$ from first customer $k$ to drop-off centre $d$ in period $t$
$es_{ldit}$	quantity of product $i$ from second customer $l$ to drop-off centre $d$ in period $t$
$n_{dgit}$	quantity of product $i$ from drop-off centre $d$ to consolidation centre $g$ in period $t$
$\varphi_{gmjt}$	quantity of raw material $j$ from consolidation centre $g$ to manufacturer $m$ in period $t$
$u_{gxjt}$	quantity of material $j$ from consolidation centre $g$ to disposal centre $x$ in period $t$
$In_{rit}$	quantity of new product $i$ holding as the inventory in retailer $r$ in period $t$
$ya_m$	1 if manufacturer $m$ is open; 0 otherwise
$yb_s$	1 if supplier $s$ is open; 0 otherwise
$yc_r$	1 if retailer $r$ is open; 0 otherwise
$yd_d$	1 if drop-off centre $d$ is open; 0 otherwise
$ye_g$	1 if consolidation centre $g$ is open; 0 otherwise

$$\begin{aligned}
\text{Max profit} = & \sum_r \sum_k \sum_l \sum_i \sum_t (P_i^n a_{rkit}^n + P_i^u a_{rlit}^u + P_i^c a_{rlit}^c) \\
& - \left[ \sum_m f a_m y a_m + \sum_s f b_s y b_s + \sum_r f c_r y c_r + \sum_d f d_a y d_a + \sum_g f e_g y g_g \right. \\
& + \sum_s \sum_m \sum_j \sum_t (\omega_{sjt} + k a_{smt} \theta_{sm}) q_{smjt} \\
& + \sum_m \sum_r \sum_i \sum_t (\mu_{mit} + k b_{mrt} \theta_{mr}) a_{mrit} + \sum_r \sum_i \sum_t \rho_i \ln_{rit} \\
& + \sum_r \sum_m \sum_k \sum_i \sum_t ((dw_{rit} + \sigma_{it}) b_{krit}^c + dw_{rit} b_{krit}^u + (dw_{rit} \\
& + k c_{rmt} \theta_{mr}) a_{rmit}^l) + \sum_d \sum_g \sum_i \sum_t (\gamma_{git} + k d_{dgt} \theta_{dg}) n_{dgit} \\
& \left. + \sum_m \sum_g \sum_x \sum_j \sum_t ((k e_{gmt} \theta_{gm} - \eta_j) \varphi_{gmjt} + (k f_{gxt} \theta_{gx} + d h_{xjt}) u_{gxjt}) \right]
\end{aligned}$$

s.t.

$$\sum_r \sum_i \beta_{ij} a_{mrit} = \sum_s q_{smjt} + \sum_g \varphi_{gmjt} + \sum_r \sum_i \beta_{ij} a_{rmit}^l \quad \forall j, m, t \quad (3.1)$$

$$\sum_m a_{mrit} + \ln_{r(t-1)i} = \ln_{rit} + \sum_k a_{rkit}^n \quad \forall i, r, t \quad (3.2)$$

$$\sum_r a_{rkit}^n \leq A c_{kit} \quad \forall i, k, t \quad (3.3)$$

$$\sum_r a_{rlit}^u + \sum_r a_{rlit}^c \leq A s_{lit} \quad \forall i, l, t \quad (3.4)$$

$$\sum_m a_{mrit} + \ln_{rit} \geq \sum_k a_{rkit}^n \quad \forall i, r, t \quad (3.5)$$

$$\sum_r a_{rkit}^n \geq \sum_d e f_{kdit} \quad \forall i, k, t \quad (3.6)$$

$$\sum_r a_{rlit}^u + \sum_r a_{rlit}^c \geq \sum_d e s_{ldit} \quad \forall i, l, t \quad (3.7)$$

$$\sum_k e f_{kdit} + \sum_l e s_{ldit} = \sum_g n_{dgit} \quad \forall i, d, t \quad (3.8)$$

$$\sum_d \beta_{ij} n_{dgit} = \sum_m \varphi_{gmjt} + \sum_x u_{gxjt} \quad \forall i, j, g, t \quad (3.9)$$

$$\sum_d e f_{kdit} = z c_{kit} \quad \forall i, k, t \quad (3.10)$$

$$\sum_d e s_{ldit} = z s_{lit} \quad \forall i, l, t \quad (3.11)$$

$$\sum_r b_{krit}^c = \tau c_{kit} \sum_r a_{rkit}^n \quad \forall i, k, t \quad (3.12)$$

$$\sum_r b_{krit}^u = \tau u_{kit} \sum_r a_{rkit}^n \quad \forall i, k, t \quad (3.13)$$

$$\sum_m a_{rmit}^l = \tau l_{rit} b_{krit}^u \quad \forall i, k, r, t \quad (3.14)$$

$$\varepsilon_j \sum_d \sum_i \beta_{ij} n_{dgit} \leq \sum_m \varphi_{gmjt} \quad \forall j, g, t \quad (3.15)$$

$$\sum_s \sum_j q_{smjt} + \sum_g \sum_j \varphi_{gmjt} + \sum_r \sum_i \sum_j \beta_{ij} a_{rmit}^l \leq y a_m \sum_j mcap_{mj} \quad \forall m, t \quad (3.16)$$

$$\sum_m \sum_i a_{mrit} + \sum_i l_{rit} + \sum_k \sum_i b_{krit}^c + \sum_k \sum_i b_{krit}^u \leq y c_r \sum_i rcap_{ri} \quad \forall r, t \quad (3.17)$$

$$\sum_k \sum_i e f_{kdit} + \sum_l \sum_i e s_{ldit} \leq y d_d \sum_i dcap_{di} \quad \forall d, t \quad (3.18)$$

$$\sum_d \sum_i n_{dgit} \leq y e_g \sum_i gcap_{gi} \quad \forall g, t \quad (3.19)$$

$$\sum_m \sum_j q_{smjt} \leq y b_s \sum_j scap_{sj} \quad \forall s, t \quad (3.20)$$

$$y a_m, y b_s, y c_r, y d_d, y e_g \in \{0, 1\} \quad \forall m, s, r, d, g \quad (3.21)$$

$$\begin{aligned} & a_{rkit}^n, a_{rlit}^u, a_{rlit}^c, q_{smjt}, a_{mrit}, b_{krit}^c, b_{krit}^u, \\ & a_{rmit}^l, e_{(k+l)dit}, n_{dgit}, \varphi_{gmjt}, u_{gxjt}, l_{rit} \geq 0 \quad \forall i, j, s, m, r, k, l, d, g, x, t \end{aligned} \quad (3.22)$$

The objective function is designed to maximize the entire profit in the mobile phone CLSC network. The first section is about the net income provided by selling products including selling

new products in addition to commercial and used returned products. The second part is deducted from the total fixed-costs regarding the locations of the suppliers, manufacturers, retailers, drop-off centres, and consolidation centres. The third portion describes purchasing and transporting expenditures of materials from suppliers to the manufacturers. Production and shipping costs among manufacturers and retailers are implied in the fourth portion. The expenses associated with the retailers include inventory cost, inspection cost of the returned products by the first customers, shipping cost of un-reusable goods to the manufacturers, and penalty cost,  $\sigma_{it}$ . The commercial returned products are resold to the second customers with a lower price from that of a new product. This difference is considered as a penalty cost for retailers. In fact,  $\sigma_{it} = p_i^n - p_i^c$ . The expenses of transporting EOL products from drop-off centres to the consolidation centres as well as decomposition cost by the consolidation centres are considered in the next part of the objective function. It is assumed that after decomposition of EOL products to the principal materials, the usable materials will be shipped to the manufacturer to be consumed in the future products. Therefore, a revenue can be defined,  $\eta_j$ , which is the cost saving owing to the product decomposition. Finally, the costs related to shipping unrecoverable materials from consolidation centres to the disposal centres, and the disposal cost are stated in the objective function.

The first constraint implies that the materials consumed to produce a product should be equal to the total materials purchased from suppliers and materials came from consolidation centres along with materials provided by unusable returned products from retailers. Constraint (3.2) shows that the quantity of the products sent from manufacturers to the retailers ( $a_{mrit}$ ) and inventory in period  $t$  are identical to the inventory in period  $(t - 1)$  and the amount of products sold by retailers to the first customer ( $a_{rkit}^n$ ). Constraints (3.3) and (3.4) satisfy the demands related to customers (first and second customers). Constraint (3.5) illustrates that the number of products transported from the manufacturers to the retailers plus the current inventory should exceed the number of products sold to the first customers. Constraints (3.6) and (3.7) signify the trade-off between the products sold to the first and second customers and the returned products. Constraint (3.8) is the network constraint. Constraint (3.9) specifies the balance between the materials of the returned products and the recovered materials directed to manufacturers in addition to unrecoverable materials shipped to the disposal centres. Returned products are defined in Constraints (3.10), (3.11), (3.12), (3.13), and (3.14). Constraint (3.15) implies the disposal part of the returned products. Constraints (3.16), (3.17), (3.18), (3.19), (3.20) are related

to the capacities of the manufacturers, retailers, drop-off centres, consolidation centres, and suppliers, respectively. Eventually, Constraints (3.21) and (3.22) describe non-negative and binary variables.

### 3.4. Application of the proposed model and solution approach

The optimization model is applied to configure a mobile phone CLSC network in Toronto, Canada. Toronto is divided into 44 wards which have been illustrated in Fig. 3.2. In this study, each ward is considered as a potential first customer. It is supposed that there are 22 second demand markets. Furthermore, it is assumed that there exist 4 potential manufacturer locations, 5 suppliers, 15 locations for retailers, 7 locations for drop-off centres, 5 locations for consolidation centres, and 3 potential sites for disposal centres. Moreover, 4 types of mobile phones and 6 types of materials are considered in the model. The distances among various facilities are estimated using Google Maps.

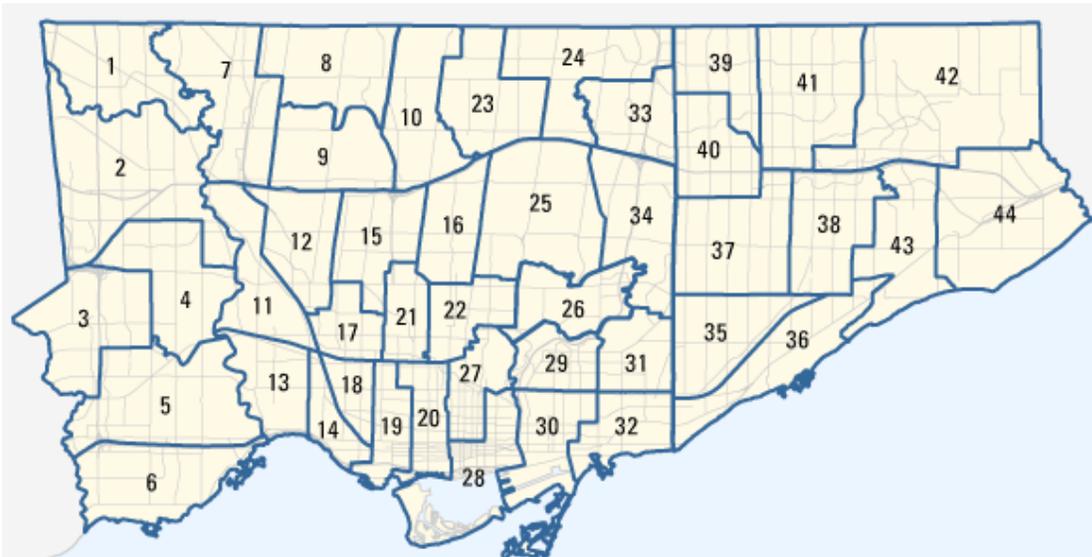


Fig. 3.2. Toronto wards

The demand of the first and second customers for product  $i$  ( $Ac_{kit}$  and  $As_{lit}$ ) are assumed to be 0.01 and 0.005 of the population of each ward, respectively. Toronto wards population is considered based on 2011 census of Canada. It is assumed that the returns of both markets,  $k$  and

$l$  for product  $i$  in period  $t$  is ten percent of each market demand. Other parameters are assigned based on Table 3.1.

Table 3.1.

Values of some parameters defined to solve the mathematical model

$M = 4$	$fa_m = 100,000,000$	$\sigma_{it} = 20$
$S = 5$	$fb_s = 100,000$	$mcap_{mj} = 500,000$
$R = 15$	$fc_r = fd_d = fe_g = 150,000$	$rcap_{ri} = 14,000$
$K = 44$	$P_i^n = 100$	$dcap_{di} = 10,000$
$L = 22$	$P_i^n = 100$	$gcap_{gi} = 10,000$
$D = 7$	$P_i^u = 50$	$scap_{sj} = 150,000$
$I = 4$	$P_i^c = 80$	$\eta_j = 10$
$J = 6$	$ka_{smt} = ke_{gmt} = kf_{gxt} = 0.002$	$\epsilon_j = 0.1$
$G = 5$	$kb_{mrt} = kc_{rmt} = kd_{dgt} = 0.005$	$\rho_i = 35$
$T = 2$	$\mu_{mit} = 15$	

The mathematical model is solved using IBM ILOG CPLEX 12.7.1.0. The computation time is 11.36 seconds. There exist 10,294 constraints, 34,076 single variables, 41 binary variables, and 165,266 non-zero coefficients. The model output is summarized in Table 3.2. The optimal mobile phone CLSC network for Product 1 is depicted in Fig. 3.3. It is shown in Fig. 3.3 that Suppliers 3 and 4 are selected to provide raw materials for open Manufacturers 2 and 3. These chosen manufacturers ship new mobile phones to Retailers 1, 2, 3, 4, 6, 12, 13, 14, 15. Not only the first and second customers deliver used mobile phones to Drop-off centre 6, but also this open drop-off centre sends reusable materials to the selected manufacturers. However, the unusable components will be shipped to Consolidation centre 5 by Drop-off centre 6.

Table 3.2.

Some values of the model for  $i = j = t = 1$

$s = 3, m = 2, r = 12, k = 18, l = 13, d = 6, g = 5, x = 1$

Single Variables	Value	Binary Variables
Objective	24,236,760.294	Suppliers: 3, 4
$a_{rkit}^n$	1,241.125	Manufacturers: 2, 3
$a_{rlit}^c$	231.5	Retailers: 1, 2, 3, 4, 6, 12, 13, 14, 15

$a_{rlit}^u$	222.3	Drop-off centres: 6
$q_{smjt}$	59,886.66	Consolidation centres: 5
$a_{mrit}$	22,647.183	
$b_{krit}^c$	744.675	
$b_{krit}^u$	992.9	
$a_{rmit}^l$	151.52	
$ef_{kdit}$	284.35	
$es_{ldit}$	249.1	
$\varphi_{gmjt}$	6,565.54	
$u_{gxjt}$	9,848.31	

### 3.5. Sensitivity analysis

To evaluate the sensitivity of the mathematical model, one of the most vital parameters, customer's demand ( $Ac_{kit}$  and  $As_{lit}$ ), is changed, and the results are analysed. The effect of 20% increase in the demand for Product 1 (to avoid complexity) of the first and second customers in the first ward (Etobicoke North) is investigated. The changes in the profit according to the changes in the demand are illustrated in Fig. 3.4. It is clear that as the demand increases, the profit raises. Furthermore, by increasing the demand, the chosen retailers are 1, 2, 3, 4, 5, 6, 10, 11, 12, 13, 14, and 15. More open retailers are required in order to satisfy the demand.

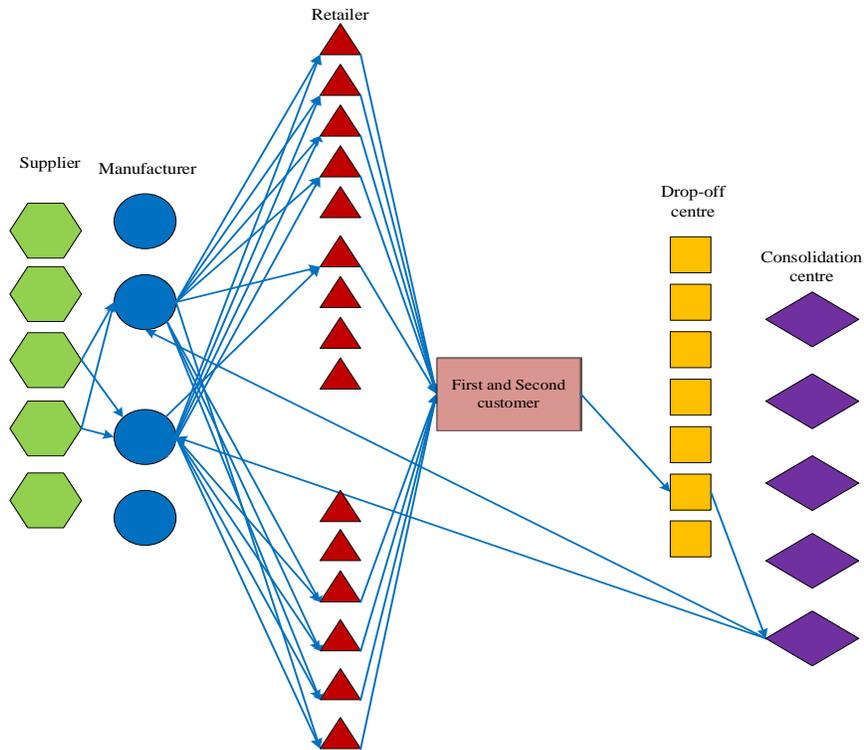


Fig. 3.3. Flow through the CLSC network based on the results

Also, the effect of 20% increase in the returned product from first and second customers in Ward 1 (Etobicoke North) to the drop-off centres is examined. Previously, Drop-off centre 6 was preferred because the location of this drop-off centre is in the area with the highest rate of product return (Willowdale). Nevertheless, by increasing the returned product, the selected drop-off centres are 2 and 6 since Drop-off centre 2 is near Ward 1 in which the returned product rate is increased.

Fig. 3.5 illustrates the new mobile phone CLSC network as the result of the increase in the demand and the returned product, simultaneously. According to Fig. 3.5, it can be seen that by the increase in the demand and rate of returned product, the selected suppliers and manufacturers remain same. However, comparing to Fig. 3.3, three more retailers are chosen to satisfy the increase in demand, and one more drop-off centre is open because of the increase in the rate of the returned product.

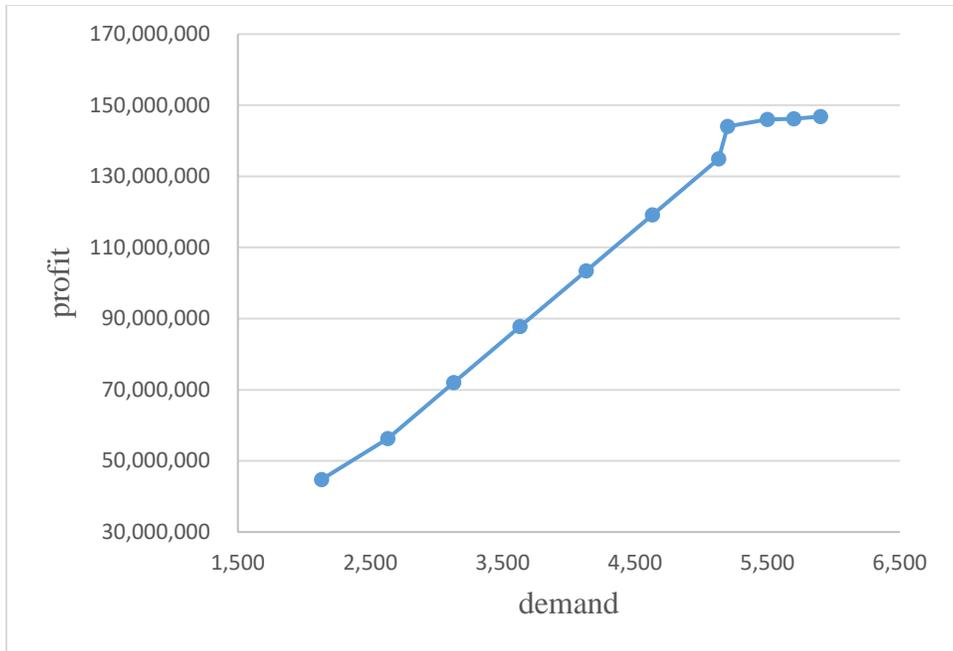


Fig. 3.4. The changes of the profit due to the demand changes

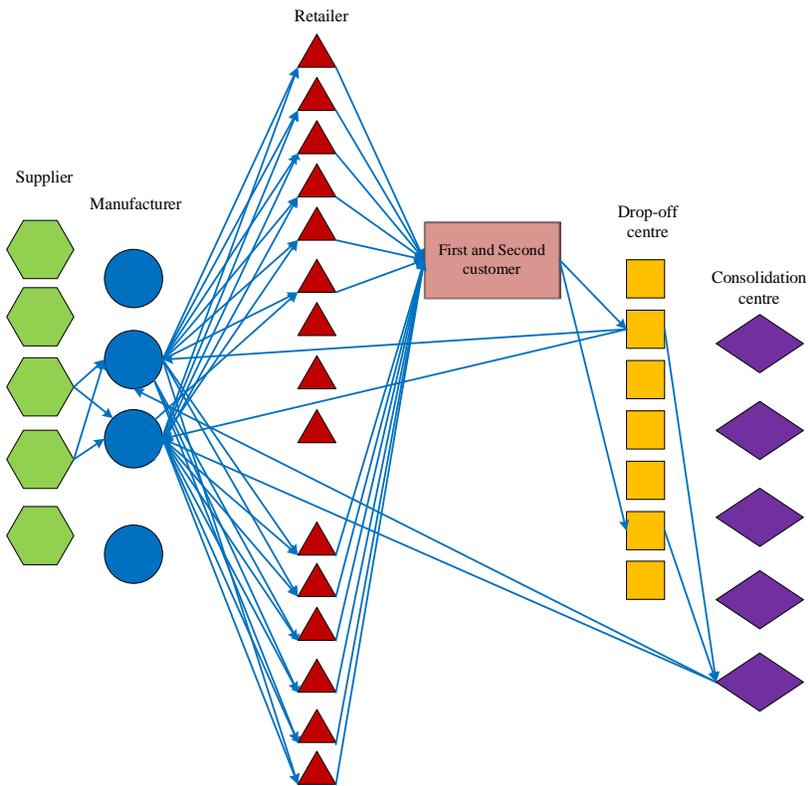


Fig. 3.5. Flow through the new CLSC network (a) based on the results

Afterward, the effect of an increase in the fixed-cost related to the Consolidation centre 5 is examined. The result of this increase is depicted in Fig. 3.6. According to Fig. 3.3 and Fig. 3.5, Drop-off centre 6 and Consolidation centre 5 are selected. However, as the result of 10% increase in the fixed-cost of Consolidation centre 5, although the previous suppliers, manufacturers, and retailers are selected, Consolidation centre 2 is chosen instead of Consolidation centre 5. Consequently, Drop-off centre 6 is replaced by Drop-off centre 4, since the distance between Drop-off centre 4 and Consolidation centre 2 is less.

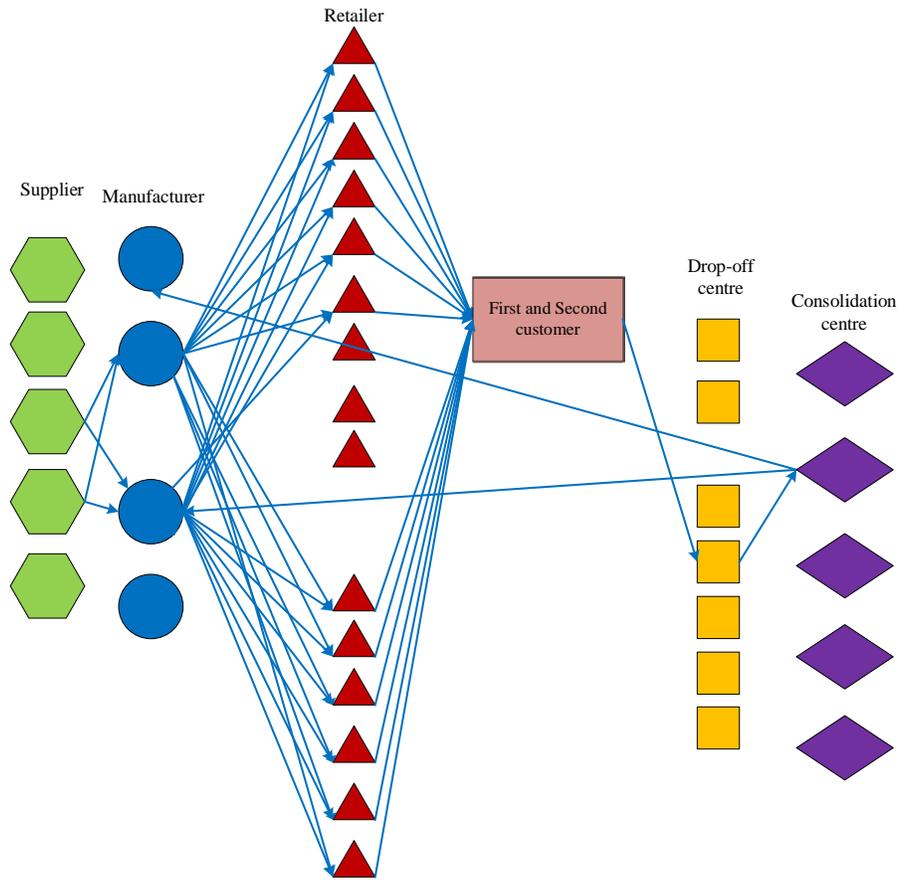


Fig. 3.6. Flow through the new CLSC network (b) based on the results

On the other hand, the impact of 10% increase in the capacity of Supplier 3 is shown in Fig. 3.7. Therefore, considerable variations are applied to the network. As the result of an increase in the capacity of Supplier 3, only this supplier is selected and no more supplier is needed.

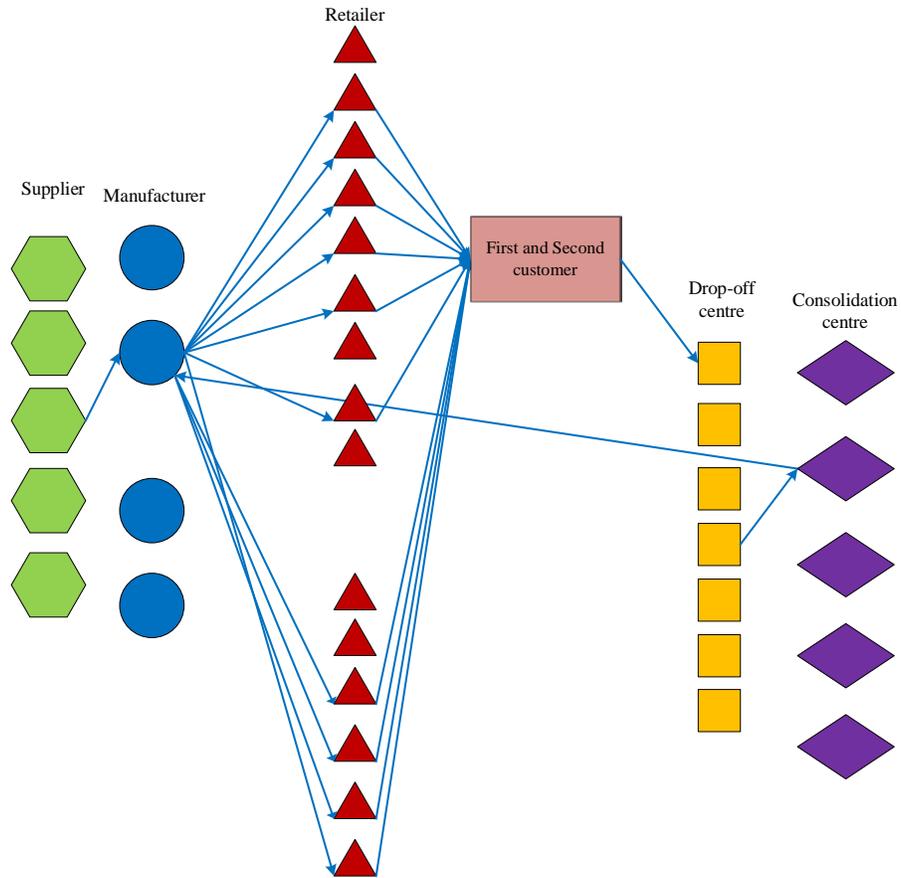


Fig. 3.7. Flow through the new CLSC network (c) based on the results

### 3.6. Conclusions

In this chapter, a deterministic closed-loop supply chain network for mobile phone industry has been developed. A multi-period, multi-product, multi-echelon, and multi-customer model considering different types of product returns is considered. The application of the proposed mathematical model is illustrated in Toronto, Canada using real maps. Furthermore, it is assumed that there exist 4 potential manufacturer locations, 5 suppliers, 15 locations for retailers, 7 locations for drop-off centres, 5 locations for consolidation centres, and 3 potential sites for disposal centres. Moreover, 4 types of mobile phones and 6 types of materials are considered in the model. It is assumed that the returns of both markets,  $k$  and  $l$  for product  $i$  in period  $t$  is ten percent of each market demand. The optimal solution of the objective function as well as the

values of different decision variables are provided with respect to multiple periods. Moreover, 2 suppliers, 2 manufacturers, 9 retailers, 1 drop-off centre, and 1 consolidation centre are selected.

According to Table 3.2, Retailers 1, 2, 3, 4, 6, 12, 13, 14, and 15 were selected since not only these retailers are closer to the open manufacturers (2 and 3), but also the market demand in the vicinity of these retailers is higher. Furthermore, according to the sensitivity analysis, the capacity of suppliers can be considered as a very sensitive parameter. On the other hand, as the result of increasing the capacity of suppliers, one supplier, and one manufacturer will be sufficient to produce mobile phones which reduces the fixed-costs. Moreover, two open consolidation centres can provide more recycled materials which will decrease the need to purchase raw components from suppliers. Hence, the total profit will be improved and the environmental issues will be decreased.

In this study, it is assumed that demand and product return rate are deterministic and constant. Furthermore, the only objective of the model is maximization of the entire profit. According to these limitations, taking into account stochastic programming in order to accomplish uncertainties in specific parameters such as quantity of the returned products and customer demands, and adding more objectives considering green factors can be mentioned as the future extensions of this work.

## **CHAPTER 4. AN INTEGRATED CHANCE-CONSTRAINED STOCHASTIC MODEL FOR A MOBILE PHONE CLOSED-LOOP SUPPLY CHAIN NETWORK WITH SUPPLIER SELECTION**

### **4.1. Introduction**

Purchasing raw materials from supplier is a curtail issue for all producers and companies. Therefore, the purchasing cost should be considered in selecting suppliers. In addition to cost of raw materials, several other factors can affect supplier selection. For instance, state-of-the-art technology of raw materials is a prominent criterion regarding manufacturing a mobile phone. Therefore, so many criteria can be mentioned which should be taken into account in order to assess the suppliers to select the most proper ones. Supplier selection is a multi-criteria decision-making problem including either qualitative or quantitative factors or both (Amin and Razmi, 2009).

Most studies have considered supplier selection in forward logistics. Therefore, various significant factors related to closed-loop supply chain will be ignored. Very few studies have investigated supplier selection in closed-loop supply chain networks. According to Kahraman et al. (2003), various factors of supplier selection can be categorized into four different groups consisting of criteria of supplier, material, service, and cost. Product performance criteria play a very important role in closed-loop supply chain since several characteristics of raw materials including durability and strength make the materials to be reusable for manufacturers. Using environmental friendly materials, reduction of waste, energy consumption, and eco-design are characteristics that can be considered under another group as environmental criteria in closed-loop networks.

On the other hand, various factors in designing a CLSC network are uncertain, and considering them as deterministic is not realistic. Therefore, decision-makers are required to take into account these uncertain criteria. To do so, stochastic programming plays a crucial role in optimization issues. In this thesis, the goal is to develop a chance-constrained stochastic model in order to investigate the uncertainty of demand and return along with supplier selection for mobile phone closed-loop supply chain network.

This chapter is organized as follows: Section 4.2 is devoted to the problem definition and supplier evaluation. Section 4.3 includes chance-constrained programming. The solution approach including the distance method and the  $\varepsilon$ -constraint method along with the results are presented in Section 4.4. Section 4.5 describes the value path approach. Sensitivity analysis is presented in Section 4.6. Finally, Section 4.7 is assigned to conclusions.

## 4.2. Problem definition

According to the network described in Chapter 3, suppliers are evaluated. The various steps of the solution approach are illustrated in Fig. 4.1. The first phase is devoted to the determination of the weights of suppliers using a fuzzy method. In the second phase, the closed-loop supply chain network proposed in Chapter 3 is extended as multi-objective so that the demand and return are considered to be stochastic. The final stage calculates the value of the variables.

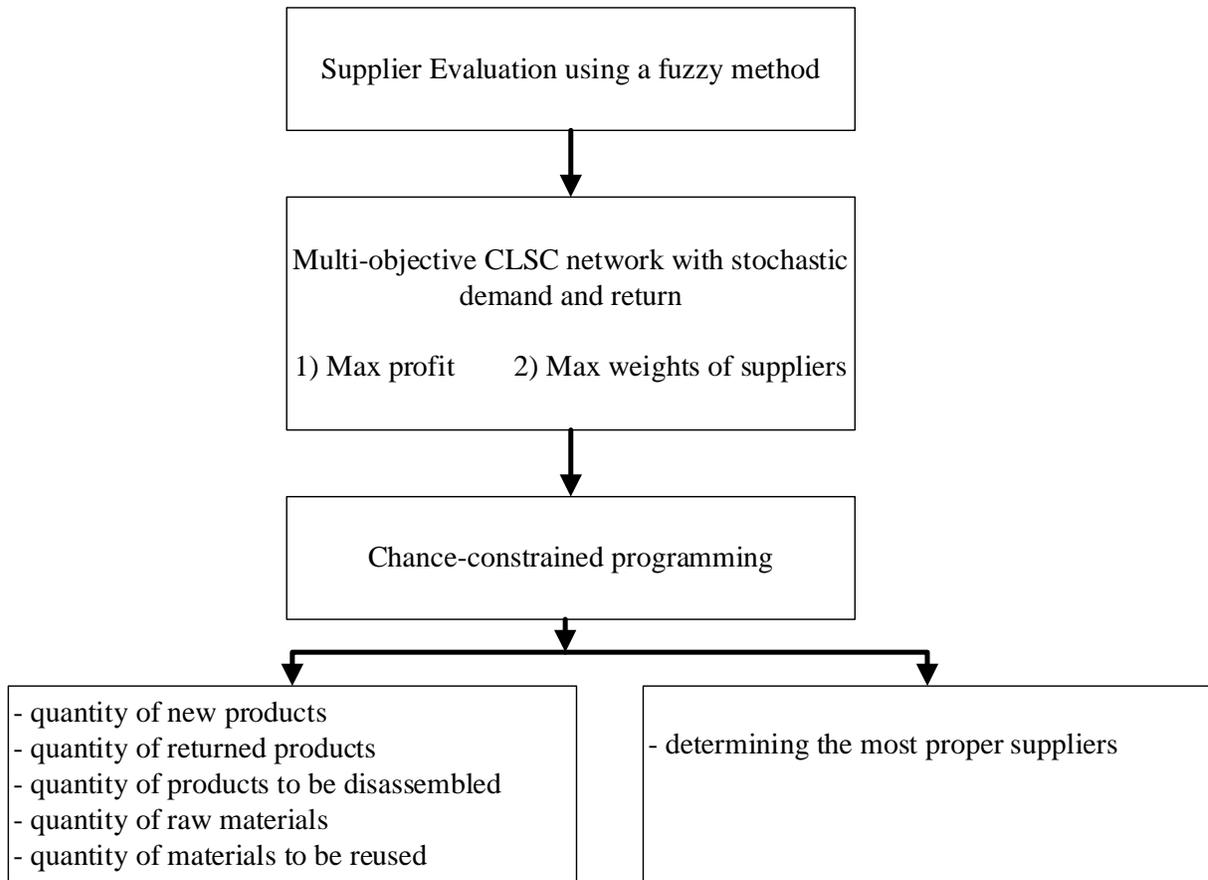


Fig. 4.1. The various steps of the solution approach

### 4.2.1. Supplier evaluation

Preference of human for making decision in many real situations is uncertain. Therefore, applying exact numerical values for comparison can be unfavorable. On the other hand, evaluation of factors may be influenced by characteristics of the decision-makers. For such reasons, fuzzy methods can be applied in the process of making decision.

Amin and Zhang (2012b) developed a fuzzy model to rank the suppliers. In this section, a fuzzy approach which is based on their proposed method is developed and applied. My method considers linguistic variables and trapezoidal fuzzy numbers (TFNs) in order to calculate the weights of suppliers. Using this method, various criteria can be categorized in different groups and the importance of each group can be ranked. Especially for configuring a CLSC network for mobile phones, this issue becomes significant. A group of decision-makers including three managers with different levels of experience and expertise assign weights to different categories and criteria. Since the opinions of experienced decision-makers are more reliable, it is necessary to consider the level of experience of decision-makers to assess the weights of criteria. In order to evaluate the level of experience of each decision-maker, a linguistic variable is defined as depicted in Fig. 4.2. The membership function is a number between 0 and 1. The lowest level of experience is determined by (0, 0, 3, 6), while the average level of experience is given by (0, 3, 9, 12), and the highest level of experience is assigned by (6, 9, 12, 12). Therefore,  $\omega e_1 = (0, 3, 9, 12)$ ,  $\omega e_2 = (6, 9, 12, 12)$ , and  $\omega e_3 = (6, 9, 12, 12)$ , where  $\omega e_{DM}$  is the level of experience (weight) of each decision-maker and  $DM(dm = 1, 2, 3, \dots, DM)$  is the number of decision-makers. The number of criteria and the number of suppliers are given by  $N$  ( $n = 1, 2, 3, \dots, N$ ) and  $S$  ( $s = 1, 2, 3, \dots, S$ ), respectively. Each Supplier  $s$  provides  $J$  materials ( $j = 1, 2, 3, \dots, J$ ). The steps of this process are as follows:

**Step 1:** In this step, appropriate criteria should be determined. Supplier, material, service, and environmental are the main categories of my framework which are shown in Fig. 4.3. In mobile phone CLSC network design, several criteria related to components such as defect rate, small size, being state-of-the-art, durability, and strength are significant. Moreover, because of the hazardous substances applied in mobile phones manufacturing, it is crucial for their materials to be recyclable and reusable. In addition, the latest technology should be taken into account to provide environmental friendly and less polluting components.

**Step 2:** Assume that the opinion of each decision-maker is expressed by the linguistic variables  $\Lambda = \{VL, L, ML, M, MH, H, VH\}$ . Utilizing trapezoidal fuzzy numbers, these variables are quantified as shown in Fig. 4.4. Each decision-maker evaluates all categories and provides a level of importance for them using linguistic scales. Using Fig. 4.4, a TFN is assigned to each linguistic variable. The weight of decision-makers is multiplied by the weight of each category in order to contribute the level of experience of each decision-maker in their opinions regarding each category. Suppose  $\lambda_p$  represents the weight of each category, where  $p$  is defined as each category ( $p = 1, 2, 3, 4$ ). Therefore, the aggregated weight of each category is calculated by Eq. (4.1). The results are shown in Table 4.1.

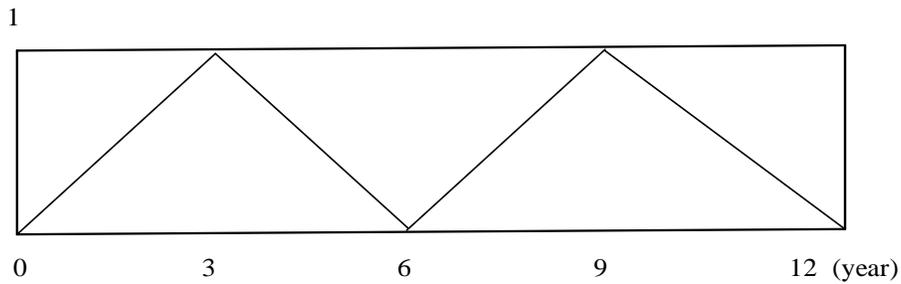


Fig. 4.2. A linguistic scale for providing experience level

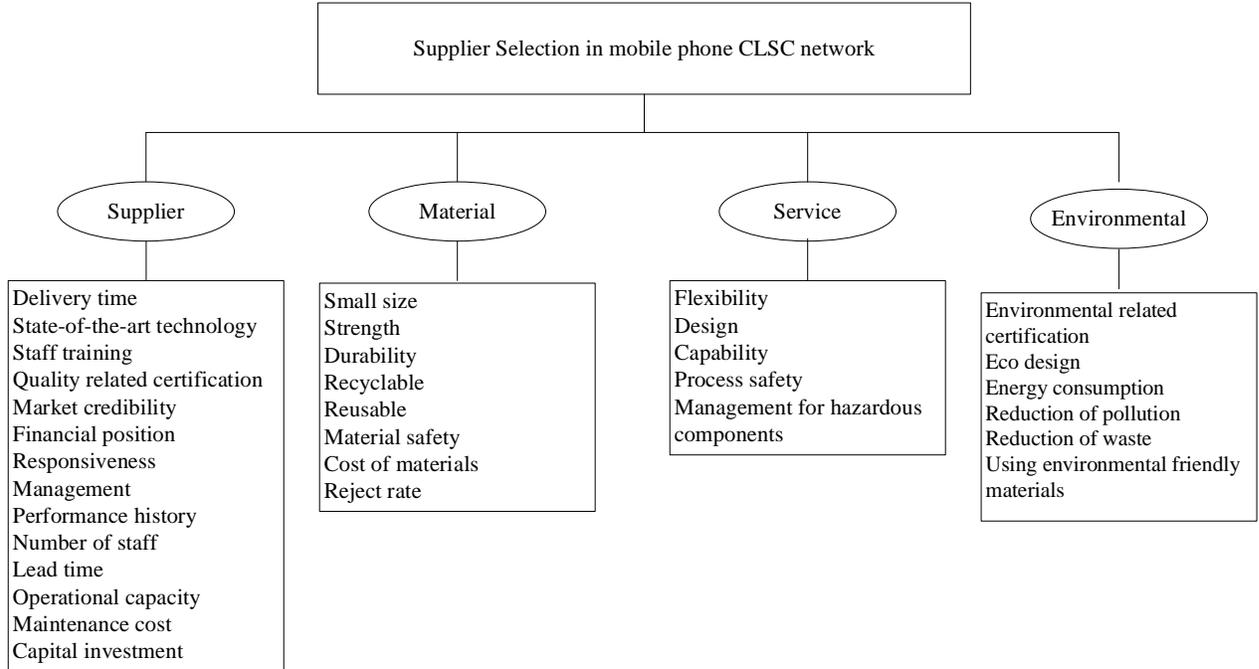


Fig. 4.3. Supplier selection framework in mobile phone CLSC network

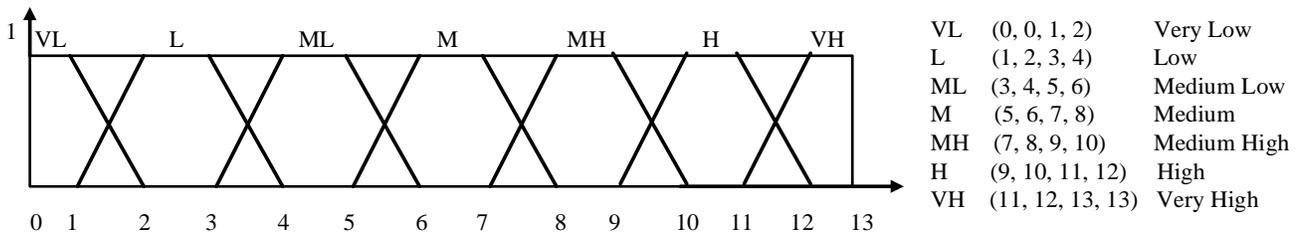


Fig. 4.4. Linguistic scale

$$\lambda_p = \frac{(\omega e_1 \times \lambda_{p1}) + (\omega e_2 \times \lambda_{p2}) + \dots + (\omega e_D \times \lambda_{pDM})}{DM} \quad (4.1)$$

**Step 3:** If  $U_{pnDM}$  is defined as the weight of criterion  $n$  in category  $p$  provided by decision-maker  $DM$ , the aggregated weight of each criterion can be calculated using Eq. (4.2) (see Table 4.2).

$$U_{pn} = \frac{(\omega e_1 \times U_{pn1}) + (\omega e_2 \times U_{pn2}) + \dots + (\omega e_{DM} \times U_{pnDM})}{DM} \quad (4.2)$$

**Step 4:** Assume that the evaluation of supplier  $s$  which provides material  $j$  regarding criterion  $n$  in category  $p$  established by decision-maker  $DM$  is represented by  $Ft_{sjpnDM}$ . The aggregated level of importance of supplier  $s$  according to criterion  $n$  and material  $j$  in category  $p$  is determined by Eq. (4.3). Table 4.3 illustrates decision-makers' ranking related to supplier 1 who provides material 1.

$$Ft_{sjpn} = \frac{(\omega e_1 \times Ft_{sjpn1}) + (\omega e_2 \times Ft_{sjpn2}) + \dots + (\omega e_{DM} \times Ft_{sjpnDM})}{DM} \quad (4.3)$$

**Step 5:** In this step, all calculated weights in the previous steps are multiplied as shown in Eq. (4.4). The results are provided in Table 4.4. Since the calculated number,  $\zeta_{js} = (a, b, c, d)$ , is a TFN, it is required to be defuzzified using Eq. (4.5) (Chou and Chang, 2008).

$$\zeta_{sj} = \sum_{p=1}^4 \sum_{n=1}^N \lambda_p \times U_{pn} \times Ft_{sjpn} \quad (4.4)$$

$$\psi_{sj} = \frac{a + b + c + d}{4} \quad (4.5)$$

**Step 6:** In the final step, each supplier is ranked by normalizing its level of importance according to each criterion using Eq. (4.6). The rank of each supplier for each material is written in Table 4.5.

$$\pi_{sj} = \frac{\psi_{sj}}{\sum_{s=1}^S \psi_{sj}} \quad (4.6)$$

Table 4.1.  
Weights of categories

Category	DM <sub>1</sub>	DM <sub>2</sub>	DM <sub>3</sub>	$\omega e_1 \times \lambda_{p1}$	$\omega e_2 \times \lambda_{p2}$	$\omega e_3 \times \lambda_{p3}$	$\lambda_p$
Supplier	H	MH	M	(0,30,99,144)	(42,72,108,120)	(30,54,84,96)	(24,52,97,120)
Material	MH	H	H	(0,24,81,120)	(54,90,132,144)	(54,90,132,144)	(36,68,115,136)
Service	MH	M	H	(0,24,81,120)	(30,54,84,96)	(54,90,132,144)	(28,56,99,120)
Environmental	M	M	MH	(0,18,63,96)	(30,54,84,96)	(42,72,108,120)	(24,48,85,104)

Table 4.2.  
Weights of criteria

Criteria	DM <sub>1</sub>	DM <sub>2</sub>	DM <sub>3</sub>	$\omega e_1 \times U_{pn1}$	$\omega e_2 \times U_{pn2}$	$\omega e_3 \times U_{pn3}$	$U_{pn}$
State-of-the-art technology	H	VH	H	(36,68,115,136)	(36,68,115,136)	(36,72,127,148)	(40,76,129,148)
Market credibility	H	M	H	(0,30,99,144)	(30,54,84,96)	(54,90,132,144)	(28,58,105,128)
Performance history	H	MH	VH	(0,30,99,144)	(42,72,108,120)	(66,108,156,156)	(36,70,121,140)
Strength	MH	H	MH	(0,24,81,120)	(54,90,132,144)	(42,72,108,120)	(32,62,107,128)
Durability	MH	M	M	(0,24,81,120)	(30,54,84,96)	(30,54,84,96)	(20,44,83,104)
Recyclable	H	MH	H	(0,30,99,144)	(42,72,108,120)	(54,90,132,144)	(32,64,113,136)
Flexibility	H	VH	H	(0,30,99,144)	(66,108,156,156)	(54,90,132,144)	(40,76,129,148)
Design	H	MH	MH	(0,30,99,144)	(42,72,108,120)	(42,72,108,120)	(28,58,105,128)
Process safety	MH	MH	H	(0,24,81,120)	(42,72,108,120)	(54,90,132,144)	(32,62,107,128)
Energy consumption	VL	ML	L	(0,0,9,24)	(18,36,60,72)	(6,18,36,48)	(8,18,35,48)
Environmental friendly	MH	H	H	(0,24,81,120)	(54,90,132,144)	(54,90,132,144)	(36,68,115,136)
Lead time	MH	H	H	(0,24,81,120)	(54,90,132,144)	(54,90,132,144)	(36,68,115,136)
Cost of materials	VH	H	H	(0,36,117,156)	(54,90,132,144)	(54,90,132,144)	(36,72,127,148)
Reject rate	L	VL	L	(0,6,27,48)	(0,0,12,24)	(6,18,36,48)	(2,8,25,40)

Table 4.3.  
Evaluation of supplier 1 for material 1

Criteria	DM <sub>1</sub>	DM <sub>2</sub>	DM <sub>3</sub>	$\omega e_1 \times Ft_{smjpn1}$	$\omega e_2 \times Ft_{smjpn2}$	$\omega e_3 \times Ft_{smjpn3}$	$Ft_{smjpn}$
State-of-the-art technology	H	MH	M	(0,30,99,144)	(42,72,108,120)	(30,54,84,96)	(24,52,97,120)
Market credibility	H	VH	H	(0,30,99,144)	(66,108,156,156)	(54,90,132,144)	(40,76,129,148)
Performance history	MH	H	MH	(0,24,81,120)	(54,90,132,144)	(42,72,108,120)	(32,62,107,128)
Strength	H	MH	VH	(0,30,99,144)	(42,72,108,120)	(66,108,156,156)	(36,70,121,140)
Durability	M	M	MH	(0,18,63,96)	(30,54,84,96)	(42,72,108,120)	(24,48,85,104)
Recyclable	H	VH	H	(0,30,99,144)	(66,108,156,156)	(54,90,132,144)	(40,76,129,148)
Flexibility	MH	MH	H	(0,24,81,120)	(42,72,108,120)	(54,90,132,144)	(32,62,107,128)
Design	M	M	M	(0,18,63,96)	(30,54,84,96)	(30,54,84,96)	(20,42,77,96)
Process safety	H	MH	H	(0,30,99,144)	(42,72,108,120)	(54,90,132,144)	(32,64,113,136)
Energy consumption	VL	VL	L	(0,0,9,24)	(0,0,12,24)	(6,18,36,48)	(2,6,19,32)
Environmental friendly	MH	M	M	(0,24,81,120)	(30,54,84,96)	(30,54,84,96)	(20,44,83,104)
Lead time	M	M	M	(0,18,63,96)	(30,54,84,96)	(30,54,84,96)	(20,42,77,96)
Cost of materials	H	VH	VH	(0,30,99,144)	(66,108,156,156)	(66,108,156,156)	(44,82,137,152)
Reject rate	L	ML	L	(0,6,27,48)	(18,36,60,72)	(6,18,36,48)	(8,20,41,56)

Table 4.4.  
Final score for supplier 1 according to material 1

Criteria	$\lambda_p$	$U_{pn}$	$Ft_{smjpn}$	Final score
State-of-the-art technology	(24,52,97,120)	(40,76,129,148)	(24,52,97,120)	(23040,205504,1213761,2131200)
Market credibility	(24,52,97,120)	(28,58,105,128)	(40,76,129,148)	(26880,229216,1313865,2273280)
Performance history	(24,52,97,120)	(36,70,121,140)	(32,62,107,128)	(27648,225680,1255859,2150400)
Strength	(36,68,115,136)	(32,62,107,128)	(36,70,121,140)	(41472,295120,1488905,2437120)
Durability	(36,68,115,136)	(20,44,83,104)	(24,48,85,104)	(17280,143616,811325,1470976)
Recyclable	(36,68,115,136)	(32,64,113,136)	(40,76,129,148)	(46080,330752,1676355,2737408)
Flexibility	(28,56,99,120)	(40,76,129,148)	(32,62,107,128)	(35840,263872,1366497,2273280)
Design	(28,56,99,120)	(28,58,105,128)	(20,42,77,96)	(15680,136416,800415,1474560)
Process safety	(28,56,99,120)	(32,62,107,128)	(32,64,113,136)	(28672,222208,1197009,2088960)
Energy consumption	(24,48,85,104)	(8,18,35,48)	(2,6,19,32)	(384,5184,56525,159744)
Environmental friendly	(24,48,85,104)	(36,68,115,136)	(20,44,83,104)	(17280,143616,811325,1470976)
Lead time	(24,52,97,120)	(36,68,115,136)	(20,42,77,96)	(17280,148512,858935,1566720)
Cost of materials	(36,68,115,136)	(36,72,127,148)	(44,82,137,152)	(57024,401472,2000885,3059456)
Reject rate	(36,68,115,136)	(2,8,25,40)	(8,20,41,56)	(576,10880,117875,303640)

$\zeta_{111}=(355136,2762048,14969536,25598720), \psi_{111}=10921360$

Table 4.5.  
Weight of supplier  $s$  according to material  $j$

$j \backslash s$	1	2	3	4	5
1	0.36	0.34	0.35	0.35	0.35
2	0.33	0.36	0.35	0.35	0.36
3	0.35	0.39	0.34	0.32	0.35
4	0.29	0.25	0.21	0.23	0.27
5	0.33	0.35	0.35	0.36	0.33
6	0.21	0.21	0.38	0.35	0.36

#### 4.2.2. Mathematical model

The model presented in chapter 3 can be extended as follows:

$$\begin{aligned}
 Max z_1 = & \sum_r \sum_k \sum_l \sum_i \sum_t (P_i^n a_{rkit}^n + P_i^u a_{rlit}^u + P_i^c a_{rlit}^c) \\
 & - \left[ \sum_m f a_m y a_m + \sum_s f b_s y b_s + \sum_r f c_r y c_r + \sum_d f d_d y d_d + \sum_g f e_g y g_g \right. \\
 & + \sum_s \sum_m \sum_j \sum_t (\omega_{sjt} + k a_{smt} \theta_{sm}) q_{smjt} \\
 & + \sum_m \sum_r \sum_i \sum_t (\mu_{mit} + k b_{mrt} \theta_{mr}) a_{mrit} + \sum_r \sum_i \sum_t \rho_i I n_{rit} \\
 & + \sum_r \sum_m \sum_k \sum_i \sum_t ((d w_{rit} + \sigma_{it}) b_{krit}^c + d w_{rit} b_{krit}^u + (d w_{rit} + k c_{rmt} \theta_{mr}) a_{rmit}^l) \\
 & + \sum_d \sum_g \sum_i \sum_t (Y_{git} + k d_{dgt} \theta_{dg}) n_{dgit} \\
 & \left. + \sum_m \sum_g \sum_x \sum_j \sum_t ((k e_{gmt} \theta_{gm} - \eta_j) \varphi_{gmjt} + (k f_{gxt} \theta_{gx} + d h_{xjt}) u_{gxjt}) \right] \\
 Max z_2 = & \sum_s \sum_m \sum_j \sum_t \pi_{sj} q_{smjt}
 \end{aligned}$$

The first objective function is designed to maximize the entire profit in the mobile phone CLSC network whereas the second objective function maximizes the weights of eligible suppliers which are estimated based on the developed fuzzy method. Constraints (3.1) to (3.22) can be considered for this multi-objective mixed-integer linear programming model. However, it is assumed that demand ( $\widehat{AC}_{kit}$  and  $\widehat{AS}_{lit}$ ) and return ( $\widehat{zC}_{kit}$  and  $\widehat{zS}_{lit}$ ) are stochastic. Therefore, Constraints (3.3), (3.4), (3.10), and (3.11) can be written as follows:

$$\sum_r a_{rkit}^n \leq \widehat{AC}_{kit} \quad \forall i, k, t \quad (4.7)$$

$$\sum_r a_{rlit}^u + \sum_r a_{rlit}^c \leq \widehat{AS}_{lit} \quad \forall i, l, t \quad (4.8)$$

$$\sum_d e f_{kdit} = \widehat{zC}_{kit} \quad \forall i, k, t \quad (4.9)$$

$$\sum_d e s_{ldit} = \widehat{zS}_{lit} \quad \forall i, l, t \quad (4.10)$$

### 4.3. Chance-constraint programming

Some methodologies can be taken into account to deal with stochastic parameters in optimization models. One of the methods that has been used in many studies is Chance-Constrained Programming (CCP) proposed by Charnes et al. (1990). Assume a mathematical programming with stochastic parameters as follows:

$$\begin{cases} \max f(x) \\ \text{subject to:} \\ g_v(x, \xi) \leq 0, v = 1, 2, \dots, p \end{cases} \quad (4.11)$$

where  $x$  and  $\xi$  are a decision vector and a stochastic vector, respectively.  $f(x)$  is a non-stochastic objective function and  $g_v(x, \xi)$  is a stochastic constraint. A stochastic decision problem can be also written as follows (Liu, 1999):

$$\begin{cases} \max f(x) \\ \text{subject to:} \\ \Pr\{\xi | g_v(x, \xi) \leq 0\} \geq \alpha_v, v = 1, 2, \dots, p \end{cases} \quad (4.12)$$

where  $\alpha_v$  is a predetermined confidence level to the respective stochastic constraint and  $\Pr\{.\}$  indicates the probability of the event in  $\{.\}$ . It ensures that the probability of a certain constraint is above a certain level. In other words, it restricts the feasible region so that the confidence level of the solution is high (Li et al., 2008). The stochastic constraint is required to be converted to its deterministic equivalent.

In this study,  $\widehat{Ac}_{kit}$ ,  $\widehat{AS}_{lt}$ ,  $\widehat{zC}_{kit}$ , and  $\widehat{zS}_{lt}$  are stochastic parameters which are in some constraints. In order to deal with them, they are transferred to their respective deterministic equivalents based on their predetermined confidence levels. Hence, a deterministic programming model will be acquired which can be solved with typical solution approaches. Although this process sounds hard and can be only favourable for some special cases, the stochastic constraints can be dealt with the aid of some identified results.

**Case I:** Assume that the chance-constrained programming is as follows:

$$\Pr\{\xi_v | h_v(x) \leq \xi_h\} \geq \alpha_h \quad h = 1, 2, \dots, p \quad (4.13)$$

where  $h_v(x)$  and  $\xi_h$  are decision functions and stochastic parameters, respectively.  $F_v(\xi_v)$ ,  $v = 1, 2, \dots, p$  is defined as a cumulative distribution function. Therefore, the deterministic equivalent of Eq. (4.13) can be calculated by Eq. (4.14) (Moheb-Alizadeh and Handfield, 2017).

$$h_v(x) \leq f_v^{-1}(1 - \alpha_v) \quad (4.14)$$

where  $f_v^{-1}$  is the inverse of cumulative distribution function.

On the other hand, if the chance-constrained programming is as follows:

$$\Pr\{\xi_v | h_v(x) \geq \xi_v\} \geq \alpha_v \quad v = 1, 2, \dots, p \quad (4.15)$$

The deterministic equivalent of Eq. (4.15) can be written as Eq. (4.16).

$$h_v(x) \geq f_v^{-1}(\alpha_v) \quad (4.16)$$

Thus, the stochastic Constraints (4.7), (4.8), (4.9), and (4.10) can be reformulated as follows:

$$\Pr\{g(x, \widehat{Ac}) \leq 0\} = \Pr\left\{\sum_r a_{rkit}^n \leq \widehat{Ac}_{kit}\right\} \geq \alpha_1 \quad \forall i, k, t \quad (4.17)$$

$$\Pr\{g(x, \widehat{As}) \leq 0\} = \Pr\left\{\sum_r a_{rlit}^u + \sum_r a_{rlit}^c \leq \widehat{As}_{lit}\right\} \geq \alpha_2 \quad \forall i, l, t \quad (4.18)$$

$$\Pr\{g(x, \widehat{zc}) \leq 0\} = \Pr\left\{\sum_d ef_{kdit} = \widehat{zc}_{kit}\right\} \geq \alpha_3 \quad \forall i, k, t \quad (4.19)$$

$$\Pr\{g(x, \widehat{zs}) \leq 0\} = \Pr\left\{\sum_d es_{ldit} = \widehat{zs}_{lit}\right\} \geq \alpha_4 \quad \forall i, l, t \quad (4.20)$$

Then, the deterministic equivalent of the stochastic constraints can be derived:

$$\sum_r a_{rkit}^n \leq f_{\widehat{Ac}_{kit}}^{-1}(1 - \alpha_1) \quad \forall i, k, t \quad (4.21)$$

$$\sum_r a_{rlit}^u + \sum_r a_{rlit}^c \leq f_{\widehat{As}_{lit}}^{-1}(1 - \alpha_2) \quad \forall i, l, t \quad (4.22)$$

$$\sum_d ef_{kdit} = f_{\widehat{zc}_{kit}}^{-1}(\alpha_3) \quad \forall i, k, t \quad (4.23)$$

$$\sum_d es_{ldit} = f_{\widehat{zs}_{lit}}^{-1}(\alpha_4) \quad \forall i, l, t \quad (4.24)$$

where  $f_{\widehat{AC}_{kit}}^{-1}(\cdot)$ ,  $f_{\widehat{AS}_{lit}}^{-1}(\cdot)$ ,  $f_{\widehat{zC}_{kit}}^{-1}(\cdot)$ , and  $f_{\widehat{zS}_{lit}}^{-1}(\cdot)$  are the inverse cumulative density functions of  $\widehat{AC}_{kit}$ ,  $\widehat{AS}_{lit}$ ,  $\widehat{zC}_{kit}$ , and  $\widehat{zS}_{lit}$ , respectively. Now, the proposed multi-objective mixed-integer linear programming model can be solved considering Constraints (3.1), (3.2), (3.5) - (3.9), (3.12) - (3.22), (4.21) - (4.24).

Chance-constrained programming is a unique method compared to other stochastic programming methods especially for supplier selection frameworks since a high level of reliability is provided by assigning the probability of satisfying constraints, i.e. the predetermined confidence level to be feasible (Moheb-Alizadeh and Handfield, 2017).

#### 4.4. Solution Approach

All the assumptions are the same as explained in Chapter 3. Therefore, there are 44 first and 22 second demand markets. There exist 4 potential manufacturer locations, 5 eligible suppliers, 15 locations for retailers, 7 locations for drop-off centres, 5 locations for consolidation centres, and 3 potential sites for disposal centres. Moreover, 4 types of mobile phones and 6 types of materials are considered in the model. The stochastic demand and return are modeled using lognormal density function. Not only lognormal distribution maintains the non-negativity of the values of both demand and return, but also Kamath and Pakkala (2002) proved that the most suitable distribution to model some stochastic parameters such as demand is lognormal. The parameters of demand and return lognormal density functions are calculated as follows:  $\widehat{AC}_{kit}$  and  $\widehat{AS}_{lit} \sim \text{lognormal}(7.82, 0.17)$ , and  $\widehat{zC}_{kit}$  and  $\widehat{zS}_{lit} \sim \text{lognormal}(5.52, 0.12)$ . It is assumed that all of the stochastic constraints have a confidence level of 0.95. Moreover, distances among various facilities are estimated using Google Maps. The values of other parameters are presented in Table 4.6.

Table 4.6.  
Values of some parameters defined to solve the mathematical model

$M = 4$	$fa_m = 100,000,000$	$\sigma_{it} = 20$
$S = 5$	$fb_s = 100,000$	$mcap_{mj} = 500,000$
$R = 15$	$fc_r = fd_d = fe_g = 150,000$	$rcap_{ri} = 14,000$
$K = 44$	$p_i^n = 100$	$dcap_{di} = 10,000$
$L = 22$	$p_i^n = 100$	$gcap_{gi} = 10,000$
$D = 7$	$p_i^u = 50$	$scap_{sj} = 150,000$
$I = 4$	$p_i^c = 80$	$\eta_j = 10$
$J = 6$	$ka_{smt} = ke_{gmt} = kf_{gxt} = 0.002$	$\varepsilon_j = 0.1$
$G = 5$	$kb_{mrt} = kc_{rmt} = kd_{dgt} = 0.005$	$\rho_i = 35$
$T = 2$	$\mu_{mit} = 15$	

#### 4.4.1. $\varepsilon$ -constrained method and results

The application of  $\varepsilon$ -constraint method is to transfer a multi-objective model to a single-objective one. The methodology is that the most privilege objective function is taken into account as the main objective and other objectives are supposed to be as constraints (Ehrgott, 2005). The obtained single objective model is as follows:

$$\text{Max } z_3 = z_1$$

(4.25)

s. t.

$$z_2 \geq \varepsilon_1$$

Eq. (3.1), (3.2), (3.5) - (3.9), (3.12) - (3.22), (4.21) - (4.24)

Various values of  $\varepsilon$  are examined in order to obtain the trade-off solution.  $\varepsilon$  is changed from 800,000 to 856,709. For the values of  $\varepsilon$  under 800,000, the value of the main objective function (maximization of the profit) is equal to 24,236,760.294. However, for every  $\varepsilon$  higher than 856,709, the solution is unbounded or infeasible. The values of first and second objective functions for the values of  $\varepsilon$  in the mentioned range are illustrated in Table 4.7.

Table 4.7.

Values of objective functions obtained by  $\varepsilon$ -constraint method

$\varepsilon$	850,000	845,000	840,000	835,000	830,000	825,000
First objective	5,817,150.987	10,152,341.026	14,487,531.065	18,822,721.105	23,157,911.144	24,236,760.294
Second objective	850,000	845,000	840,000	835,000	828,430	810,780

#### 4.4.2. Distance method and results

The distance method is an approach to deal with a multi-objective CLSC network in order to obtain an approximate solution close to the perfect one. In this method, the perfect solution is the best value achieved for each objective function while other functions are ignored (Branke and

Miettinen, 2008). According to Eq. (4.26),  $W_o$  is utilized as the distance metric representing the weight of each segment mentioned in the objective function (Mirzapour Al-E-Hashem et al., 2011). A set of solutions named Pareto or efficient solutions will be created as the result of solving the multi-objective model. The final set of solutions acquired by completion of exploration is named the Trade-off surface or Pareto front (Collette and Siarry, 2003). In this thesis, the goal is to maximize the total profit along with maximization of the weights of suppliers. Hence, the model can be presented as follows:

$$z = \left( \sum_o W_o^{\tau a} \left( \frac{z_o - z_o^*}{z_o^*} \right)^{\tau a} \right)^{\frac{1}{\tau a}} \quad \forall o = 1, 2, \dots \quad (4.26)$$

$$\text{Max } z = (W_1^{\tau a} \left( \frac{z_1 - z_1^*}{z_1^*} \right)^{\tau a} + W_2^{\tau a} \left( \frac{z_2 - z_2^*}{z_2^*} \right)^{\tau a})^{\frac{1}{\tau a}} \quad (4.27)$$

s. t.

Eq. (3.1), (3.2), (3.5) - (3.9), (3.12) - (3.22), (4.21) - (4.24)

First of all, the value of each objective function is calculated separately. The optimal values of the total profit and weights of suppliers are 24,236,760.294 and 828,778.368, respectively. Next, the distance method is implemented to solve the multi-objective problem.

Various values of  $W_o$  are examined while satisfying  $\sum_o W_o = 1$  condition in order to obtain the trade-off solution between two objective functions. The values for the first and second objective functions are shown in Table 4.8 with respect to different values of  $W_1$ .

Table 4.8.  
Values of objective functions obtained by distance method

$W_1$	0	0.2	0.3	0.4	0.5	0.6	0.8	1
First objective	987,500	3,246,700	9,607,100	11,550,000	18,764,000	20,411,000	22,832,000	22,954,000
Second objective	863,390	861,390	847,750	775,460	642,630	472,190	336,980	80,255

#### 4.5. Value Path Approach (VPA)

In this section, the Value Path Approach (VPA) is investigated in order to describe the tradeoffs among various objectives of a multi-objective problem (Schilling et al., 1983; Wadhwa and Ravindran, 2007; Amin and Zhang, 2014; Tosarkani and Amin, 2018b). The display consists of a set of parallel scales, one for each criterion, on which is drawn the value path for each of the alternatives. Each element of Table 4.9 is the value of non-dominated solutions which is calculated as the value of each objective function divided by the best value of that objective. Hence, 1 will be the minimum value for each axis. The results are depicted in Fig. 4.5. Based on VPA, value paths that intersect are considered as non-dominated, while inferior solutions are non-intersecting paths, where one lies above the other one. Therefore, Fig. 4.5 illustrates that all solutions are non-dominated.

Table 4.9.  
Results of Value Path Approach (VPA)

$W_1$	0	0.2	0.3	0.4	0.5	0.6	0.8	1
First objective	1	3.287	9.728	11.696	19.001	20.67	23.121	23.244
Second objective	10.758	10.733	10.563	9.662	8.007	5.883	4.198	1

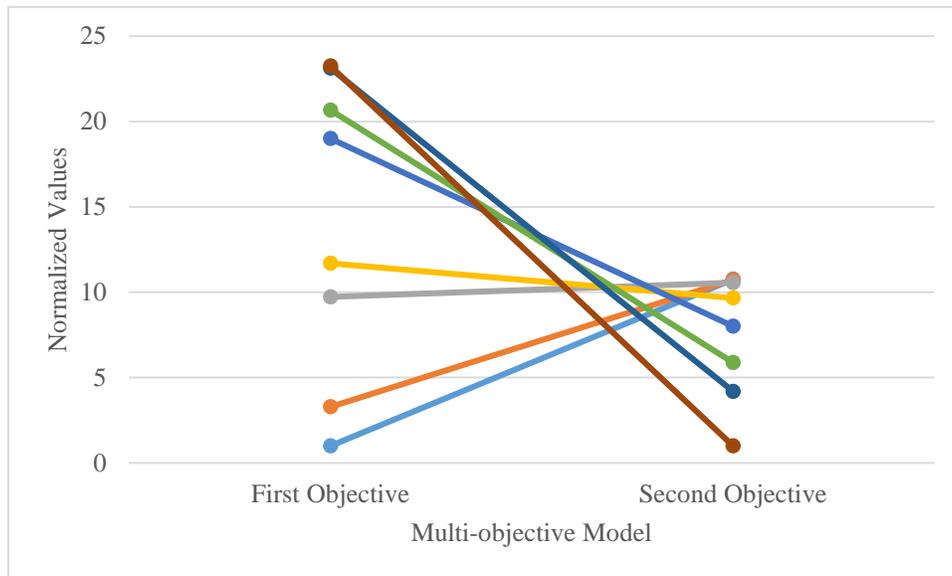


Fig. 4.5. Value Path Approach (VPA)

#### 4.6. Sensitivity analysis

The sensitivity analysis is discussed in this section. To do so, it is assumed that  $\varepsilon$  is equal to 825,000. Table 4.10 indicates the results of some variables of the model. Fig. 4.6. depicts the optimal mobile CLSC network considering Product 1 (to avoid complexity).

Table 4.10.

Some values of the model for  $i = j = t = 1$

$s = 3, m = 2, r = 12, k = 18, l = 13, d = 6, g = 5, x = 1, \varepsilon = 825,000$

Single Variables	Value	Binary Variables
First objective	24,236,760.294	Suppliers: 3, 4
Second objective	810,780	Manufacturers: 2, 3
$a_{rkit}^n$	1,036.45	Retailers: 1, 2, 3, 4, 6, 12, 13, 14, 15
$a_{rlit}^c$	210.5	Drop-off centres: 2, 6
$a_{rlit}^u$	235.6	Consolidation centres: 5
$q_{smjt}$	56,789.86	
$a_{mrjt}$	21,753.235	
$b_{krit}^c$	699.853	
$b_{krit}^u$	945.9	
$a_{rmit}^l$	148.73	
$ef_{kdit}$	279.2	
$es_{ldit}$	237.35	
$\varphi_{gmjt}$	6,348.4	
$u_{qxjt}$	9,732.24	

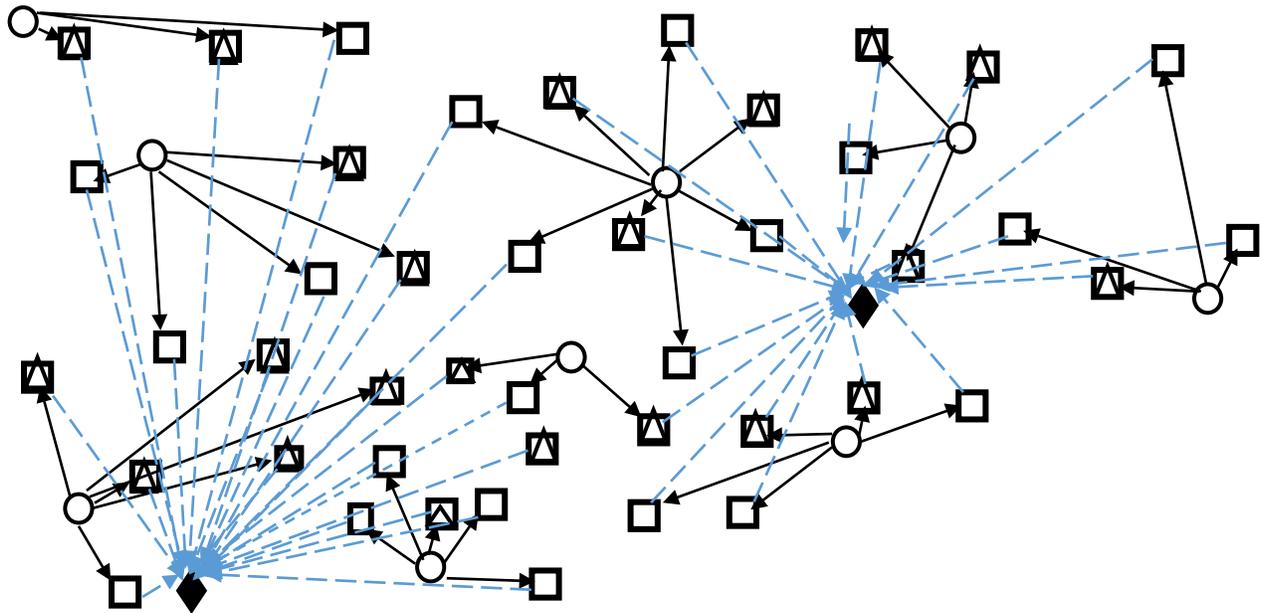


Fig. 4.6 The optimal mobile CLSC network (→ forward supply chain, → reverse supply chain)

Retailer ○, First customers □, Second customers △, Drop-off centre ◆

One of the most important parameters that can be changed to evaluate the sensitivity of the model is customers' demand. Hence,  $\alpha$  as a parameter determined by decision-maker and effective for demand is examined. In the previous section, the confidence level was set to 0.95. Now, the effect of a decrease in  $\alpha$  on profit regarding both first and second customers' demand for Product 1 in the first ward (to avoid complexity) is investigated. The changes in the profit according to the changes in  $\alpha$  are illustrated in Fig. 4.7. It is clear that as  $\alpha$  decreases, the demand increases, resulting in a rise in the profit.

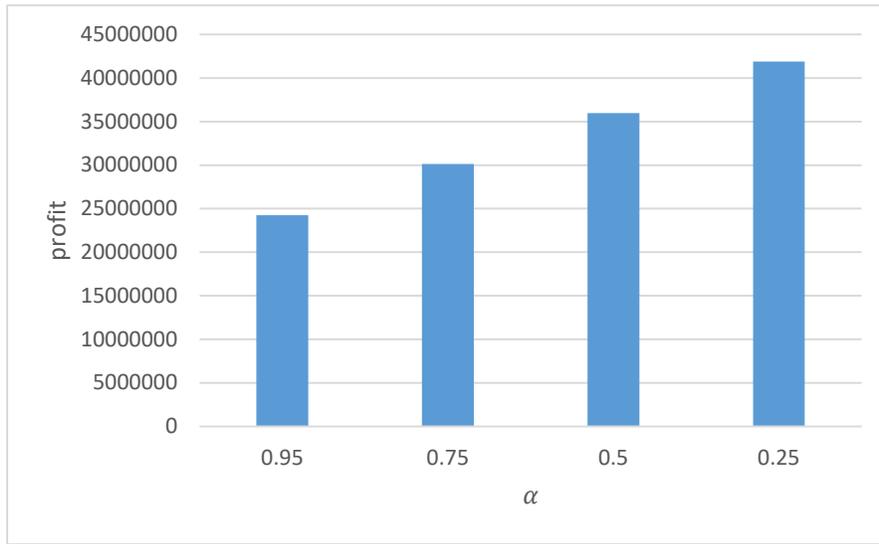


Fig. 4.7. The changes of the profit due to the change in  $\alpha$

#### 4.7. Conclusions

In this chapter, a framework based on the network presented in Chapter 3 was introduced. Accordingly, a stochastic, multi-objective, mixed-integer linear programming model was proposed. It was assumed that demand and return are stochastic parameters. Moreover, as an extension to the model, supplier selection and order allocation have been applied to the model. A fuzzy method was developed to estimate the weights of qualified suppliers. Therefore, the objectives are the maximization of the whole profit as well as maximization of the weights of suppliers. Chance-constrained programming has been employed to deal with uncertainty in the proposed model. The operation of the proposed mathematical model has been illustrated in Toronto, Canada using real maps. In addition,  $\varepsilon$ -constraint and distance methods have been

utilized to solve the multi-objective model. The value path approach has been described in order to analyze the tradeoffs among various objectives. Furthermore, the level of confidence has been changed in order to investigate the sensitivity of the model.

Because of the complexity of applying supplier selection and order allocation to closed-loop networks, metaheuristic approaches such as genetic algorithms can be utilized as a future research. Besides, additional factors including various prices can also be considered as uncertain parameters. Moreover, the return was assumed as a stochastic parameter and to deal with that chance-constraint programming was applied. However, a propensity model such as logistic regression model can be developed based on several predictive variables in order to forecast the probability of return.

## CHAPTER 5. CONCLUSIONS AND FUTURE RESEARCH

### 5.1. Research contributions

The main research contributions of this study in CLSC field are as follows:

- Development of a mathematical formulation to configure a CLSC network for mobile phone recovery and recycling in a multi-period and multi-product situation with considering different types of returned products in Toronto, Canada.
- Investigating reselling commercial and EOU returned products to the second customers with different selling prices.
- Applying chance-constrained programming to deal with stochastic sources in the CLSC network such as demand and rate of returned products
- Developing a fuzzy method to estimate the quantitative and qualitative weights for supplier selection and order allocation in the proposed model and therefore extending the model to a multi-objective programming model in order to maximize the weight of suppliers along with the maximization of the profit
- Employment of distance method and  $\varepsilon$ -constraint technique to conclude the trade-off surface of solutions
- Providing real distances in the proposed multi-echelon model using Google maps.

### 5.2. Conclusions

The goal of this study was to design and optimize a Closed-Loop Supply Chain (CLSC) network for a mobile phone network considering different types of product returns. Commercial, end of life, and end-of-use returns are well-known in practice. To do so, a network has been analyzed and a mathematical formulation along with solution approaches have been proposed.

In Chapter 3, a deterministic mathematical model for mobile phone industry has been developed. A multi-period, multi-product, multi-echelon, and multi-customer model considering different types of product returns is considered. Moreover, the application of the proposed mathematical model was illustrated in Toronto, Canada using real maps. The optimal solution of

the objective function, as well as the values of different decision variables, have been provided with respect to multiple periods. Furthermore, the sensitivity of the model was investigated in order to evaluate the proposed model. According to the sensitivity analysis, the capacity of suppliers can be considered as a very sensitive parameter.

In Chapter 4, a framework based on the network presented in Chapter 3 was extended in order to consider the uncertainty. Accordingly, a stochastic, multi-objective, mixed-integer linear programming model was proposed. It was assumed that demand and return are stochastic parameters. Moreover, as an extension to the model, supplier selection and order allocation have been applied. A fuzzy method was developed to estimate the weights of qualified suppliers. Therefore, the objectives are the maximization of the whole profit as well as maximization of the weights of suppliers. Chance-constrained programming has been employed to deal with uncertainty in the proposed model. The operation of the proposed mathematical model has been illustrated in Toronto, Canada using real maps. In addition,  $\varepsilon$ -constraint and distance methods have been utilized to solve the multi-objective model. Furthermore, the level of confidence has been changed in order to investigate the sensitivity of the model.

### **5.3. Future research**

Various potential research subjects can be mentioned as the extensions to this study in which environmental issues, metaheuristic solution approaches, probabilistic uncertainty, and different financial factors can be investigated.

- **Considering environmental issues**

In Chapter 4, the proposed model was extended to a multi-objective model in order to consider the supplier selection and order allocation. However, the proposed mobile phone CLSC network can be developed to a multi-objective optimization model to take into account the environmental factors. Several environmental objectives including minimizing of waste, energy consumption, and carbon emission can be added to the mathematical model.

- **Considering metaheuristic solution approaches**

In real world, we deal with non-linear programming optimization models with complicated constraints as well as large-size problems. In these cases, metaheuristic algorithms such as genetic algorithm or particle swarm can be applied to achieve the best solution, although there is no assurance to achieve the optimal solution.

- **Considering probabilistic uncertainty**

In this study, the return was assumed as a stochastic parameter and to deal with that chance-constraint programming was applied. However, a propensity model such as logistic regression model can be developed based on several predictive variables in order to forecast the probability of return.

- **Considering financial factors**

Various financial parameters including interest rate, energy price, inflation and exchange rate, etc. can affect the total profit of a CLSC network. All these parameters can be taken into account throughout the design of an optimization model along with the maximization of the total profit.

- **Considering other sources of uncertainty**

In this thesis, I focused on two sources of uncertainty including demand and return. However, other parameters such as price, capacity of facilities, and costs can be considered as uncertain. Therefore, uncertainty can be reflected in the objective functions as well.

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