

Modeling Supply Chain Network under Risk and Uncertainty

Gebrewold Teklay

A Thesis Submitted to

The School of Mechanical and Industrial Engineering

Presented in Fulfilment of the Requirements for the Degree of Master of Science

(Mechanical and Industrial Engineering)

Addis Ababa University

Addis Ababa, Ethiopia

June 2017

Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

This is to certify that the thesis prepared by Gebrewold Teklay, entitled: Modeling Supply Chain Network under Risk and Uncertainty and submitted in partial fulfillments of the requirements for the degree of master of science(Mechanical and Industrial Engineering) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by Examining Committee:

Internal Examiner _____ Signature _____ Date _____

External Examiner _____ Signature _____ Date _____

Advisor: Dr.-Ir. Eshetie Berhan Signature _____ Date _____

Co-Advisor: Mr.Fitsum Getachew Signature _____ Date _____

School or center Chairperson

Declaration

I hereby declare that the work which is being presented in this thesis entitled “ Modeling Supply Chain Network under Risk and Uncertainty” is original work of my own and has not been presented for a degree of any other university and all the resources of references used for the thesis have been duly acknowledged.

Gebrewold Teklay

Signature

Date

Abstract

Supply Chain network design (SCND) is a principle emphasizing the utilization of an efficient integrated system of suppliers, producers, warehouses, retailers and customers, so that items can be produced and distributed system-wide at the right quantities and right locations so as to minimize costs and maximize services. It deals with strategic decisions such as deciding on the number, location, capacities and technologies of facilities to be opened, changes to existing facilities and supplier as well as wholesaler or customer selection. In addition it includes tactical decisions such as production, shipping plans and material flow through the network. The supply chains are complex, dynamic and highly uncertain. Uncertainty in supply chain may take in the form of demand uncertainty (inaccurate forecasting, seasonality, changes in customer preferences, etc.), supply uncertainty (e.g. supply yields, supply capacities, etc.).

Underestimating the impact of uncertainties of supply chain and optimizing under the assumptions of deterministic parameters is risky. Uncertainties of supply chain should be explicitly included in the decision making process. In this paper, a stochastic single objective optimization model have been considered for the supply chain network optimization problem under risk and uncertainty and finally cost effective supply chain network is forwarded.

This thesis address the design of four echelon (supplier, plants, warehouse and wholesaler) supply chain network (SCN), where both the plant's supplier and customer demand are considered to be uncertain and stochastic but other parameters are deterministic and known in advance. This paper proposes a single objective-single product optimization model for handling the inherent uncertainties in the forward supply chain for designing the supply chain network problem. A linear programming (LP) model is applied to realize the design of supply chain network problem effectively. First a survey questionnaire on the existence of risk and uncertainty to the Ethiopian textile industries, found in Addis Ababa, have been conducted so as to have contextual meaning on the literature review towards the Ethiopian textile industries context. Then the survey has been analyzed in a way that can be understandable clearly so that risks to be taken into the model has been prioritized based on the respondent rate and finally these with high respondent rate have been modeled into the transportation cost minimization problem, which considers the shipment cost per kg and capacity (quantity) in kg.

General Algebraic Modeling System (GAMS 24.8.3) is used as a tool to formulate and solve the LP model. A case study of Yirgalem Addis textile factory PLC is taken to demonstrate the validity of the model. By evaluating the output data, the supply chain network for this case is designed and the optimal product flow and or material flow between the suppliers, plant, warehouse and wholesalers is calculated. The result of the optimization model is compared to the existing transportation cost of the case company and by the application of this model about 9% annual cost reduction is achieved.

Finally a sensitivity analysis of the supply and demand uncertainty have been conducted to illustrate their impacts on the expected minimum cost. The result of the sensitivity analysis shows that the suggested network diagram has a consistency to tolerate the variations in demand and supply uncertainty. This contradicts with the case of the deterministic environments in a way that, the variation in demand and supply will cause the network structure and this requires another network development. Optimization of the supply chain network has great importance in the case of stochastic environment in such a way that, the developed network is tolerable to the demand and supply uncertainty and risk. If there is a variation in the supply and demand, the suggested network diagram will not fail easily, it has the ability to resist these variations of demand and supply uncertainty. Therefore the author concludes that, optimization of the supply chain network under the assumption of deterministic feature of supply and demand is risky and this may cause to the uncertainty of the supply chain structure.

Keywords: SCND and uncertainty, supply chain network optimization, Linear Programming(LP), Yirgalem Addis Textile factory PLC, GAMS build system.

Acknowledgment

First and foremost, I would like to thank to God for giving his blessing and lighting way through all these years to go through this research paper fully.

Next I heartily thank my supervisor, Dr.- Ir. Eshetie Berhan (Associate Professor) for all the help and guidance he provided me throughout my work. Thanks to him I found my thesis very interesting and enjoyable. He helped me unlock my potentials and develop my research starting from the time of taking his course lecture.

Also I would like to extend my gratitude to my co-advisor, Fitsum Getachew(PhD Candidate) for his continuous guidance from start up to the end of the research.

In addition I would like to thank my friends(researchers) for giving me their comment on my work of the research paper and also I owe sincere and earnest thankfulness to my friends for their continuous follow up and guidance to do my thesis potentially.

I owe sincere and earnest thankfulness to Addis Ababa University, Institute of Technology and School of Mechanical and Industrial Engineering for the opportunity I have been given to study my M.Sc. degree and all the support and facilities provided to me.

I would like to thank the staffs of Ethiopian Textile Industry Development Institute(ETIDI) Yirgalem Addis Textile Factory PLC, Ethiopian Sewing Thread Factory, DH Geda and Industry PLC, KK Textile Industry and G-7 Weaving I for their corporate help during time of questionnaire survey and initial problem gathering. I would like also to extend my thankfulness to Ato Fantaye Eshetu and Nigussie Godana for their contribution during the time of interview for obtaining relevant data for the sake of model validation and searching for the existence of the problem respectively.

Finally my appreciation goes to my family especially to my brother (Mulubrhan Belay) and my sister(Masho Belay) and my co- brother (Mehari Beyene) for their basic assistance in my life to reach this stage.

Contents

Declaration.....	ii
Abstract.....	iii
Acknowledgment.....	v
List of Tables	ix
List of Figures.....	x
List of Abbreviations	xi
CHAPTER ONE	1
1. Background and Justification of the Study.....	1
1.1. Introduction	1
1.2. Problem Statement	2
1.3. Objectives of the Study	3
1.3.1. General Objective of the Study.....	3
1.3.2. Specific Objective of the Study	4
1.4. Significance of the Study	4
1.5. Scope of the Study.....	5
1.6. Limitation of the Study	5
1.7. Organization of the Study	5
CHAPTER TWO	6
2. Literature Review	6
2.1. Introduction	6
2.2. Basic Concepts of Supply Chain.....	6
2.2.1. Supply Chain Definition	6
2.2.2. Forward Supply Chain	7
2.2.3. Reverse Supply Chain.....	7
2.2.4. Closed Loop Supply Chain	8
2.2.5. Process View of Supply Chain Integration.....	8

2.3.	Fundamentals of Supply Chain Management	9
2.3.1.	Supply Chain Management.....	9
2.3.2.	Supply Chain as a Management Philosophy.....	11
2.4.	Risk and Uncertainty	11
2.5.	Forms of Supply Chain Risk and Uncertainty	14
2.5.1.	Internal Forms Supply Chain Risk and Uncertainties.....	15
2.5.2.	External Forms Supply Chain Risk and Uncertainties	17
2.6.	Supply Chain Risk Management.....	18
2.7.	Supply Chain Risk Response Strategy	22
2.8.	Methods Applied to Supply Chain Network Design under Risk and Uncertainty ..	23
2.8.1.	Mathematical Models.....	24
2.9.	Summary of Literature Review and Gaps Identified	27
CHAPTER THREE	.....	33
3.	Research Design and Methodologies.....	33
3.1.	Introduction	33
3.2.	Research Design.....	33
3.3.	Research Framework.....	34
3.4.	Research Methodologies	34
3.4.1.	Literature Review.....	34
3.4.2.	Data Collection and Source of Data.....	35
3.4.3.	Tools and Methods of Data Analysis and Presentation	35
CHAPTER FOUR	.....	37
4.	Data Presentation and Analysis.....	37
4.1.	Introduction	37
4.2.	Data Presentation, Analysis and Summary	37
CHAPTER FIVE	.....	44
5.	Model Development, Model Fitting and Model Solving	44

5.1.	Introduction	44
5.2.	Model Assumption	44
5.3.	Model Input and Output	45
5.4.	Model Input Parameters and Variables	46
5.5.	Model Formulation.....	46
5.6.	Running the Model.....	48
5.7.	Hypothetical Value to Test the Model	49
5.8.	Result and Discussion Regarding to the Hypothetical Model Testing.....	54
5.9.	Model Fitting for the Case Study	57
5.10.	Model Solving for the Case Study.....	60
5.11.	Result and Discussion of the Case Study Analysis	66
5.12.	Sensitivity Analysis of Supply and Demand Uncertainties for the Case Study	70
5.12.1.	Sensitivity Analysis of Supply uncertainty on Expected Minimum Cost.....	71
5.12.2.	Sensitivity Analysis of Demand Uncertainty on Expected Minimum Cost	75
5.13.	Result and Discussion Regarding to the Sensitivity Analysis.....	81
CHAPTER SIX	.....	83
6. Conclusion, Recommendation and Future Research Direction	.....	83
6.1.	Conclusion.....	83
6.2.	Recommendation.....	85
6.3.	Future Research Direction.....	86
Bibliography	.....	87
Appendix	.....	94

Appendix

Annex A: Result of the Optimization Model for the Hypothetical Testing.....	94
Appendix B: Result of the Optimization Model for the Case Study	116
Appendix C: Supply Chain Risk and Uncertainty Survey Questionnaire	128
Appendix D: Interview Questions	131

List of Tables

Table 1: Literature summary, issues critically examined in the literature.....	30
Table 2: Respondent survey number for the different form of risk and uncertainty in the supply chain	39
Table 3: Representation of variables in the model for the hypothetical model testing.....	49
Table 4: Interpretation of the variables in the model for the case study.....	59
Table 5: Production capacity with its attainable capacity of Yirgalem Addis Textile	60
Table 6: Result and discussion of the case study	66
Table 7: characteristics of supply uncertainty based on level of randomness	70
Table 8: Characteristics of demand uncertainty based on level of randomness	70
Table 9: Sensitivity analysis of supply uncertainty ‘C6’ on expected minimum cost.....	71
Table 10: Sensitivity analysis of supply uncertainty ‘C1’ on expected minimum cost.....	72
Table 11: Sensitivity analysis of supply uncertainty ‘C2’ on expected minimum cost.....	72
Table 12: Sensitivity analysis of supply uncertainty ‘C3’ on expected minimum cost.....	73
Table 13: Sensitivity analysis of supply uncertainty ‘C4’ on expected minimum cost.....	74
Table 14: Sensitivity analysis of supply uncertainty ‘C5’ on expected minimum cost.....	74
Table 15: Sensitivity analysis of demand uncertainty ‘D6’ on expected minimum cost.....	75
Table 16: Sensitivity analysis of demand uncertainty ‘D7’ on expected minimum cost.....	76
Table 17: Sensitivity analysis of demand uncertainty ‘D8’ on expected minimum cost.....	76
Table 18: Sensitivity analysis of demand uncertainty ‘D9’ on expected minimum cost.....	77
Table 19: Sensitivity analysis of demand uncertainty ‘D10’ on expected minimum cost.....	78
Table 20: Sensitivity analysis of demand uncertainty ‘D11’ on expected minimum cost.....	78
Table 21: Sensitivity analysis of demand uncertainty ‘D12’ on expected minimum cost.....	79
Table 22: Sensitivity analysis of demand uncertainty ‘D13’ on expected minimum cost.....	79
Table 23: Sensitivity analysis of demand uncertainty ‘D14’ on expected minimum cost.....	80
Table 24: Sensitivity analysis of demand uncertainty ‘D15’ on expected minimum cost.....	80

Table 25: Sensitivity analysis of demand uncertainty ‘D16’ on expected minimum cost.....81

List of Figures

Figure 1: Simplified supply chain model	7
Figure 2: General illustration of closed loop supply chain	8
Figure 3: Supply chain management framework	10
Figure 4: General illustration of supply chain management activities	11
Figure 5: Conceptual framework of supply chain risk management	19
Figure 6: Supply chain risk management process	22
Figure 7: Summary of reviewed papers	29
Figure 8: Conceptual research framework	36
Figure 9: Supply chain structure in textile industries	38
Figure 10: Forms of supply chain risk and uncertainty	39
Figure 11: Percentage respondent rate for survey questionnaire	41
Figure 12: Number of respondent for survey questionnaire	42
Figure 13: Model input/ output	45
Figure 14: The supply chain structure considered in the study	47
Figure 15: Hypothetical supply chain network diagram with 5-4-5-7 suppliers, plant, warehouse and wholesaler respectively	52
Figure 16: Restructured supply chain network diagram for the hypothetical testing	57
Figure 17: Existing supply chain structure of the case study	62
Figure 18: Restructured supply chain network of the case company	69

List of Abbreviations

SC: Supply Chain

SCM: Supply Chain Management

SCRM: Supply Chain Risk Management

SCNO: Supply chain Network Optimization

SCND: Supply Chain Network Design

CLSC: Closed Loop Supply Chain

CLSCN: Closed loop supply chain network

SCOR: Supply Chain Operations Reference Model

ERM: Enterprise Risk Management

MILP: Mixed Integer Linear Programming

GAMS: General Algebraic Modeling System

MINLP: Mixed Integer nonlinear Programming

LP: Linear Programming

PHD: Product with High Demand

PMD: Product with Medium Demand

ETIDI: Ethiopian Textile Industry Development Institute

CHAPTER ONE

1. Background and Justification of the Study

1.1.Introduction

A supply chain is the linkage of series of organizations with facilities, functions, processes, and logistics activities that are involved in producing and delivering a product or service.

(Norrman, 2002), define supply chain as collaboration with partners to deal with risks and uncertainties caused by or impacting on, logistics related activities or resources.

In Manufacturing supply chain customers face with demand for increasing product variety, shorter product life cycle, lower cost, better quality and faster response. With the advent of increased product/service complexity, and outsourcing of supply networks across international borders, risk and uncertainties are increasing and the location of risk has shifted through complex changing supply chain networks.

To be successful in increasing globalized and competitive market, companies must constantly strive to reduce supply chain costs and improve customer service while planning for the unexpected (M. A. Vonderembse, 2006). Since uncertainty plays a great role in today's world, the importance of effectively connecting entities in supply chain has been highlighted in recent years and is known in the literature as supply chain network design problem. The uncertainty that dominate today's decision making, process affects many supply chain network design parameters such as plant capacity, demand rate, transportation time and supplier capacity.

Supply Chain network design (SCND) focuses on the utilization of an efficient integrated system of suppliers, producers, warehouses, retailers and customers, so that items can be produced and distributed system-wide at the right quantities, locations, and time to minimize costs and maximize services. It deals with strategic decisions such as deciding on the number, location, capacities and technologies of facilities to be opened, changes to existing facilities and supplier as well as wholesaler or customer selection. In addition it includes tactical decisions such as production shipping plans and material flow through the network. The supply chains are complex, dynamic and highly uncertain. Uncertainty in supply chain may take the form of demand uncertainty (inaccurate forecasting, seasonality changes, changes in customer preferences, etc.), supply uncertainty (e.g. supply yields, supply capacities, etc.). underestimating the impact of uncertainties of supply chain and optimizing under the

assumptions of deterministic parameters is risky. Uncertainties of supply chain should be explicitly included in the decision making process. Many industrial cases have shown different outcomes after risk events due to diverse actions (or lack of action) taken in facing supply chain disturbances and disruptions. To gain cost advantage and market share, many firms implemented various initiatives such as outsourced manufacturing and product variety. These initiatives are effective in a stable environment, but they could make a supply chain more vulnerable to various types of disruptions caused by uncertain economic cycles, consumer demands, and natural and manmade disasters.

An optimization model under risk and uncertainty that captures the SCND problem, which is motivated by textile industries found in Addis Ababa is developed. To illustrate the validity of the model, a case of Yirgalem Addis Textile Factory has been undertaken.

In this thesis both supply chain network optimization(SCNO) and supply chain network design(SCND) have been used interchangeably.

1.2.Problem Statement

Supply chain has become a major component of competitive strategy to enhance organizational productivity and profitability. Unfortunately the constituent activities in the supply chain do not operate without chances of failure to meet the desired objectives. Hence, supply chain network design under risk and uncertainty in supply chain activities are a very important factor of competitive advantage formula. It is evident that both qualitative as well as quantitative research methods are utilized for solving supply chain network design problem while considering uncertainties (Colicchia, 2012). To enterprises which aim at increasing the impact of their activities (by minimizing costs and/or optimizing profits), the need to continuously restructure the supply chain network is fundamental, and to carry out such activities effectively, proper and adequate tools (both qualitative and quantitative) are needed.

In textile industry risk effects are compounded by factors such as, complex supply chain, short product life cycle and volatile market demand which make them highly sensitive to exposure of uncertainty, as they operate on the borderline of stability(sources: ETIDI Report). When looking at the structure of the Ethiopian textile industry, it is full of variability having the players and supporters at every level of their supply chain with lot of structural, operational and performance differences (Hailu, Asseb, 2009). Since, importation process takes long time due to foreign currency issues and poor logistic infrastructure along with underdeveloped communications system the downstream (mainly fabric manufacturing firms)

of the value chain are forced to hold large amount of inventories. Random customer selection both in upstream and downstream of the supply chain and inappropriate capacity allocation are the major constraints in this stage of the supply chain. According to the information obtained from Ethiopian Textile Development Institute(ETIDI), the demand for a product is increasing rapidly. However the existing supply chain network is not able to capture available demand at different location and means of selecting appropriate supplier of raw material and the customer service is not to the satisfactory level with the increased demand. As a result some segment of the market is experiencing shortage of outgoing product due to imbalance between incoming materials. Currently the Ethiopian textile industry does not have well established means to sense the shortage in the market. Due to the existence of these problem the cost of shipping raw material and finished product is getting high (source: ETIDI Report). The novelty of this research is therefore to design a cost effective supply chain network under demand and supply uncertainty and also to provide optimal capacity allocation so as to cope up with these challenges. Here a linear programming model with the objectives of cost minimization for incoming material to the plant and outgoing product from the plant with four echelon supply chain is restructured based on the result of the mathematical model. The supply chain network designed and the optimization model would be helpful to similar companies seeking to compete successfully for similar purpose.

Therefore this research will attempt the following basic research questions identified from the problem statement.

1. What are the methodological requirements for quantitative decision support in SCN optimization under risk and uncertainty?
2. Which uncertainties need to be considered in SCN optimization problem?
3. What is an appropriate way to model the SCN optimization problem while considering risk and uncertainty in supply chain?
4. How do we solve the SCN optimization problem considering risk and uncertainty?

1.3.Objectives of the Study

1.3.1. General Objective of the Study

The foremost objective of this study is to optimize and analyze supply chain network under risk and uncertainty .

1.3.2. Specific Objective of the Study

To attain the general objective set forth, the following specific objectives have been identified for its achievement. The specific objectives of the research are to:

- ✚ Identify the methodological requirement for quantitative decision support in supply chain network optimization problem considering risk and uncertainty.
- ✚ Identify the different types of risk and uncertainty that should be considered within the supply chain network optimization problem.
- ✚ Find out the appropriate means of modeling the supply chain optimization problem while considering risk and uncertainty.
- ✚ Develop optimization model with the objectives of minimizing cost and finally to provide a means of solving supply chain network optimization problem under risk and uncertainty.

1.4. Significance of the Study

The significance of the study can be seen in terms of theoretical aspect as well as practical aspect. The theoretical aspect of the study is it gives a vast literature review on supply chain network modeling with the consideration of risk and uncertainty in addition to the literature of risk and uncertainty. Some of the practical aspect of this study may be conducting the various risk and uncertainty in textile industry found in Addis Ababa in addition to the development of the model for the sector. First of all, supply chain network modeling under risk and uncertainty can lead to cost savings in terms of control over sales- and market-share loss. Further, if something occurs in the supply chain, an organization can recover faster than its competitors, and thereby achieve competitive advantage. Generally the main contributions of this research are threefold:

- First this research is among the few that discuss the modeling and analysis of textile industries' supply chain with the consideration of risks and uncertainties.
- The second contribution of this paper is that it proposes an optimization procedure to optimize supply chain while considering risk and uncertainty.
- The study is also important in terms of knowledge sharing and significance to fill the gap.

In addition to the significance of the study its beneficiary is also , the suggested supply chain network optimization model would be helpful to similar companies seeking to compete successfully for similar purpose.

1.5.Scope of the Study

Generally this paper is limited up to the development of an optimization model by considering supply and demand uncertainties , validation of the model with the real situation of Yirgalem Addis textile factory, designing optimal supply chain network based up on the result of the mathematical model for Yirgalem Addis Textile factory and finally providing an appropriate conclusion and recommendation to the sector.

1.6.Limitation of the Study

The study has its own limitation and some of these limitations are: One limitation is that since the research is mainly based on primary data, therefore the knowledge and experience of the respondents (both for questionnaire and interviews) may limit the reliability of the research findings. The other limitation of the study is that data for the sensitivity analysis are taken from interview based on work experience since they are not interested to give a recorded data and therefore this may limit the conclusions made on the sensitivity analysis. However these limitation does not affect the quality of the study addressed within its specific objectives and basic research questions.

1.7.Organization of the Study

The remainder of the paper is organized as follows. The study has six chapters. The first chapter is all about an overview on the general background and justification of the problem. The second chapter presents the review of available literature in the area of supply chain network optimization under risk and uncertainty. It gives particular emphasis to optimization models in supply chain network under uncertainty and risk. The third chapter focuses on the research framework and methodology. Chapter 4 presents about data presentation and analysis. Chapter 5 is about model development model fitting , model solving for both the hypothetical and real cases and sensitivity analysis of supply and demand uncertainty for the case study. Finally the last chapter, chapter six, contains the conclusions, recommendations and future research areas.

CHAPTER TWO

2. Literature Review

2.1. Introduction

In this section literature review on the basics of supply chain, supply chain risk and uncertainty, risk and uncertainty definition by different authors, supply chain risk management, strategies for supply chain risk response and modeling approaches (Mathematical Modeling) for supply chain under risk and uncertainty which have been done so far will be presented in detail. It is also part of this section that provides examples for stochastic SCNO/SCND studies that consider demand uncertainties, supply uncertainty and process uncertainty. Finally once a literature review on these area have been undertaken a literature summary and gaps identified from the literature will be presented.

2.2. Basic Concepts of Supply Chain

2.2.1. Supply Chain Definition

Supply chain can be defined as the flow of goods, information, and finance, from supplier to manufacturer to wholesaler to retail to customer. The council of logistics defines supply chain as the process of planning, implementing and controlling the efficient, cost effective flow of materials, in-process inventory, finished goods and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirement. The supply chain is also related to as the value chain as it adds value to the organization by providing what the customer wants and market demand that too at a low cost. Supply Chain is a set of activities that includes purchasing, manufacturing, logistics, distribution, marketing, that perform the function of delivering value to end customer. Supply chain defines as a set of three or more entities directly involved in the upstream and downstream flows of product, service, finance and or information from a source to a customer and vice versa (Mentzer J. T., 2001). A supply chain is the linkage of series of organizations with facilities, functions, processes, and logistics activities that are involved in producing and delivering a product or service. The supply chain, which is also referred to as the logistics network, consists of suppliers, manufacturing centers, warehouses, distribution centers, and retail outlets, as well as raw materials, work-in-process inventory, and finished products that flow between the facilities. The Figure 1 which is shown below depicts a simplified supply chain (SC) model.

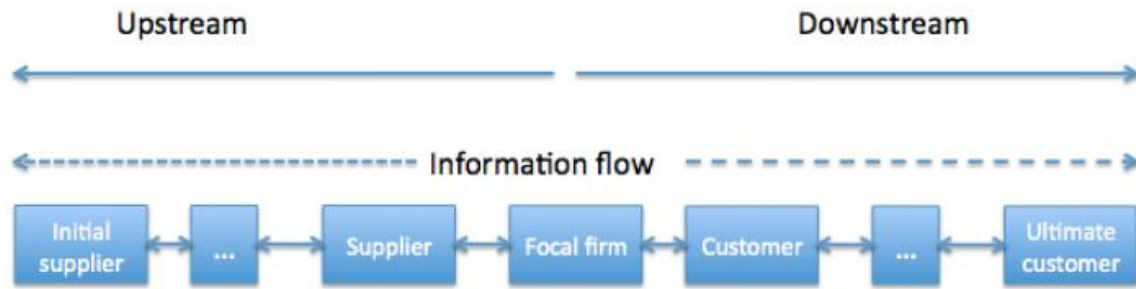


Figure 1: Simplified supply chain model (Mentzer J. a., 1994)

Additionally, (Mentzer J. a., 1994), distinguish between four different types of supply chains, namely a “basic supply chain”, an “extended supply chain”, an “ultimate supply chain” and a “partnership”. As indicated in (Hahn, G.J., Kuhn, H., 2012), the supply chain is formed by external suppliers, the internal process to produce products or render services, and customers due to its high relevance to any business based on the need to obtain inputs to meet demand and the many events that can interrupt it.

2.2.2. Forward Supply Chain

The forward supply chain (FSC) contains of a series of activities which result in the conversion of raw materials to finished products. Forward supply chain refers to the flow of products to customer stayed ahead of the computation.

2.2.3. Reverse Supply Chain

There are great variety of definitions of reverse logistics which changes in scope and significance. Reverse logistics is a process in which a manufacturer systematically accepts the previously shipped products or parts from the point of consumption for possible recycling, remanufacturing, or disposal (Shad, 2000). Reverse logistics is a part of a broader supply chain management process called return management. Reverse logistics refers to the process of planning, implementing and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal (Kaebernick, 2008). Reverse Logistics refers to all logistic activities to collect disassemble and process used products, product parts, and/or materials in order to ensure a sustainable. Reverse supply chain (RSC) is defined as the activities of collection and recovery of product returns in Supply Chain Management (SCM). It also refers to the movement of goods and services from the customer to the retailers.

2.2.4. Closed Loop Supply Chain

There are various definitions regarding to closed loop supply chain given by different authors and scholars. A complete supply chain should include both forward and reverse logistics (R.Sridharan, 2014), see for example Figure 2. Closed loop supply chain refers to the design, control and operation of a system to maximize value creation over the entire lifecycle of a product with dynamic recovery of value from different types and volumes of returns over time. Closed loop supply chain are designed and managed to explicitly consider the reverse and forward supply chain activities over the entire lifecycle of the product.

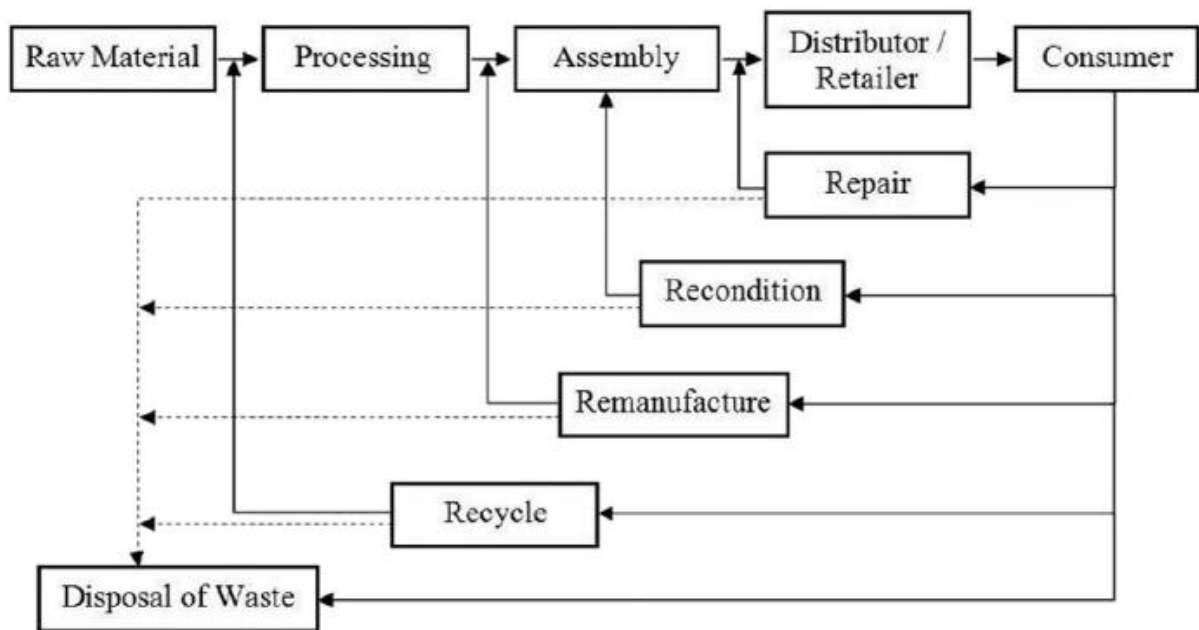


Figure 2: General illustration of closed loop supply chain (Khor, 2012)

2.2.5. Process View of Supply Chain Integration

Supply chain management(SCM) is the integration of key business processes from end users through original suppliers that provide products, services, and information that add value for customers and other stakeholders (Lambert D. M.-D., 2005). Thus, a process view of supply chain integration is fundamental. A business process refers to a structured and measured set of activities with specific business outcomes for customers (Davenport, 1995). (Zairi, 1997), further defined, business process management as “a structured approach to analyze and continually improve fundamental activities such as manufacturing, marketing, communications and other major elements of a company’s operation.” The process paradigm implies looking at organizations based on the processes they perform rather than on the

functional units, divisions, or departments. The process approach broadens the focus of the organization. The interaction across functions can create value in meeting customers' needs. However, the complexity of business processes must be acknowledged. Business processes can vary significantly in terms of level (strategic or operational process) and scope (activities involved in a process). SCM itself, in fact, can be considered a business process. For example, (Ross, 1998), viewed supply chain process as the actual physical business functions, institutions, and operations that characterize the way a particular supply chain moves goods and services to market through the supply chain pipeline. Alternately, a small set of activities employed to handle a customer's defective product complaint is also a business process. Unless all major business processes and relevant sub-processes can be identified and understood explicitly, process management can be difficult to implement (Lambert D. M., 2004). One illustration of the process approach to supply chain integration is the Supply Chain Council's Supply Chain Operations Reference-model (SCOR) that suggests that business should be managed based on key processes. Similarly, the Global Supply Chain Forum also proposed that it is necessary to identify the relevant business processes and manage them effectively without considering all business processes, integration can lose focus (Croxtton, 2001).

2.3.Fundamentals of Supply Chain Management

2.3.1. Supply Chain Management

All organizations have supply chains but as it differ from each other in size and the kind of product manufactured so due the supply chains. The important components of supply chains are order management, logistics, warehousing, inventory control, retail packaging. The components are different pieces of supply chain that have to be managed and coordinated in such a way that it adds value to the company in terms of product quality as well as customer satisfaction but at the same time keeping the cost down. The ultimate goal of supply chain is to meet customers demand more efficiently by providing the right product, with the right quantity, at the right location on the right time and in the right condition. The Figure 3 shown below shows that SCM is designed to provide the following major goals: waste reduction, time compression, flexible response, unit cost reduction.

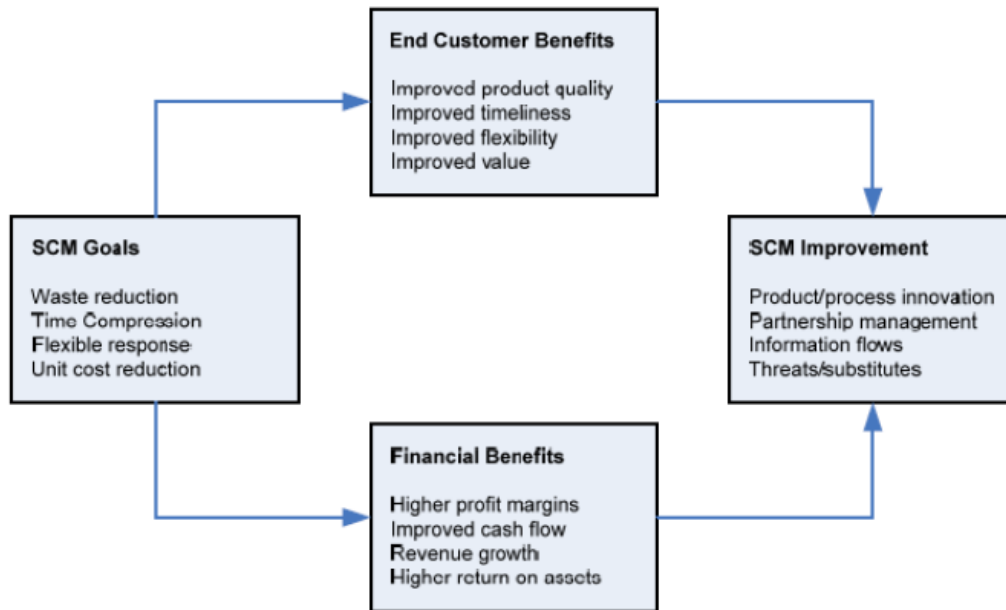


Figure 3: Supply chain management framework (Brewer, 2000)

These goals have been articulated in several context associated with SCM, emphasizing the importance of both inter and intra-firm coordination (Brewer, 2000). Firms practicing SCM, seek to reduce waste throughout the supply chain by minimizing, duplication, harmonizing operations and systems and enhancing quality. When production and logistics process are accomplished in less time, all entities in the supply chain are able to operate more efficiently and primary results in the reduced inventories throughout the system. flexible response is in order handling , including how orders are handled, product variety , order configuration , order size and several other dimensions means that a customer's unique requirements can be met in a cost effective way. Supply chain management (SCM) is the control of the supply chain as a process from supplier to manufacturer to wholesaler to retailer to consumer. Supply chain management at the organizational level encompasses the following activities(see Figure 4).

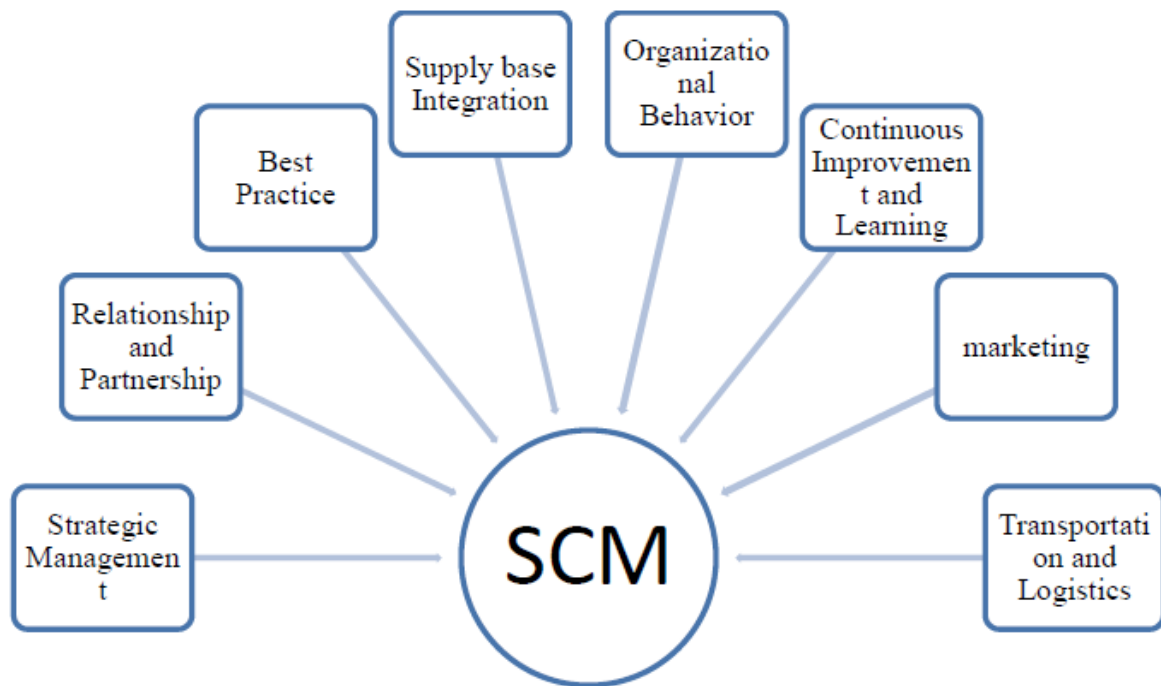


Figure 4: General illustration of supply chain management activities

2.3.2. Supply Chain as a Management Philosophy

Supply chain management as a management philosophy takes a system approach to viewing the supply chain as a single entity, rather than as a set of fragmented parts, each performing its own function. The partnership concept is extended into a multi firm effort to manage the flow of goods from supplier to the ultimate customer. Each firm in the supply chain directly or indirectly affects the performance of other supply chain members, as well as the overall performance of the supply chain (Cooper Martha c., 1997). Supply chain management as philosophy has the following characteristics:

- ✓ A system approach to viewing the supply chain as a whole and managing the total flow from the supplier to the ultimate customer.
- ✓ A strategic orientation toward cooperative effort to synchronize and converge in the firm and intra- firm operational and strategic capabilities into a unified whole.
- ✓ A customer focus, to create unique and individualized sources of customer value, leading towards customer satisfaction.

2.4. Risk and Uncertainty

Different authors and scholars presents relevant definitions of risk and uncertainty. Risk used to be simply linked to unexpected events. (Christopher M. L., 2004), View risk as the “effect of external events such as wars, strikes or terrorist attacks and impact of changes in business

strategy”. (Kleindorfer, 2005), follow the same line and relate risk to i) operational contingencies, ii) natural hazards, earthquakes, hurricanes and storms; and iii) terrorism and political instability. (Quinn, 2006), also refers the natural and manmade disasters, to “catastrophic events” which are the source of risk. (Tang, 2006), defines risk as an operational as well as a disruption risks, but the author however, does not distinguish between them. Looking at various perspectives of risk, (Spekman R. D., 2006), claim that risk definition can either be objective or subjective. Risk which relies on probability alone, such as coin flipping or dice throwing, is considered to be objective. However, when the consequences of risk need to be assessed along with its expectation of occurrence, it is categorized as subjective risk. Risk can be broadly defined as a chance of danger, damage, loss, injury or any other undesired consequences. (Chopra, S., Sodhi, M.S.,, 2004), Presents nine risk categories, which include disruptions, delays, systems, forecast, intellectual property, procurement, receivables, inventory and capacity.

Therefore it is important for all members of the supply chain to have a common understanding of supply chain risk. A comparison of risk and uncertainty is made by (Khan, O. and Burnes, B.,, 2007). They conclude that risk is measurable and manageable. On the other hand, however, uncertainty may not be measurable. Furthermore, risk emerges as measurable “in the sense that estimation can be made of the probabilities of the outcome”. In another set of literature, risk is viewed as the negative outcome after the impact of events. (Christopher M. L., 2004), look at it broadly as any negative consequence resulting from any external event, whereas (Paulson, 2005) specifically identifies risk as “an event with negative economic consequences”.

However, some authors view risk as the variance of outcome, no matter whether it affects the organization positively or negatively. For example (Spekman R. D., 2004) view risk as the variance of outcome, this may affect an organization positively or negatively. Recent studies of supply chain risk discuss the elasticity of supply chain performance, which (Sheffi, 2005) calls supply chain resilient, the aim of avoiding a risk event, minimizing the effect as well as quickly returning to business, the author also defines risk as events with “high impact/ Low-probability”.

Risk events represent a daily challenge to supply chains and logistics management. The ability to respond and to mitigate these risk events puts a company ahead of its competitors and reduces the expected long term damage to its business. The key drivers for supply chain

profitability are responsiveness, efficiency and reliability (Hendricks, K., and Singhal, V., 2005). To maintain their profitability, supply chain must be able to quickly respond to external and internal risk events, and keep their business efficient and dynamic. Furthermore supply chains have to be resilient to unexpected catastrophic events. Risk exists in supply chain because of the uncertainty about future risk events, which can appear at any point in time in the supply chain. Supply chain performance can be negatively impacted because of the occurrence of risk events in different stages of the supply chain system.

It is a challenge to capture the multidimensional and interdependent behavior of the risks. Raw material passes through various processes, geographic and political regions, changes ownership and modes of transportation before reaching the end customer in the form of finished products (Handfield, 2002).

All of these processes expose potential points where supply chains are vulnerable to disruptions. Modern supply chain trends such as, globalization, decentralization, and outsourcing and just- in –time are introduced to make supply chain efficient. However this has led to an increase to the number of exposure points. In order to identify these failure points, within the network, supply chain systems need a holistic perspective to understand and capture the complex network of interconnected nodes. We believe that a risk event can create disruption in either one or a combination of these flows. Supply chain risk could be mitigated if we have a detailed investigation and description of the root causes of disruption from the aspect of these flows. Similar ideas have been presented by (Chopra, S., Sodhi, M.S.,, 2004), (Spekman R. D., 2006), who all identify the dimension of risk in the form of supply chain flows.

(Spekman R. D., 2004), however go further, and concentrate on information sharing and network relationships and add the security of internal information systems, relationships forged among supply chain partners and corporate social responsibility to their risk dimensions. (Arlbjorn, 2002), share this idea of viewing risk on the flows of material and information, but view the third perspective in terms of flow of services.

Decisions are made under certainty when perfect information is available and under uncertainty when one has only partial or imperfect information, see for example (Stewart., 2005). The term under this paradigm is value neutral, i.e. it includes the chance of gain and conversely the chance of damage or loss. As explained by (Stewart., 2005), uncertainty leads to risk which is the possibility that undesirable outcomes could occur.

Generally a better definition of risk and uncertainty are given by (Garrick, S. Kaplan and B. J., 1981) who set out as

$$\text{Risk} = \text{uncertainty} + \text{damage}$$

Note that risk is a subjective concept that depends on a decision maker's information, goals, personal preferences as well as the decision itself. For example high demand might be positive for a company if its supply has the ability to fulfill it, and negative otherwise.

2.5. Forms of Supply Chain Risk and Uncertainty

In reviewing risk management literature, the first difficult question is what is supply chain risk? It is particularly difficult to distinguish risk and uncertainty in supply chain operations.

Several researchers provided different definitions for supply chain risk and uncertainty.

Global supply chains are becoming more complex and more vulnerable to disruption with large anticipated consequences of seemingly contained events (Craighead, 2007).

Although these definitions have applicability in specific domains, such as supply risk (Zsidisin G. ..., 2003), information flow risk, material flow risk and product flow risk (Jüttner., 2003), they focus on specific function or a part of supply chain, and do not span

across the entire supply chain. (Davis., 1993), identified three distinct sources of uncertainty in supply chain, supply, process, and demand uncertainty. There is no simple solution to

manage supply chain risk. The implementation of one strategy in mitigating a particular risk may cause the supply chain to face another risk. Numerous examples of severe supply chain

disruptions exist. In most instance such disruptions are either naturally made (like earthquake, floods, fire etc.) or man-made risks (such as cyber-attack, terrorist attack) (Heckmann, 2015).

In addition to major disruptions supply chain also face interruptions by several sources of inherent uncertainties such as demand fluctuations, supply capacity changes, lead time

variability and exchange rate volatility, quality failures as well as information failure (bullwhip effect), where orders at the upstream supply chain members tends to exaggerate the

true consumption of end customers. Since each supply chain is unique, the risk mitigation strategies should be tailored accordingly to suit the entire supply chain. Even though they are

not explicitly distinguished, the risk categories discussed by (Chopra, S., Sodhi, M.S.,, 2004), such as disruption, delays, systems, forecast, intellectual property, procurement,

inventory and capacity are established on the basis of supply chain flows. However, a clear definition of the fundamentals of risk seems to be lacking. In some of the risk categories,

such as the forecast risk, where the authors highlight the issues of the bullwhip effect, one may argue whether this could be considered as operational uncertainty and could be managed

with correctly operating supply chain. (Zsidisin G. ..., 2003), Classifies supply chain risk as “the probability of an incident associated with inbound supply chain from individual supplier failures or the supply market occurring, in which its outcome results in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety”. On the demand side, even more cases of referring demand risk to uncertainties, for example, the trend of rapid changes of customer demand and the short life cycle of product resulting in fluctuated demand can be noticed. (Johnson, 2001), defines risk in terms of operational deviations, such as “unpredictable demand, short product life cycle, rapid product turnover and seasonal changes”. In the author’s opinion, these should be considered to be the drivers for demand fluctuation.

Apart from supply and demand uncertainty, uncertainty can take other forms, for instance technology (Chen I. P., 2004). There also exist different viewpoints on uncertainty. Instead of looking at demand uncertainty as a fluctuation of demand volume, (Lee, 2002), believes that demand uncertainty should be “the predictability of the demand”. Another significant development in this research is the introduction of supply chain preparedness to risk events. What distinguishes one disruption case from another is the severity and duration of the disruption and this depends on the level of preparedness.

Generally, a better definition of supply chain risk should refer to i) probable events which may occur suddenly, and ii) these events bring substantial negative consequences to the system. It is clear that as it is observed from the literature the various risk and uncertainty within the supply chain are: inventory holding cost (both incoming material and outgoing material), backorder cost, transportation lead time, or delays, procurement, intellectual property, supply capacity and demand fluctuation. Generally supply chain risk and uncertainty can take the following forms.

2.5.1. Internal Forms Supply Chain Risk and Uncertainties

1. Supply uncertainty: supply risk is the uncertainty associated with supplier activities and in general supplier relationships such as the transpiration of significant and/or disappointing failures with inbound goods and services (Zsidisin G. A., 2000) .

Supply uncertainty can take any of the following forms.

- ✓ Uncertain supply yields: occurs when a buyer receives a random fraction of the order quantity from the vendor (Tang, 2006).

The raw material yield at the supplier side is often lower the initial production due to factors like long lead times, complicated production process and unpredictable factors like weather and environment (He, 2012).

- ✓ Uncertain supply capacity: a closely related concept to yield uncertainty is capacity uncertainty, in which the supplier delivery capacity is random variable that is typically independent of the order quantity while yield uncertainty is random variable dependent on the order quantity (Snyder, 2010).
 - ✓ Uncertain lead times: replenishment leads times are stochastic parameter.
 - ✓ Uncertain supply cost: (Chopra, S., Sodhi, M.S.,, 2004), defined procurement risk as unanticipated increases in acquisition cost resulting from fluctuating exchange rates or supplier price. (Zhang, 2011), have modeled a multi echelon production system under demand and raw material price uncertainties. According to him, supply price uncertainty is less volatile than demand uncertainty that is uncertainty range is small and can be predicted more accurately. This is due to the reason that usually there exist long term relationships between manufacturers and procurement market. In his study, (Zhang, 2011) considered an automobile production system and have mentioned that uncertain demands has higher impact on the corporate profit comparing to uncertain prices that is why most companies focus on calculating large data set for demand forecasting while they could easily predict price variation due to the availability of multiple sourcing options for raw materials. (Chopra, S., Sodhi, M.S.,, 2004), have mentioned some strategies to cope with price increase by suppliers such as dealing for long term agreements having redundant supplier or holding inventory in rare situation.
2. Process uncertainty: operational risk is the possibility of an event associated with the focal firm that may affect the firm's internal ability to produce goods and services, quality and timeliness of production and or profitability of a company.
 - Uncertain production capacity: includes variations in output due to machine failure, accidents, and change in employee productivity (Miller., 1992) .
 - Uncertain process yield: relates to quality issues and scrap rates, inadequate manufacturing and high level of process variations (Mentzer I. M., 2008).
 3. Demand uncertainty: probably demand is the most studied source of supply chain uncertainties and this may be referred to the fact that meeting customer demand is what primarily drives most supply chain planning initiatives. New product may be

source of uncertainty when it is inappropriately introduced and this might lead to lost market opportunities or to inventory. Also variation in demand caused by seasonality, changes in customer preferences, fads and introductions of new products by competitors contribute to demand uncertainty (Mentzer I. M., 2008). Finally the author notes that depending on the type or nature of product, demand risks vary, with the demand of functional products being more predictable than innovative products. According to typology of supply chain uncertainty sources, demand and distribution uncertainty may be one of the following forms: uncertain demand quantity, uncertain demand specification and uncertain customer order lead times (Van der Vorst, 2000).

2.5.2. External Forms Supply Chain Risk and Uncertainties

(Miller., 1992) ,has discussed general environmental uncertainties and provided examples for each category. Environmental uncertainties include political instability which refers to potential or actual changes in political system such as war, revolution; policy instability which refers to government policies instability like price controls trade restrictions; macroeconomic uncertainty which are uncertainties related with fluctuation in price and level of economic activity such as price inflation, uncertain interest rate, uncertain exchange rate; social uncertainties which result from contradiction between population and government policies and lastly natural uncertainties associated with weather impact like agricultural industry or natural disaster like earth quakes. (Christopher M. P., 2004), described environmental uncertainties as disruptions external to supply chain network through which the value stream or products flow. He explained that disruption could have direct impact on the focal firm or any other point upstream or downstream. (Chopra, S., Sodhi, M.S.,, 2004), agree with (Christopher M. P., 2004), in that environmental uncertainties or disruptions as referred in the paper are unpredictable in most cases. They added that though their occurrence is rare their impact is quite damaging and that the problem with most companies is that they usually ignore these uncertainties. Also they discussed some of the strategies to cope with this type of unpredictable uncertainties by building inventory or contracting with multiple suppliers to avoid the high risk of single supplier disruption.

In the literature, supply chain risk and uncertainty can be classified as small scale disruptions (internal sources of uncertainty) or large scale disruptions (external sources of uncertainty). Recent events like the Heparin tragedy, hurricane Katrina, the September 11 disaster and the 2011 Japanese earthquake, war, policy and tsunami belong to the latter category. Small scale

disruptions are those that are often caused by the usual random variations like, consumer demand or delivery lead time.

2.6. Supply Chain Risk Management

Supply chain risk management focuses on developing new approaches for management of disruption. The field of supply chain risk management has originated from the idea of enterprise risk management (ERM), the paradigm for managing the portfolio of risks that threaten organization (Gordon, 2009). Risk events represent a daily challenge to supply chain and logistics management. The ability to respond and mitigate these risk events puts a company ahead of its competitors and reduces the expected long term damage to its business. The key drivers for supply chain profitability are responsiveness, efficiency and reliability (Hendricks, K., and Singhal, V., 2005). To maintain their profitability supply chain must be able to quickly respond to external and internal risk events and keep their business efficient and dynamic. Furthermore supply chains have to be resilient to unexpected catastrophic events. Risk exists in supply chain because of the uncertainty about future risk events, which can appear at any point in supply chain. Supply chain performance can be negatively affected because of the occurrence of risk events in different stages of supply chain system. The management of such events is known as supply chain risk management (SCRM), which has become a critical part of the organization strategy.

Supply chain risk management (SCRM) has gained more attention with the movement to global supply chain and the increasing occurrence of internal and external events that cause disruptions of supply chain operation. It is an important part of supply chain management due to the fact that risks can cause unanticipated changes in material flow in the supply chain. Supply chain risk management is a systematic approach for identifying, assessing, mitigating and monitoring potential disruptions in supply chain in order to reduce the negative impact of these disruptions in the supply chain operations. The conceptual framework of managing supply chain risk and uncertainty is depicted in Figure 5. An essential step for risk management is the understanding of the different categories of risks and the event and conditions that drive these risks. The goal of SCRM is to prepare the company to be able to respond to different types of risks in such a way that minimize the impact on its operations. The art of risk management is to identify risks specific to an organization and to respond to them in an appropriate way (Merna, T., & Al-Thani, F. F. , 2005).

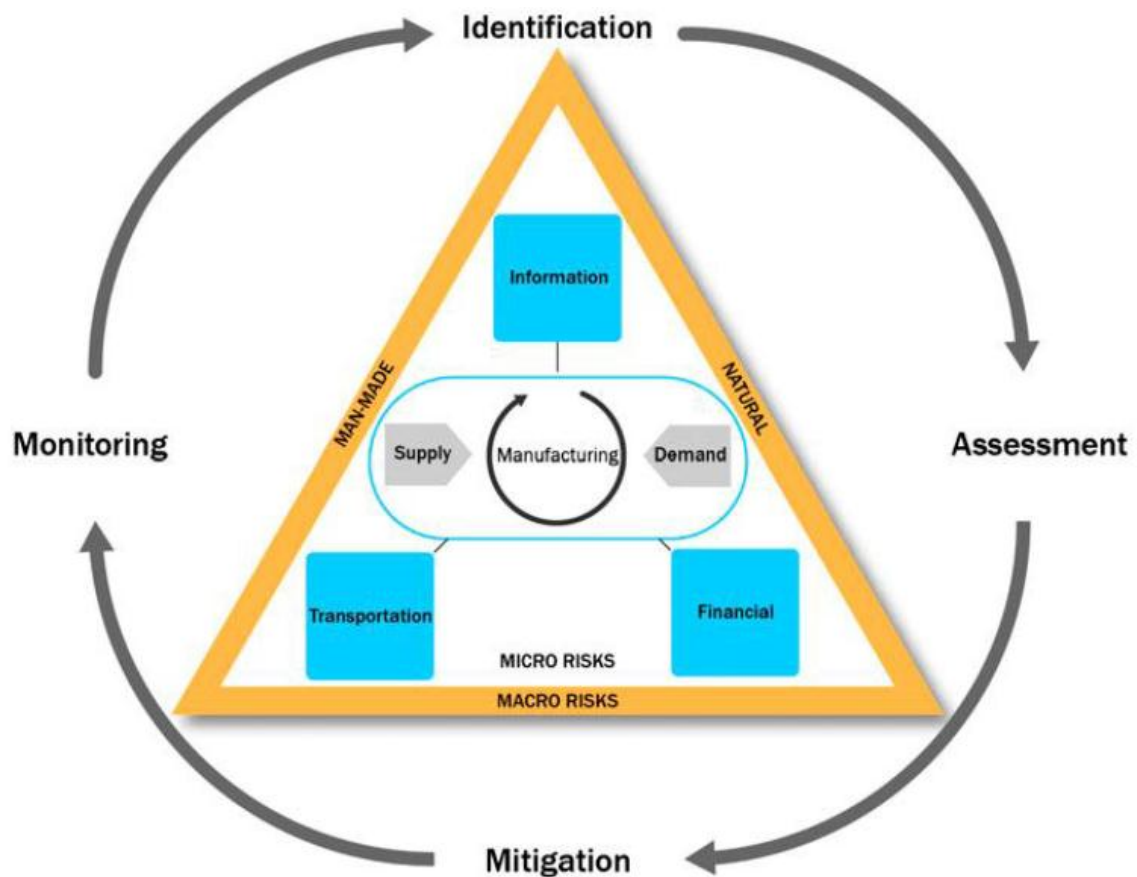


Figure 5: Conceptual framework of supply chain risk management (William Ho, 2015)

For risk management to be effective all level of the organization need to be considered. According to (Chopra, S., Sodhi, M.S.,, 2004), there is no silver – bullet strategy to protect organizational supply chain against risks; managers need to choose the proper mitigation strategy for each risk. In his paper (Wu, T., & Blackhurst, J., 2009), most of the definitions of SCRM include the following: (1) risk identification and modeling, (2) Risk analysis, assessment and impact measuring, (3) Risk management (4) risk monitoring and evaluation, (5) organizational and personal learning including knowledge transfer. As indicated in (Zsidisin G. a., 2009), risk mitigation strategies are divided in to: (1) eliminate the risk (2) reduce the frequency and consequences of the risk (3) transfer the risk by means of insurance and sharing and (4) accept the risk. Managers typically chose the proper mitigation strategies based on several factors, such as the nature of the risk, origin of the risk, and company resources. While certain supply chain risks can be prevented, other risks can be mitigated so that supply chain operations can be restored quickly after disruption. Some of the more common strategies for mitigating supply chain risks include managing vulnerabilities through Agility (Lee, H., 2004), flexibility (Tang, C., 2008) and resilience (Sheffi, 2005). Similar to other management approach SCRM requires good quality of knowledge, abilities experiences

and skills. It ensures that the principles established by managers are applied to logistics risk (Waters, 2007). Some of the management policies that can be used to protect supply chain risks include (Liu, 2009). (1) Inventory holding, (2) capacity, (3) flexibility, and (4) insurance. Inventory is however the easiest way to manage supply chain risks. However inventory can be expensive, highly customized or perishable. Nevertheless inventory can always be used as a protector against supply chain risks. Capacity can be in the form of excess capacity within the firm or outside the firm. In some cases excess capacity can be expensive. Flexibility provides virtual capacity and represents one of the effective means to mitigate supply chain risks; this includes product flexibility, process flexibility as well as price flexibility. Risks that are internal to the organizations are mostly controllable (example; quality risks capacity and flexibility risks) or at least partially controllable (example; occupational risks). (Kouvelis, P., Chambers, C., Wang, H.,, 2006), view SCRM in terms of managing the uncertainty of demand, supply and costs. (Carter, C.R., Rogers, D.S.,, 2008), define SCRM as “the ability of a firm to understand and manage its economic, environmental, and social risks in the supply chain” which could be materialized by the adoption of contingency planning and having a resilient and agile supply chains. There are also other notations related to risk management in supply chains. Supply chain risk management can be defined as the management of risks through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity (Tang, 2006). (Rice, 2003), define supply chain resilience as the ability of an organization “to react to an unexpected disruption and maintain operations after the event”. Resilience can be achieved by employing high flexibility and adequate redundancy in the organization. A more content oriented definition of resilience as “the ability of a system to return to its original state or move to a new, more desirable state after being disturbed” is provided by (Christopher M. P., 2004). Contingency planning is interchangeably referred to as business continuity planning, which is an approach to prepare for the possibility of future emergency or disruption. This approach involves continuous supplier assessment, development and maintenance of alternative capacities, mirrored and backup information systems and specific emergency response plans (Rice, 2003). Risks covered all the activities of the organizations so management of any business focuses on coping these risks at all levels. Companies have been aware of the need for risk management and contingency planning for some considerable time and there exist a wide body of literature from such diverse fields as economics, finance, strategic management, and international management. Due to increasing market competition that require higher customer satisfaction and lower cost, most supply chains became more

complex and consequently more vulnerable to disruptions than they were before. Supply chain disruptions can have effect either inside or outside a supply chain. Moreover, external factors such as natural hazard, global outsourcing, and shorter product life cycle have heightened the exposure of supply chains to risks. (Kouvelis, P., Chambers, C., Wang, H.,, 2006), view Supply chain risk management in terms of managing the uncertainty of costs, demand and supply. (Carter, C.R., Rogers, D.S.,, 2008), define SCRM as “the ability of a firm to understand and manage its economic, environmental, and social risks in the supply chain” which could be achieved by the adoption of contingency planning and having a resilient and agile supply chains. The essence of SCRM is to make decisions that optimally align organizational processes and decisions to exploit opportunities while simultaneously minimizing risk. (Wagner, 2008), point out, the financial default of a supplier and an earthquake that destroys production capacity are situations with completely different attributes and therefore has different effects on the supply chain. As supply chains become longer and parts of larger networks of demand and supply nodes and interacting logistics nodes and modes, they become more liable to the negative attributes of systems, complexity, flexibility, sensitivity, reliability and vulnerability.

Therefore, supply chain risk management needs to look at understanding and reducing vulnerability to the supply chain as a whole, rather than at a focal firm level.

Managing risk in supply chains have great importance due to increase in strategic outsourcing by firms, globalizations of markets, increasing reliance on suppliers for specialized capabilities and innovation, reliance on supply chain networks for competitive advantage, and emergence of information technologies that make it possible to control and coordinate extended supply chains. A detailed description of the supply chain risk management process together with the various risk categories in the supply chain process is depicted in Figure 6 shown below.

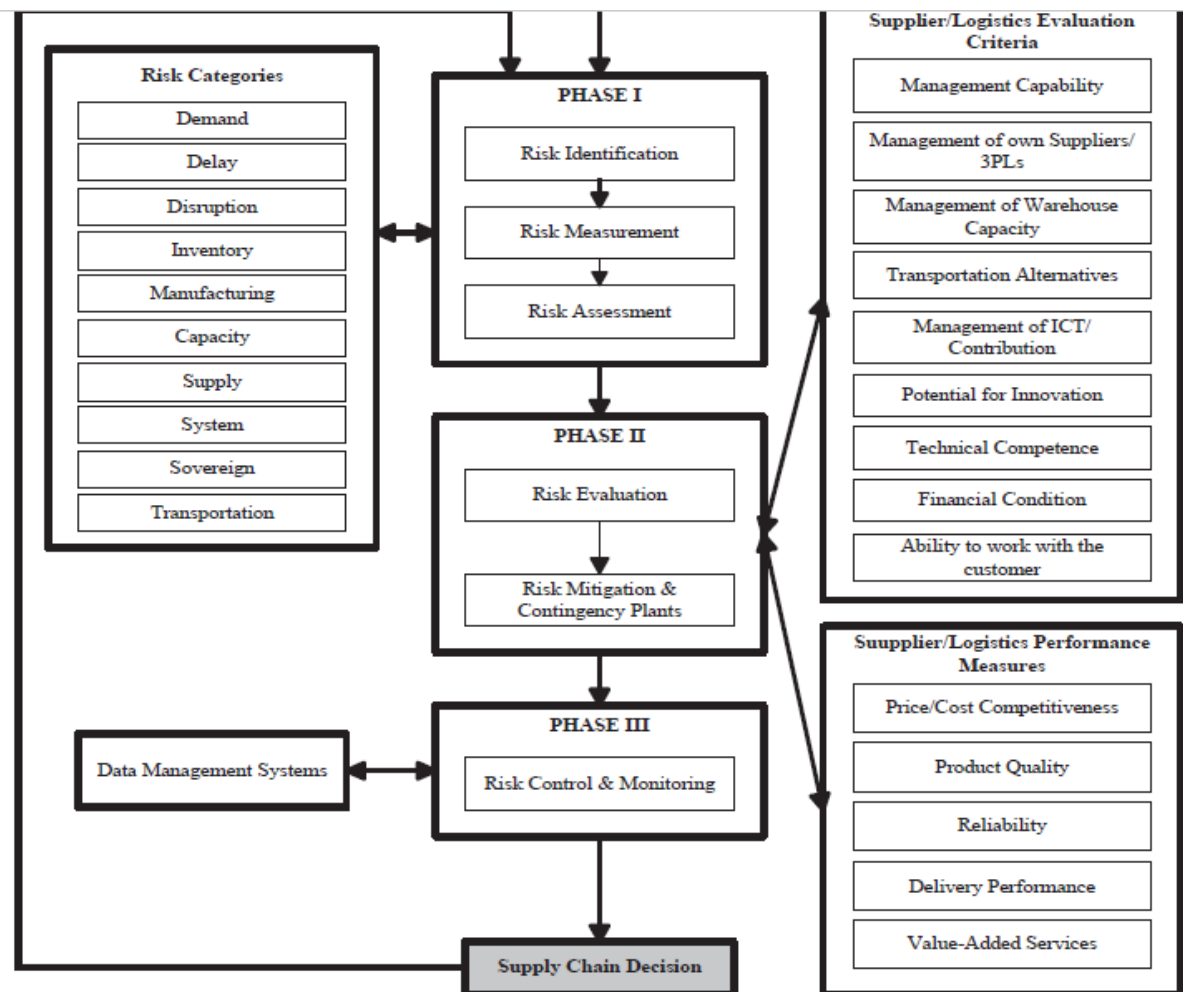


Figure 6: Supply chain risk management process (Tummala, R., Schoenherr, T., 2011)

2.7. Supply Chain Risk Response Strategy

Though, supply chain management (SCM) has matured much as a discipline, risk management in an overall context of supply chain is still in its nascent stage. In this part variables that can impact risk management in supply chain are selected based on literature review. According to (Hahn, 2000), effective communication and coordination among all elements of the supply chain are essential to its success. Increasing the visibility of demand information among the supply chain reduces the risks (Chopra, S., Sodhi, M.S., 2004). (Henriott, 1999), stated information sharing is a prerequisite for trust and current models for supply chain management. He agrees that the sharing of business information is a crucial element which binds supply chain together from end to end. As articulated in (Christopher, M. and Towill, D., 2001), Supply chain agility is the other basic supply chain mitigation enabler, which is defined as the ability to thrive in a continuously changing, unpredictable

business environment. It is a business wide capability that embraces organizational structure, information system, logistics process. Companies can reduce inventory risks by working with a highly responsive supplier (Chopra, S., Sodhi, M.S.,, 2004). Supply chain agility is a key to inventory reduction, adapting to market variations more efficiently, enabling enterprises to respond to customers demand more quickly and integrating with supplier more effectively. Lack of trust among supply chain partners is one of the major factors that contribute to supply chain risks (Sinha, 2004). Trust is an expectation that partners will not act in an opportunistic manner even if there are short term incentives to do so and it is important parameters in contributing to the long term stability of an organization and its supply chain. In order to manage risk effectively organizations also need to have collaborative relationship among supply chain partners. Also collaboration among organizations on the management of various supply chain activities can lead to competitive advantage over other supply chain. According to (Sahay, 2002), collaborative relationship requires trust and commitment for long term corporation along with a willingness to share risk. The other basic risk mitigation enabler in the supply chain process is information security, as defined by (Finch, 2004), data and information security risks are largely under the control of the organization. The goal of this enabler is to reduce the firm's risk of losses caused by intrusion, system misuse, privilege abuse, tampering, fraud, etc. Another part of risk mitigation enabler in the supply chain process is corporate social responsibility. Along with the advantages of borderless organizations, firms must also be prepared to manage the parallel risks that reflect the consequences of the partner's policies and actions on ethical and environmental issues (Spekman R. D., 2004). The other important risk mitigation enabler in the supply chain is strategic risk planning. As articulated by (Gunasekaran, 2004), at strategic level supply chain risk management is relatively new and rapidly expanding discipline that is transforming the way that manufacturing and non-manufacturing operations meet the needs of their customers. Risk sharing in supply chain is also the other part of supply chain risk mitigation enabler. According to (Mentzer J. T., 2001), a key component for supply chain is sharing both risks and rewards between the members of the supply chain.

2.8.Methods Applied to Supply Chain Network Design under Risk and Uncertainty

Supply chain risk modeling is an important aspect that needs more investigation due to the fact that having quantitative measures for the risks enable companies to assess and prioritize the risks and develop proper mitigation plans. Analytical models have different advantages such as presenting the problem concisely, providing a series of closed-form solutions,

allowing an easy assessment of the impact caused by changes in inputs on output measures, and offering the possibility of reaching an optimal (or at least sub-optimal) solution. Their main shortcomings relate to the assumptions made to describe a system which may not be very realistic (e.g., oversimplified) and/or the mathematical formulas which can be very complicated and interfere with finding a solution (Campuzano, F., & Mula, J., 2011).

2.8.1. Mathematical Models

The benefits of modeling supply chain network under risk and uncertainty can be: lead time reduction, inventory cost reduction, optimized transportation cost, increased order fill rate, early prediction of disturbance to downstream and increase customer service (Gunasekaran, 2004). Modeling approaches of supply chain risks can be divided in to 1) qualitative models 2) quantitative models 3) hybrid models that incorporate both qualitative and quantitative techniques. Qualitative methods play an important role in terms of defining concepts, identifying factors and developing frameworks followed by quantitative work focused on assessment and evaluation tools. Most of the qualitative methods are applied for risk identification (Chopra, S., Sodhi, M.S., 2004) and risk management philosophy (Christopher M. L., 2004). Thus it is obvious that qualitative methods are mainly used to categorize or identify risk and construct SCRM ideas. Simulation and Optimization models for analyzing supply chain disruptions and selecting the optimal mitigation strategies were discussed in several studies. Simulation and optimization models can be combined to quantitatively analyze supply chain risks. In this case, a stochastic single objective optimization model can be used to consider the stochastic characteristics of the supply chain uncertainties. The supply chain network design has attracted the attention of researchers for years. The main aspect of this problem is related to classical location- allocation problem, in which a set of manufacturing plants and warehouses should be installed and then allocated to customer with minimum cost combined with transportation problem.

Many researchers have considered this problem in deterministic environment, so that all parameter related to the problem are known. (Thanh, 2010.), addressed the problem of designing and planning a multi period, multi-echelon, multi- commodity supply chain where by each plant has a bill of material and all parameters are deterministic. Each plant and warehouses has limited capacity and lower and upper bounds on the utilization level. The comprehensive model they developed captures many modeling issues including: opening, closing or expansion of facilities, selecting suppliers, and planning the distribution flow as well. (Badri, 2013), developed a new mathematical model for multi-echelon multi-

commodity dynamic supply chain network design considering expansion of the supply chain according to cumulative net profit and funds supplied by external sources, in contrast to the common approach, in which expansion is restricted to predetermined fixed number of facilities. Other aspect include: bounds on utilization rate for facilities, public warehouses and potential private warehouse. (Correia, 2013), presented two new models for two echelon dynamic system. The main features are: location of new facilities, installation of warehouses, and distribution of products. While the first model is cost minimization model and the second is a profit maximization model.

In other stream of supply chain network design papers, researchers have tried to make decision making process more realistic through the incorporation of risk and uncertainty in their model. For example (Santoso, 2005), addressed a single period, single commodity network design problem in which a two stage model determines which facility should be opened, in addition to the technology of each facility. Also (Tiwari, 2010), Proposed novel model for supply chain network design with the objective of cost minimization satisfying uncertain demands at a specific service level. Other features include the availability of transportation service for manufacturers, warehouse and distribution centers and non-linearity of transportation and inventory holding cost. In addition (Pan, 2010), considered the supply chain network design (SCND) with features of considering new markets while demand is uncertain in agile manufacturing setting. The main decisions are facility selection, production and distribution. A robust scenario approach was used to handle the uncertainty of demand with the objective consisting of mean total cost, cost dispersion, and mean penalty for unmet demand. (Georgiadis, 2011), Proposed new mathematical model for SCND with multiple product flowing in the network in multiple time period under uncertain demand.

It is important to credit the previous publications that have developed various conceptual or analytical model to investigate different kinds of risk within the supply chain process. In particular (Wang, 2007), developed agent based models to simulate the dynamic behavior of the supply chain under various uncertainties such as supply capacity, plant capacity, warehouse capacity and demand uncertainty. (Goetschalckx, 2013), considered SCND problem with uncertainties in demand, capacities of supplier, manufactures, warehouse and fixed location costs. (Tabrizi, 2013), considered an SCND problem in multi- commodity, multi stage, multi- capacity and multi sources mode with sources of uncertainty in supply demand and processing side, and they modeled it using fuzzy models. (Sarkar, A., and Mohapatra, P.K., 2009), developed an optimization model to determine the optimal supply

base (number of suppliers) and the risk of supply disruptions. As articulated in (Goh, 2007), stochastic model for managing risks in global supply chains were developed. Their model considered supply, demand, exchange and disruption risks. A multi-stage supply chain network problem was formulated for supply chain operating under risks with the objective of maximizing profit and minimizing risks. For example (Viduto, 2012), Proposed a novel risk assessment and optimization model to solve a security countermeasure selection problem and a multi-objective tabu search algorithm was used to solve the model. Other methods for modeling supply chain risks include fuzzy logic (Aqlan, F. a., 2015) and Bow-tie analysis (Aqlan F. a., 2014). Supply chain risk modeling provides quantitative measures for the risks which enables companies to assess and prioritize the risks and to provide proper mitigation plans. Several studies in the literature discussed the use of analytical models for supply chain risks.

A multi objective optimization binary particle swarm algorithm for minimizing total cost and maximizing supplier delivery reliability was developed by (Venkatesan, 2012) and selected scenarios from optimization were modeled using simulation to evaluate the robustness of sourcing strategy under price and demand risks. (Claypool, 2014), conducted an integration optimization and simulation models for modeling risks in a supply chain design problem.

Stochastic optimization approach has been used extensively in SCND problems under risk and uncertainty. One can find several studies utilizing stochastic in both open loop and closed loop SCND problem. Stochastic programming may model one sources of uncertainty (Schutz, 2009), two sources (Amin, 2013), or three or more sources (Santoso, 2005). The model can be single objective stochastic programming or bi- multi objective programming. (Salema, 2007), have proposed a general MILP model for the design of a general capacitated multi product reverse logistic network under uncertainty, which integrates forward and backward flows. As indicated in his paper (Pishvae, M. S., 2011), a robust optimization model was developed for the design of closed loop supply chain (CLSC) network under uncertain demand, quantity of returns and transportation costs. First a deterministic mixed integer linear programming (MILP) with respect to a set of assumption and constraints were developed. The model is designed to enable handling both open and closed loop network structures. The model locates different facilities like collection, inspection, and recovery and distribution centers and determines the flow between them with objectives of minimization of total fixed and variable costs. Fuzzy models have been used for several sources of uncertainty. Also it is found to be applicable in both open and closed loop supply chain

networks. A bi objective possibility MILP is proposed to model a closed loop supply chain network that integrates both forward and reverse supply chain, integrates strategic and tactical planning decisions, considering a multiple period with single product flow (Pishvaei, 2010). Most optimization models are based on mathematical programs, in which all unknowns are represented by decision variables, the relations linking these variables are expressed by equations called constraints, and an objective function is maximized or minimized. A number of articles formulated mathematical programming models for the optimal supply chain network design problem, which consists of location, production, transportation, cost and/or profit and inventory uncertainties. The models identified and mitigated various risk types such as demand risk (Goh, 2007) , manufacturing risk (Qiang, 2012), supply risk (Mak, 2012) and financial risk (Goh, 2007). A wide range of mathematical programming models have been identified , including multistage stochastic programming model (Goh, 2007), multi-objective stochastic model (Azaron, 2008), two stage stochastic integer programming model (Poojari, 2008), integer nonlinear programming model (Park, 2010) , mixed integer linear programming model (Georgiadis, 2011), stochastic linear programming model (Mak, 2012), linear programming model (Qiang, 2012), convex mixed integer programming model (Azad, 2013), stochastic mixed integer nonlinear programming model (Baghalian, 2013) and mixed integer nonlinear programming model (Kumar, 2013). A common limitation is that most of the above articles did not apply their proposed models in real case but simply used simulated data to prove their effectiveness and efficiency except (Baghalian, 2013) who studied a real case in the rice industry of a country in the Middle East. The paper by (Chen W.-S. &.F., 2007), considers multi product, multi period and multi echelon supply chain network problems considering multi objectives. In his paper LP model was proposed to satisfy several connecting objectives like minimizing the total cost, maximizing the robustness to various scenarios, maximizing the local incentives and minimizing the total transport time with the consideration of capacity and transportation uncertainty.

2.9.Summary of Literature Review and Gaps Identified

By using the key words like risk and uncertainty in supply chain and optimization models, different data bases have been searched. About 63 articles contributing to the area of supply chain network design under risk and uncertainties on different journal names have been reviewed and among these three of them are thesis and PhD dissertation works in other universities.

Generally the author reviews different journals on different perspectives/approaches on the supply chain network optimization problem. Figure 7 shown below, illustrates the distribution of number of journal articles reviewed between 2000 and 2015 contributing to the area of supply chain network modeling under risk and uncertainty applying quantitative methods. Once the literature is summarized, some specific issues(like: the methodology applied, types of risk and uncertainty considered in the study, findings and/or contributions) important to the thesis were critically examined and the result of the review is shown in Table 1.

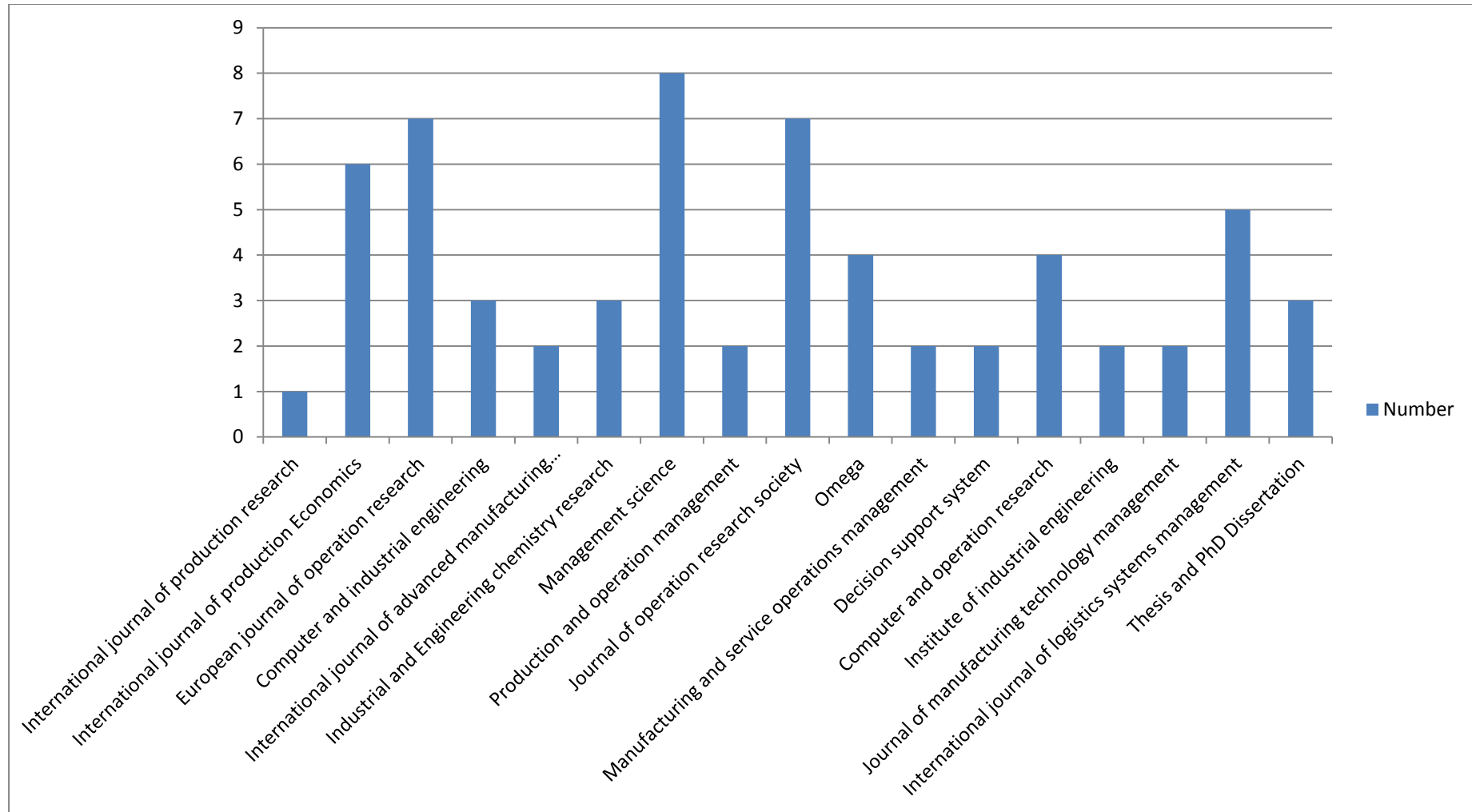


Figure 7: Summary of reviewed papers

Table 1: Literature summary, issues critically examined in the literature

No.	Author	Methodology	Risk and Uncertainties considered	Findings/ contributions
1	(Chen W.-S. & F., 2007)	MILP Model	Capacity and transportation	Minimizing total cost, Minimizing total transportation time
2	(Goh, 2007)	Multi stage stochastic programming	Demand risk, supply risk, exchange rate and disruption	Location allocation decision, Minimization of transportation time
3	(Qiang, 2012)	Linear programming model, LP	Manufacturing risk	Profit maximization
4	(Meyr., 2009.)		Demand and exchange rates	Designing the supply chain network
5	(Wang, 2007)	Agent based Modeling	Supply capacity, plant capacity, warehouse capacity, demand uncertainty	For modeling risk and uncertainty in the supply chain
6	(Santoso, 2005)	Sample average approximation(SAA), stochastic approach	Under the condition of supply and demand uncertainty.	SCND
7	(Verdegay, 2009)	Fuzzy optimization model	Supply, demand and process uncertainty	Planning for supply chain
8	(Aqlan F. a., 2014)	Fuzzy bow- tie analysis	Various risk in the supply chain	Risk assessment in chemical industry
9	(Amin, 2013)	Multi- objective fuzzy	Under demand and return uncertainty	location model for CLSCN
10	(Baghalian, 2013)	Stochastic mathematical formulation, MINLP	Disruptions and demand uncertainty	Robust SCND
11	(Georgiadis, 2011)	Mixed Integer Linear Programming model	Demand uncertainty and variations	Optimal design of supply chain network

12	(Claypool, 2014)	Mixed Integer Linear Programming(MILP)	Time to market risk, supplier reliability risk and strategic exposure risk	Modeling risk for SCND
13	(Nima H., 2014)	Two stage mixed integer stochastic programming	Assembly line balancing and demand uncertainty	Supply chain network optimization
14	(Aqlan F. , 2015)	Simulation optimization approach- MILP with Cplex and Arena Simulation	Cycle time to build order, back ordering cost and demand uncertainties	Supply chain network optimizations
15	(Pishvae, M. S., 2011)	Mathematical modeling with MILP	Uncertainties of input data to Supply Chain	Robust optimization approach for closed loop supply chain network design(CLSCND)
16	(Wagner, 2008)	-----	Under several dimension of risk	Empirical examination of supply chain performance
17	(Salem, 2015)	Simulation – optimization approach, Monte Carlo simulation and Particle Swarm Optimization(PSO)	Demand and supply uncertainty	Designing the supply chain network, location allocation decision support

The literature review part is outlined and structured in a way that can identify the gap.

This section summarizes the points raised in the literature and gives conclusion by stating the gaps observed on models contributed to supply chain network optimization under uncertainty and risk which can serve as a future study area.

- ✓ Risk and uncertainties are the other challenging issue in supply chain network optimization, still yet not touched thoroughly. Most researches try to use qualitative approach to understand and reduce the uncertainty parameters. Only a small fraction

of the papers on supply chain network design under risk and uncertainty are based on quantitative methods and the literature mainly falls under the categories of qualitative approaches, Other modeling techniques like mathematical programming have not been much used as a tool for modeling supply chain network optimization under risk and uncertainties (William Ho, 2015).

- ✓ The literature review shows that economic performance of a supply chain network optimization was the paramount concern of previous models with the purpose of maximizing overall profit or minimizing costs without considering uncertainties within the supply chain process. Few studies are now paving the road concerning the minimization of cost, maximization of total risk reduction and minimization of the total lead time for supply chain network optimization under uncertainty and risk, which need more study and integration of these optimization models.
- ✓ In the fields of supply chain network optimization under uncertainty and risk China, United States, India, United Kingdom, Canada, Hong Kong, France and South Korea are the leading contributors in the area of supply chain network optimization under risk and uncertainty (Behnam Fahimnia, 2015). However, the analysis of the real case studies in supply chain network optimization under uncertainty and risk from African countries including Ethiopia have not been studied much.

Therefore this research attempts to bridge the gap by developing an optimization model with the consideration of risk and uncertainty and again to validate the model by taking real data and finally to give appropriate conclusion and future research direction.

CHAPTER THREE

3. Research Design and Methodologies

3.1.Introduction

This chapter describes the methodology that was used in conducting the study. It includes the research design, research methodology, and data collection, operation of research variables and data analysis techniques.

3.2.Research Design

As articulated in (Blessing, L., & Chakrabarti, A., 2009) , research design supplements the research objectives achievement in an efficient way. This paper address applied research in its nature, in which an extensive literature has been reviewed on supply chain network optimization under risk and uncertainty and a sample survey questionnaire on textile industries found in Addis Ababa has been conducted to support the literature(to see existence of risk and uncertainty to the Ethiopian textile industries context). After all a conclusion from the survey has been reached and the researcher goes forward to develop an optimization model considering the results found from the survey. Once the supply chain network optimization model is formulated, primary data through interview from Yirgalem Addis textile factory have been conducted to illustrate the applicability and efficiency of the model. Before a case study is conducted, a hypothetical data are taken from 5-4-5-7 suppliers, plants, warehouses and wholesalers respectively to show the applicability of the model. Besides to this work a sensitivity analysis of the supply and demand uncertainty have been conducted to make generalization about the impacts of supply and demand uncertainty on the expected minimum cost. Finally conclusion, recommendation together with future research direction have been forwarded.

3.3. Research Framework

The research framework of the thesis is designed based on consideration of the concepts of different theories, optimization models and real-world situation in textile industries found in Addis Ababa. The costs of risk response and risk reduction/elimination strategies are two opposing factors. As the amount of risk reduction increases, the cost of response strategies will also decrease. The proposed framework focuses on optimizing the transportation cost under risk and uncertainty. The optimization model considers plant capacity, supplier capacity and warehouse capacity, unit transportation cost and risk within the supply chain network. The model insures that mitigating risk in one part of the supply chain will not increase the risk in another part, since risks can be correlated. The model provides quantitative uncertainty analysis that supports the decision on how to allocate the limited resources for these uncertainties and based on the cost obtained an optimal or cost effective supply chain network is designed specifically for the case study but the mathematical model is general and would be helpful to similar companies seeking to compete successfully for similar purpose. The research framework applied for this thesis is shown below in Figure 8.

3.4. Research Methodologies

To achieve the objectives of this research different approaches and methodologies have been used. The following methodologies are used to secure quantitative and qualitative and/or primary and secondary data. Generally the methodology used to carry out this research is three fold: the first one is systematic literature review, data collection using interview and structured questionnaire, modeling the supply and demand uncertainty using LP model and solving the model using GAMS build system which are explained clearly below.

3.4.1. Literature Review

To achieve the specific objectives, extensive literature review regarding supply chain, risk and uncertainty, supply chain risk and uncertainty as well as supply chain network design under risk and uncertainty and quantitative decision support for supply chain network modeling approach was conducted. Literature review provides a detailed theoretical background as to what critical issues are considered in the supply chain system and network design. By using the key words like risk and uncertainty in supply chain, optimization models and uncertainty in Supply chain together with different data bases have been searched. In the literature review, different articles/journals, Electronic books, conference proceedings, published researches, thesis and PhD dissertation and other materials on supply chain network design under uncertainties and risk on various sites such as science direct,

booksc.org, research gate, library resources from Addis Ababa university were thoroughly surveyed in order to assess the state of the art of supply chain network together with optimization models under risk and uncertainties.

3.4.2. Data Collection and Source of Data

Besides to the literature review, in order to have deep understanding on the risk and uncertainty existence to the context of Ethiopian textile industry found in Addis Ababa, both primary and secondary data (both qualitative and quantitative data) were collected through survey questionnaire. Primary data like the existing supply chain network, plant capacity, warehouse capacity, transportation cost per kg existing risk and uncertainty were collected from Yirgalem Addis textile factory through structured interview(face to face) to solve the existing problem of the company. Primary data will help in collecting real life cases dealing with managing risks and observations at the time of events, while secondary data will help in demonstrating the past actions and historical data about how firms deal with managing risks from scientific point of view. In addition primary data were selected due to its advantage is cost, time and amount of data to be collected. Generally the methods applied to get the Primary data are: questionnaire (both open ended and closed ended), Interviews/personal interview, written /formal/ materials residing from Yirgalem Addis textile factory for obtaining raw data for the sake of model validation as well as physical observation have been used.

3.4.3. Tools and Methods of Data Analysis and Presentation

Most of the stochastic supply chain network(SCN) optimization models are LP for the network optimization. While the early papers still investigate specialized solution algorithms to deal with supply chain network optimization problems, more recent research can focus on modeling aspects. This is due to the rapid improvements of general purpose LP solvers such as GAMS, which is simple and flexible tool for solving such kinds of model. The applied methodology was based on linear programming model. Linear programming (LP) has been used to optimize the supply chain network in the real cases with the objectives of minimizing transportation(shipment) cost so that a cost effective supply chain network can be forwarded. Thereafter a sensitivity analysis using GAMS build system have been done to see the impact of supply and demand uncertainty on the expected minimum cost. Different data presentation tools like Microsoft excel 2010 spreadsheet and other tools have been used to depict the various results and outputs. Finally The result obtained from the new approach is compared on the basis of shipment cost per year with the currently being used and a new supply chain

network with capacity allocation followed with conclusion and recommendations as well as future research direction have been drawn.

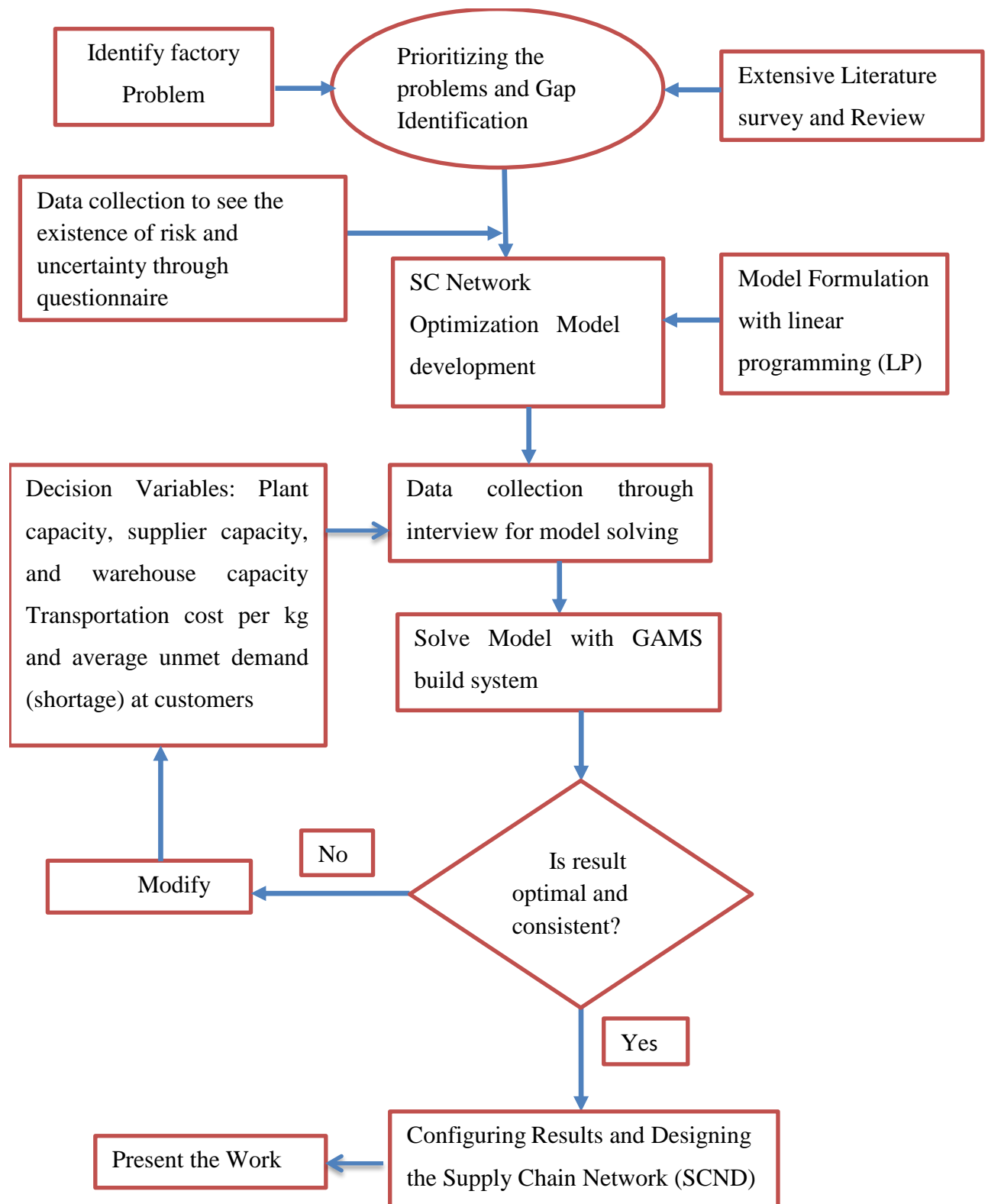


Figure 8: Conceptual research framework

CHAPTER FOUR

4. Data Presentation and Analysis

4.1. Introduction

In this chapter the author tries to present and analyze the survey result conducted from textile industries found in Addis Ababa. A survey questionnaire have been conducted and the result of the respondent on the various risk and uncertainty is shown in Table 2. This result is analyzed in a way the can be clearly understandable using excel 2010 shown in figure 11 and 12. Once the respondent rate have been shown with charts and tables the author reaches to the conclusion to take the risk and uncertainty with the high respondent rate. i.e. supply and demand uncertainty have been taken into the LP model so as to minimize the shipment cost or transportation cost together with the location allocation problem.

4.2. Data Presentation, Analysis and Summary

The Ethiopian government has recently set out a major objective to accelerate the industrialization of the country through its agricultural development led industrialization policy, and has highlighted the total textile and closing supply chain as one of its key target industries for growth of the national economy. It has identified that the development of this labor intensive industry as a key to reducing subsistence farming, which employs 85% of the country's population, as well as stabilizing it's agriculture, building an industrial base , producing foreign income from exports, increasing employment and reducing poverty (Hailu, Asseb, 2009). The textile supply chain involves the major stages of fiber and yarn production, fabrication, garmenting, distribution and retailing as shown in Figure 9.

The researcher has designed the survey questionnaire, based on the specific objectives of the research, for assessing the various risk and uncertainty in the selected textile industries for the purpose of supporting the literature and to make generalization of the problem in the textile industries found in Addis Ababa. The Survey questionnaire was distributed to production department, procurement department, and marketing and sales department of each company. Currently there are 9 textile industries (both private and governmental) in Addis Ababa. Among these, the researcher has assessed in five textile companies (KK textile PLC, G-7 Weaving factory, DH Geda blanket factory, Yirgalem Addis Textile Factory PLC and Ethiopian Sewing Thread Factory PLC), which are selected randomly, i.e. the selected textile industries(55.56%) are enough to represent the remaining textile industries.

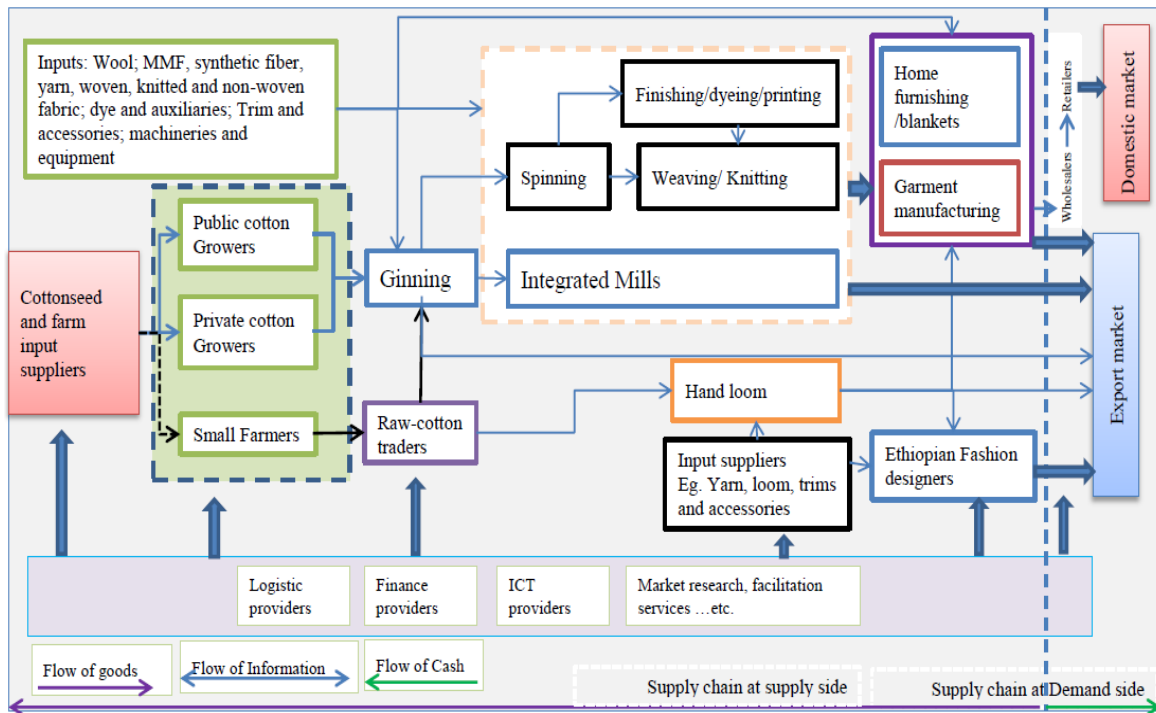
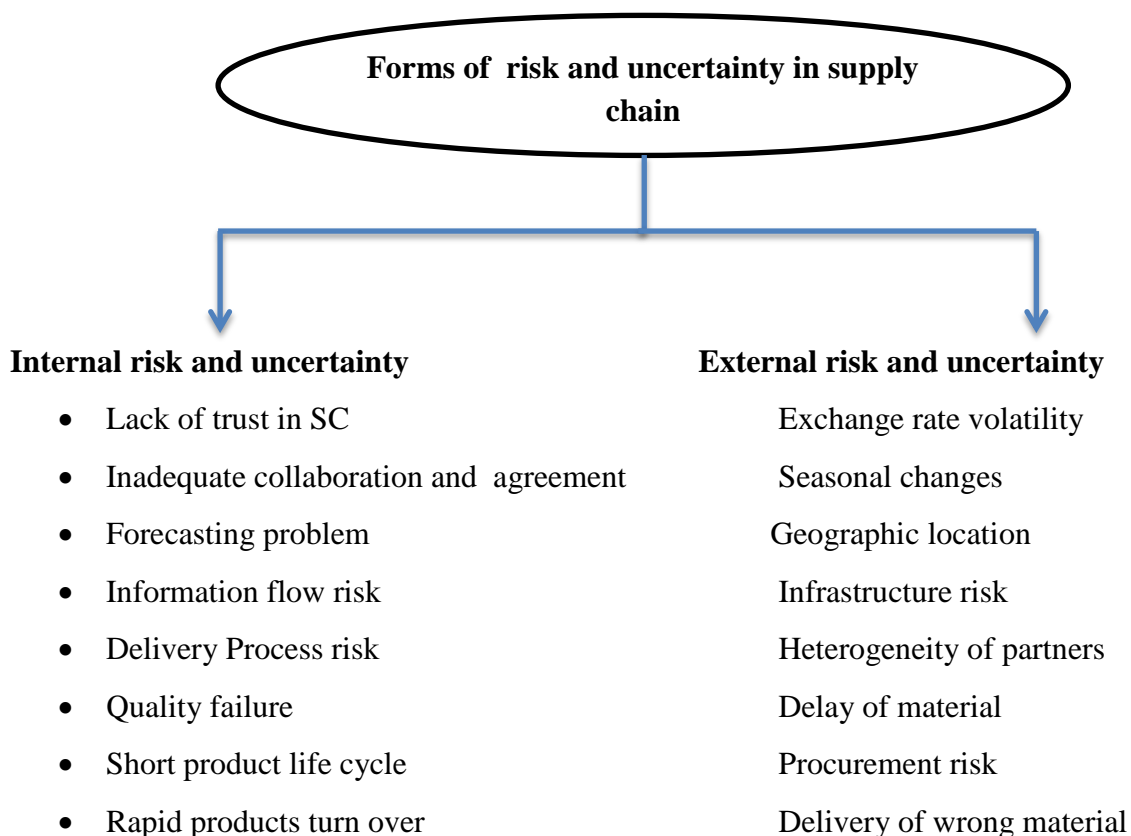


Figure 9: Supply chain structure in textile industries (G., Chaudhry H. and Hodge., 2012)

A summary of the various risk and uncertainty obtained from the factory through questionnaire is depicted in the following figure.



- Management commitment in supply chain Supplier problem
- Knowledge about risk in supply chain Supply shortage
- Wrong partner selection Scarcity of resources
- Excessive inventory
- Demand shortage Financial risk

Figure 10: Forms of supply chain risk and uncertainty

Five point likert scales was developed and the result of the respondent rate on the survey questionnaire is shown below. Once this survey have been conducted then the result of the respondent rate in the form of respondent percentage and respondent number is presented using Excel Microsoft 2010 as shown in Figure 11 and Figure 12 respectively.

Table 2: Respondent survey number for the different form of risk and uncertainty in the supply chain

Risk category	Respondent Result				
	1	2	3	4	5
Lack of trust in supply chain	7	5	0	0	0
Heterogeneity of partners	5	6	1	0	0
Inadequate collaboration and agreement	6	5	1	0	0
Forecasting problem	3	7	2	0	0
Information flow risk	2	7	3	0	0
Delay of material	2	8	2	0	0
Exchange rate volatility	5	6	1	0	0
Quality failure	3	8	1	0	0
Short product life cycle	6	6	0	0	0
Rapid products turnover	5	5	2	0	0
Seasonal changes	2	5	5	0	0
Procurement risk	4	5	3	0	0
Management commitment in supply chain	4	8	0	0	0
Knowledge about risk in supply chain	4	7	1	0	0
Wrong partner selection	5	7	0	0	0
Geographic location	9	3	0	0	0
Delivery of wrong material	2	9	1	0	0
Delivery process risk	2	9	1	0	0

Excessive inventory	5	3	4	0	0
Scarcity of resources	2	8	2	0	0
Supplier problem	1	6	5	0	0
Infrastructure risk	5	5	2	0	0
Demand shortage	1	8	2	1	
Supply shortage	1	7	2	2	0
Financial risk	6	3	2	1	0

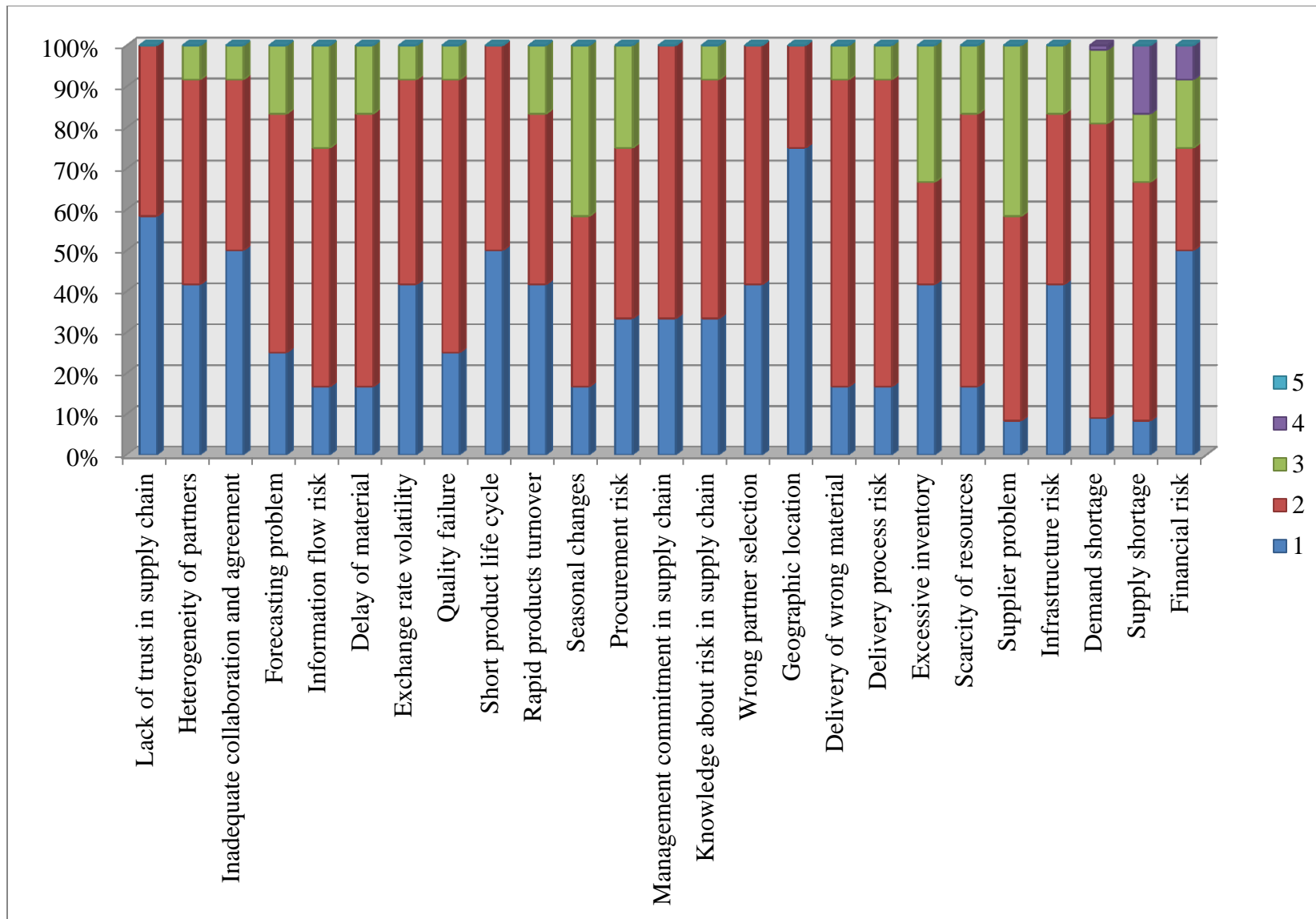


Figure 11: Percentage respondent rate for survey questionnaire

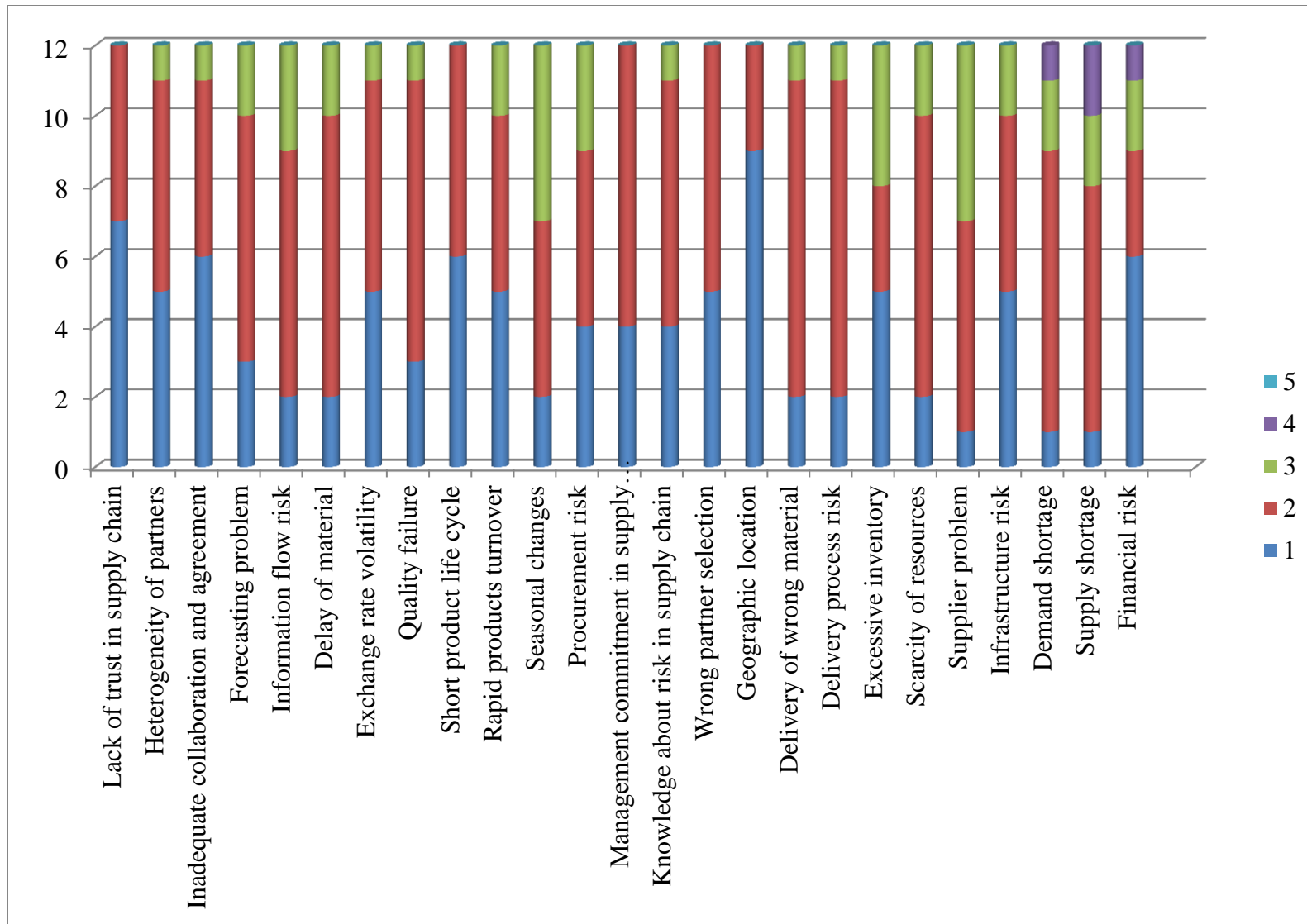


Figure 12: Number of respondent for survey questionnaire

The result of the survey shows that more respondent rate are given to : demand uncertainty, supply uncertainty, excessive inventory, exchange rate volatility, forecasting problem, information flow risk, quality problem, seasonal changes, management commitment, wrong material delivery, security and safety and scarcity of resources in their decreasing order in terms of respondent rate. More than 90% respondent rate is given to the existence of supplier problem, lack of coordination and collaboration, supply and demand uncertainty among 15 respondents. Next more than 80% respondent rate among the respondent(15 person three from each company) is given to information flow risk, process risk, delay of material, seasonal changes, delivery of wrong material, scarcity of resources and security and safety issue and the remaining risk and uncertainty have got less respondent rate.

Therefore this paper is aimed to develop optimization model considering the supply and demand uncertainty since these are prior than others. Both the demand and supply uncertainty are sources of factor for the cost maximization and therefore it is the goal of this paper to develop supply chain network with cost effective.

Therefore it is clear that from the result of the survey that, the reviewed literature can be mapped to the textile industries found in Addis Ababa in general and to the selected companies in particular. Therefore this paper provides an optimization approach, which considers supply uncertainty and demand uncertainty. The uncertainty of demand includes the plant demand, warehouse demand and wholesaler demand. Whereas the supply uncertainty includes capacity of supplier, capacity of plant and warehouse capacity. With this approach these uncertainties can be controlled or minimized though cannot be avoided. As supply and demand uncertainty can be related to cost, the optimization of cost and designing cost effective supply chain network can be related to the optimization of demand and supply uncertainty.

CHAPTER FIVE

5. Model Development, Model Fitting and Model Solving

5.1.Introduction

Analytical models have different advantages such as presenting the problem concisely, providing a series of closed-form solutions, allowing an easy assessment of the impact caused by changes in inputs on output measures, and offering the possibility of reaching an optimal (or at least sub-optimal) solution. Their main shortcomings relate to the assumptions made to describe a system which may not be very realistic (e.g., oversimplified) and/or the mathematical formulas which can be very complicated and interfere with finding a solution (Campuzano, F., & Mula, J., 2011).

This chapter tries to present a model formulation and solving the model with the real situations of Yirgalem Addis textile industries, found in Addis Ababa, for the purpose of optimizing and analyzing of the supply chain network under uncertainty and risk. A stochastic single objective and linear programming model was developed with the objectives of minimizing cost while considering risk and uncertainty. An important aspect of practical relevance that is considered in this thesis is that both the supply and demand are random and that is why we call them uncertain. The demand uncertainty can result from inaccurate forecasting or changes in customer preferences and the supply uncertainty can take the form of random supply yields or random supply capacities. finally a sensitivity analysis of the supply and demand uncertainty on the expected minimum cost will be presented.

5.2.Model Assumption

While doing this thesis, the formulated model considers the following assumptions.

1. Unmet demand are demands that cannot be fulfilled during the current planning period and the customer is willing to receive the demand in the next planning period. However a penalty cost is associated with these unmet demands.
2. The optimization model is assumed to be used in the forward supply chain network with the variables of production capacity, supplier's capacity, warehouse capacity, transportation cost per kg, and cost of unmet demand.
3. The concentration of this research is based internal sources of risk and uncertainty since the external sources of risk and uncertainty are out of control.

4. Four echelon supply chain (supplier, plant, warehouse, customer or wholesaler in this case) is considered.
5. Customer demand and plants supply are considered to be uncertain or stochastic. Other parameters like shipment cost per kg are deterministic and known in advance.
6. All products transported from plants to warehouse are shipped to wholesalers. i.e. the model does not consider the cost of inventory.

5.3. Model Input and Output

Focused on the assumptions made and reviewed literature on the theme of the thesis, the researcher proposed linear programming model, which is, for cost optimization purpose within the supply chain network so as to capture the supply chain network design problem. The research considers a stochastic single objective optimization model for a single product while considering supply and demand as uncertainty. The main input and output of the model have been clearly stated below, together with the objective function.

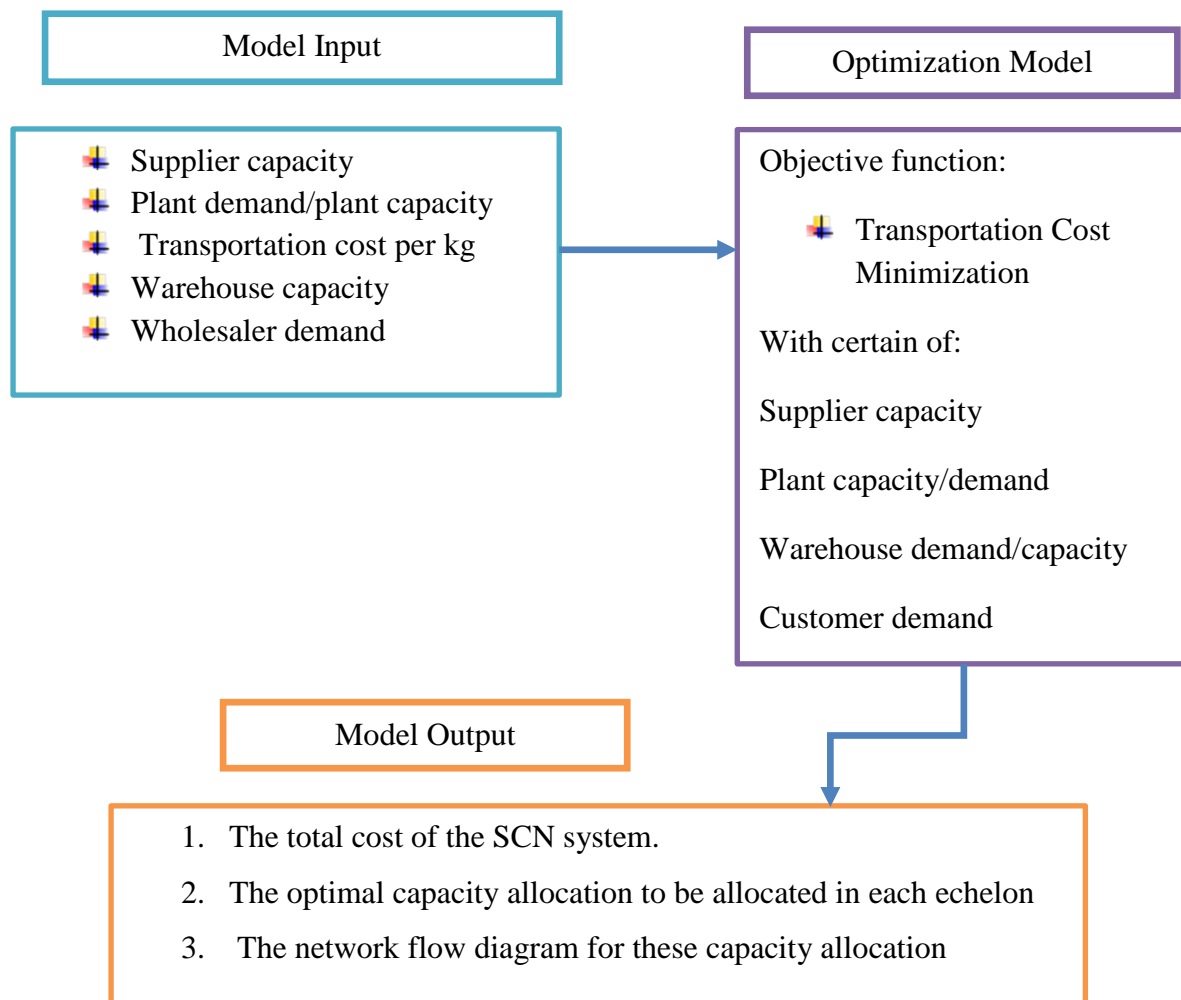


Figure 13: Model input/ output

5.4. Model Input Parameters and Variables

The following variables and parameters as well as indexes were used in the model formulation.

Definition of terms used in the Model

X_{si} = amount sent from supplier 's' to plant 'i', $i = 1 \dots P$, $s = 1 \dots \gamma$

X_{ij} = amount sent from plant 'i' to warehouse 'j', $j = 1 \dots W$, $i = 1 \dots P$

X_{jk} = amount sent from warehouse 'j' to wholesaler 'k', $k = 1 \dots C$, $j = 1 \dots W$

T_{si} = transportation cost per kg from supplier 's' to plant 'i', $i = 1 \dots P$

T_{ij} = transportation cost per kg from plant 'i' to warehouse 'j', $j = 1 \dots W$

T_{jk} = transportation cost per kg from warehouse 'j' to wholesaler 'k', $k = 1 \dots C$

D_i = demand at plant 'i', $i = 1 \dots P$

D_j = demand at warehouse 'j', $j = 1 \dots W$

D_k = demand at wholesaler 'k', $k = 1 \dots C$

C_s = capacity of supplier 's', $s = 1 \dots \gamma$

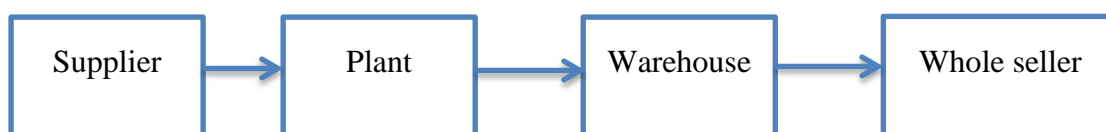
C_i = capacity of plant 'i', $i = 1 \dots P$

T_k = cost of unmet demand (opportunity cost) at plant 'i', warehouse 'j' and wholesaler 'k'

5.5. Model Formulation

The supply chain addressed in this study consists of four echelons: suppliers, manufacturer or plant, warehouse and wholesaler. In this study customer demand, supplier capacity, plant demand, and its capacity warehouse demand and its capacity are considered to be stochastic.

The supply chain structure considered in this study is shown below.




Forward supply chain: 

Figure 14: The supply chain structure considered in the study

Thus a firm must evaluate the impact on customer service and cost as it compares different distribution network. Customer services that are influenced by the supply chain problem include response time, product variety and availability, customer experience, order visibility and return-ability.

Linear programming model considering the supply and demand uncertainties as well as the penalty cost of unmet demand, which is a risk for a firm, have been organized into the cost minimization model and is applied to optimize the network.

Generic LP Model: Minimization of Transportation Cost/ Cost of Shipment

Min z

$$\sum_{s=1}^{\gamma} \sum_{i=1}^p T_{si} X_{si} + \sum_{i=1}^p \sum_{j=1}^W T_{ij} X_{ij} + \sum_{j=1}^W \sum_{k=1}^C T_{jk} X_{jk} + Tk \sum (D - C) + (E - D) + (F - E) \quad (1)$$

Subjected To:

$$\sum_{s=1}^{\gamma} X_{si} \geq D_i \quad (2)$$

$$\sum_{i=1}^p X_{ij} \geq D_j \quad (3)$$

$$\sum_{j=1}^W X_{jk} \geq D_k \quad (4)$$

$$\sum_{s=1}^{\gamma} X_{si} \leq C_s \quad (5)$$

$$\sum_{i=1}^p X_{ij} \leq C_i \quad (6)$$

$$\sum_{j=1}^W X_{jk} \leq D_j \quad (7)$$

$$X_{si}, \quad X_{ij}, \quad X_{jk}, \quad (D - C), \quad (E - D), \quad (F - E) \geq 0 \quad (8)$$

Where equation (1) represents the objective function minimizing the transportation cost. The objective function 'z' minimizes cost of single product. The total cost for transporting part from supplier to plant is represented in the first term. The second term consists of the transportation cost of the product from plant to warehouse, finished product transportation cost warehouse. The third term is about the transportation cost of finished product from warehouse to wholesaler. The last term is penalty cost of shortage in demand from plant 'i' to supplier 's' (D-C), warehouse 'j' to plant 'i'(E-D) and wholesaler 'k' to warehouse 'j'(F-E) whichever is a risk for a firm.

Equation (2) is demand constraint which says amount transported from supplier 's' to plant 'i' should be greater or equal to plant demand 'D_i'. Equation(3) is the demand constraint which says that amount transported from plant 'i' to warehouse 'j' should be greater or equal to warehouse demand 'D_j'. Equation (4) is amount transported from warehouse 'j' to wholesaler 'k' should be greater or equal to demand of wholesaler 'D_k'

Equation (5) represents amount transported from supplier 's' to plant 'i' should be less than or equal to supplier capacity 'C_s'. Equation(6) says amount transported from plant 'i' to warehouse 'j' should be less than or equal to plant capacity 'C_i'. Equation(7) is about supply constraint at wholesaler which states that amount transported from warehouse 'j' to wholesaler 'k' should be less than or equal to warehouse capacity 'D_j'. Equation 8 is sign restriction for the variables.

5.6. Running the Model

The LP model is formulated and solved using GAMS build system and the piece of the GAMS code is shown below. GAMS stands for General Algebraic Mathematical Modeling which is specifically designed for modeling linear and mixed integer optimization problems. The GAMS build system has different solvers such as BARON, BDLMP, BENCH, CNOPT, CPLEX, LGO and etc. that are capable of solving different varieties of problem like LP, NLP, MIP, MINLP and others. For this thesis CPLEX solver is chosen to solve the LP model.

GAMS Modeling Code

Positive variables (x1.....x16)

Free Variables : z, the objective function

Equations (Con1, Con2, Con3,Con18, obj;)

Assigning Constraints (Con1.., Con2.. continue up to the end of equations)

Model: cost minimization (Con1, Con2, Con3,.....Con18)

Options : LP = CPLEX

Solve cost minimization using LP minimizing z

Display : x1.L, x2.L, x3.L,x16.L; end

The GAMS code was running within 0.16sec compilation time, windows7 home premium 1TB and core i7 dell personal computer. The resulting solution of the LP model was the amount of shipped material or product in kg. After obtaining the result, total transportation cost of single product is compared to the existing cost and thereafter a cost effective supply chain network was designed for the sector in particular and the generic LP model can be adopted by other sectors characterized by four echelon supply chain.

5.7.Hypothetical Value to Test the Model

To check the consistency of the model, a hypothetical data from suppliers, plant, warehouse and wholesalers with the corresponding numbers of 5-4-5-7 respectively have been taken. These hypothetical data are fitted into the generic stochastic LP model as shown below. Assuming that all suppliers are enough to satisfy plants requirement and all plants are aimed to produce a single product(all plants have the same goal and are owned by the same name), the hypothetical configuration for 5-4-5-7 suppliers, plant, warehouse and wholesaler respectively is depicted in Figure 15.

Table 3: Representation of variables in the model for the hypothetical model testing

Variables	Description
y1	Amount transported from supplier '1' to plant '6'
y2	Amount transported from supplier '1' to plant '7'
y3	Amount transported from supplier '2' to plant '6'
y4	Amount transported from supplier '2' to plant '7'
y5	Amount transported from supplier '2' to plant '8'

y6	Amount transported from supplier '3' to plant '6'
y7	Amount transported from supplier '3' to plant '9'
y8	Amount transported from supplier '4' to plant '7'
y9	Amount transported from supplier '4' to plant '9'
y10	Amount transported from supplier '5' to plant '8'
y11	Amount transported from supplier '5' to plant '9'
y12	Amount transported from plant '6' to warehouse '10'
y13	Amount transported from plant '6' to warehouse '11'
y14	Amount transported from plant '7' to warehouse '10'
y15	Amount transported from plant '7' to warehouse '11'
y16	Amount transported from plant '7' to warehouse '14'
y17	Amount transported from plant '7' to warehouse '12'
y18	Amount transported from plant '8' to warehouse '10'
y19	Amount transported from plant '8' to warehouse '11'
y20	Amount transported from plant '8' to warehouse '12'
y21	Amount transported from plant '8' to warehouse '13'
y22	Amount transported from plant '8' to warehouse '14'
y23	Amount transported from plant '9' to warehouse '12'
y24	Amount transported from plant '9' to warehouse '13'
y25	Amount transported from plant '9' to warehouse '14'
y26	Amount transported from warehouse '10' to wholesaler '15'
y27	Amount transported from warehouse '10' to wholesaler '16'

y28	Amount transported from warehouse '10' to wholesaler '19'
y29	Amount transported from warehouse '11' to wholesaler '16'
y30	Amount transported from warehouse '11' to wholesaler '17'
y31	Amount transported from warehouse '11' to wholesaler '19'
y32	Amount transported from warehouse '12' to wholesaler '15'
y33	Amount transported from warehouse '12' to wholesaler '17'
y34	Amount transported from warehouse '12' to wholesaler '18'
y35	Amount transported from warehouse '12' to wholesaler '20'
y36	Amount transported from warehouse '13' to wholesaler '15'
y37	Amount transported from warehouse '13' to wholesaler '17'
y38	Amount transported from warehouse '13' to wholesaler '18'
y39	Amount transported from warehouse '13' to wholesaler '20'
y40	Amount transported from warehouse '13' to wholesaler '21'
y41	Amount transported from warehouse '14' to wholesaler '18'
y42	Amount transported from warehouse '14' to wholesaler '19'
y43	Amount transported from warehouse '14' to wholesaler '20'
y44	Amount transported from warehouse '14' to wholesaler '21'

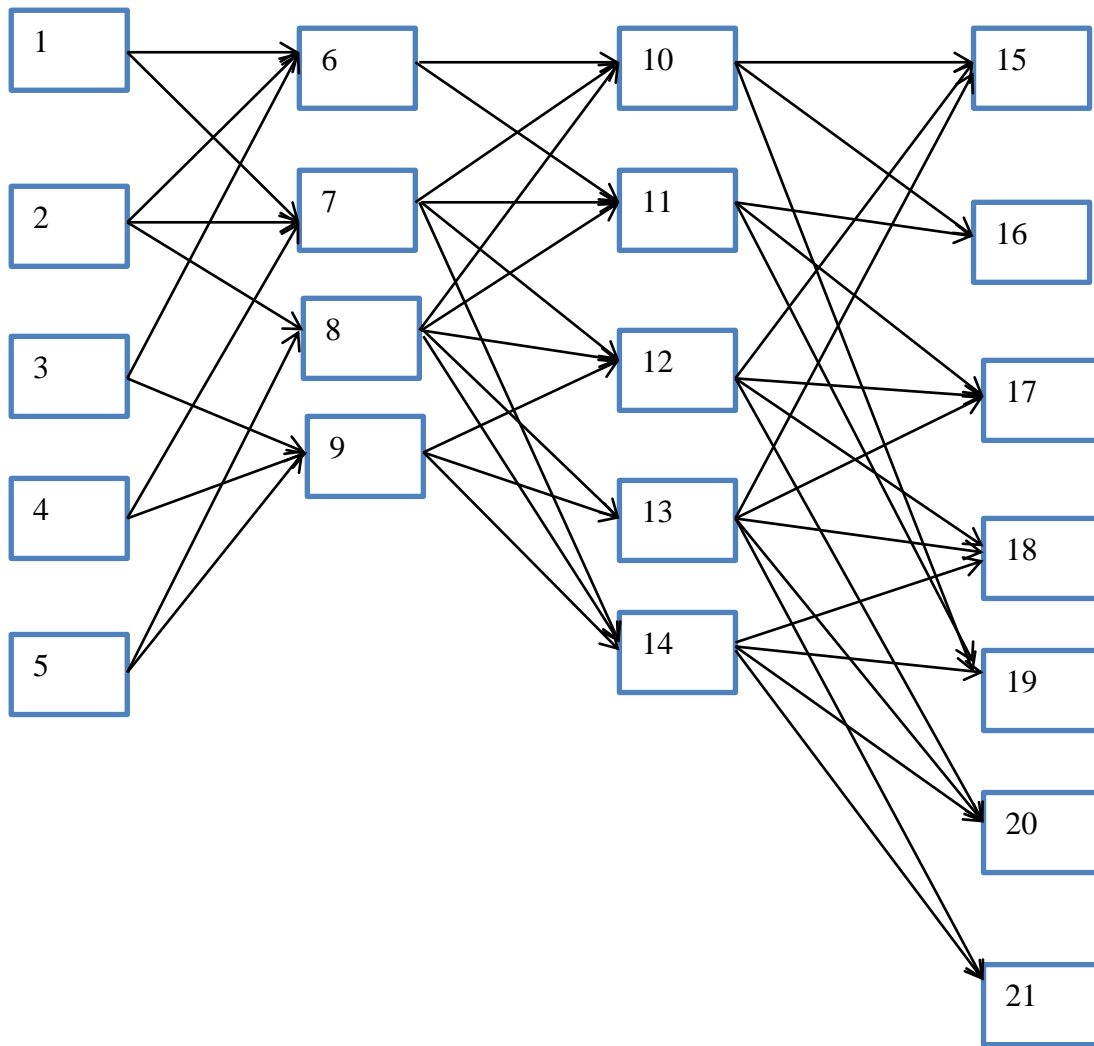


Figure 15: Hypothetical supply chain network diagram with 5-4-5-7 suppliers, plant, warehouse and wholesaler respectively

To test the consistency of the model a hypothetical values of supply capacity, plant demand and its capacity, warehouse demand and its capacity and finally wholesaler demand in kg together with the shipment cost per kg together with the constraints is given in the generic LP model as follows.

$$\begin{aligned} \text{Min } z: & 0.6*y_1 + 0.35*y_2 + 0.4*y_3 + 0.4*y_3 + 0.71*y_4 + 0.3*y_5 + 0.21*y_6 + 0.16*y_7 + 0.49*y_8 \\ & + 0.25*y_9 + 0.63*y_{10} + 0.8*y_{11} + 0.68*y_{12} + 0.81*y_{13} + 0.18*y_{14} + 0.62*y_{15} + 0.5*y_{16} + 0.2*y_{17} \\ & + 0.3*y_{18} + 0.42*y_{19} + 0.3*y_{20} + 0.15*y_{21} + 0.51*y_{22} + 0.7*y_{23} + 0.6*y_{24} + 0.4*y_{25} + 0.32*y_{26} \\ & + 0.87*y_{27} + 0.19*y_{28} + 0.6*y_{29} + 0.2*y_{30} + 0.33*y_{31} + 0.35*y_{32} + 0.21*y_{33} + 0.16*y_{34} + \\ & + 0.6*y_{35} + 0.8*y_{36} + 0.6*y_{37} + 0.52*y_{38} + 0.28*y_{39} + 0.73*y_{40} + 0.71*y_{41} + 0.68*y_{42} + 0.86*y_{43} \\ & + 0.56*y_{44} + 2 * \sum\{(D - C) + (E - D) + (F - E)\} \end{aligned}$$

Subjected To

$$y_1 + y_3 + y_6 \geq 300$$

$$y_2 + y_4 + y_8 \geq 350$$

$$y_5 + y_{10} \geq 400$$

$$y_7 + y_9 + y_{11} \geq 450$$

$$y_{12} + y_{14} + y_{18} \geq 500$$

$$y_{13} + y_{15} + y_{19} \geq 550$$

$$y_{17} + y_{20} + y_{23} \geq 600$$

$$y_{21} + y_{24} \geq 650$$

$$y_{16} + y_{22} + y_{25} \geq 700$$

$$y_{26} + y_{32} + y_{36} \geq 750$$

$$y_{27} + y_{29} \geq 800$$

$$y_{30} + y_{33} + y_{37} \geq 850$$

$$y_{34} + y_{38} + y_{41} \geq 900$$

$$y_{31} + y_{28} + y_{42} \geq 950$$

$$y_{35} + y_{39} + y_{43} \geq 1000$$

$$y_{40} + y_{44} \geq 1050$$

$$y_1 + y_2 \leq 400$$

$$y_3 + y_4 + y_5 \leq 500$$

$$y_6 + y_7 \leq 600$$

$$y_8 + y_9 \leq 700$$

$$y_{10} + y_{11} \leq 800$$

$$y_{12} + y_{13} \leq 900$$

$$y_{14} + y_{15} + y_{16} + y_{17} \leq 1000$$

$$y_{18} + y_{19} + y_{20} + y_{21} + y_{22} \leq 1100$$

$$y_{23} + y_{24} + y_{25} \leq 1200$$

$$y_{26} + y_{27} + y_{28} \leq 1300$$

$$y_{29} + y_{30} + y_{31} \leq 1400$$

$$y_{32} + y_{33} + y_{34} + y_{35} \leq 1500$$

$$y_{36} + y_{37} + y_{38} + y_{39} + y_{40} \leq 1600$$

$$y_{41} + y_{42} + y_{43} + y_{44} \leq 1700$$

$$y_1, y_2, y_3, y_4, y_5, y_6, y_7, \dots, y_{44}, (D - C), (E - D), (F - E) \geq 0$$

5.8.Result and Discussion Regarding to the Hypothetical Model Testing

Once the hypothetical values are fitted to the LP model and solving it using the GAMS build system, the optimal location- allocation result is shown below and based on this result the network diagram for this hypothetical result is depicted in Figure 16.

General Algebraic Modeling System Execution

```

---- 100 VARIABLE y1.L          =    0.000
      VARIABLE y2.L            =   350.000
      VARIABLE y3.L            =    0.000
      VARIABLE y4.L            =    0.000
      VARIABLE y5.L            =   400.000
      VARIABLE y6.L            =   300.000
      VARIABLE y7.L            =   300.000
      VARIABLE y8.L            =    0.000
      VARIABLE y9.L            =   150.000
      VARIABLE y10.L           =    0.000
    
```

VARIABLE y11.L	=	0.000
VARIABLE y12.L	=	0.000
VARIABLE y13.L	=	200.000
VARIABLE y14.L	=	500.000
VARIABLE y15.L	=	0.000
VARIABLE y16.L	=	0.000
VARIABLE y17.L	=	500.000
VARIABLE y18.L	=	0.000
VARIABLE y19.L	=	350.000
VARIABLE y20.L	=	100.000
VARIABLE y21.L	=	650.000
VARIABLE y22.L	=	0.000
VARIABLE y23.L	=	0.000
VARIABLE y24.L	=	0.000
VARIABLE y25.L	=	700.000
VARIABLE y26.L	=	350.000
VARIABLE y27.L	=	0.000
VARIABLE y28.L	=	950.000
VARIABLE y29.L	=	800.000
VARIABLE y30.L	=	600.000
VARIABLE y31.L	=	0.000
VARIABLE y32.L	=	400.000
VARIABLE y33.L	=	250.000

VARIABLE y34.L	=	850.000
VARIABLE y35.L	=	0.000
VARIABLE y36.L	=	0.000
VARIABLE y37.L	=	0.000
VARIABLE y38.L	=	50.000
VARIABLE y39.L	=	100.000
VARIABLE y40.L	=	0.000
VARIABLE y41.L	=	0.000
VARIABLE y42.L	=	0.000
VARIABLE y43.L	=	0.000
VARIABLE y44.L	=	1050.000
VARIABLE z. L	=	3160.500

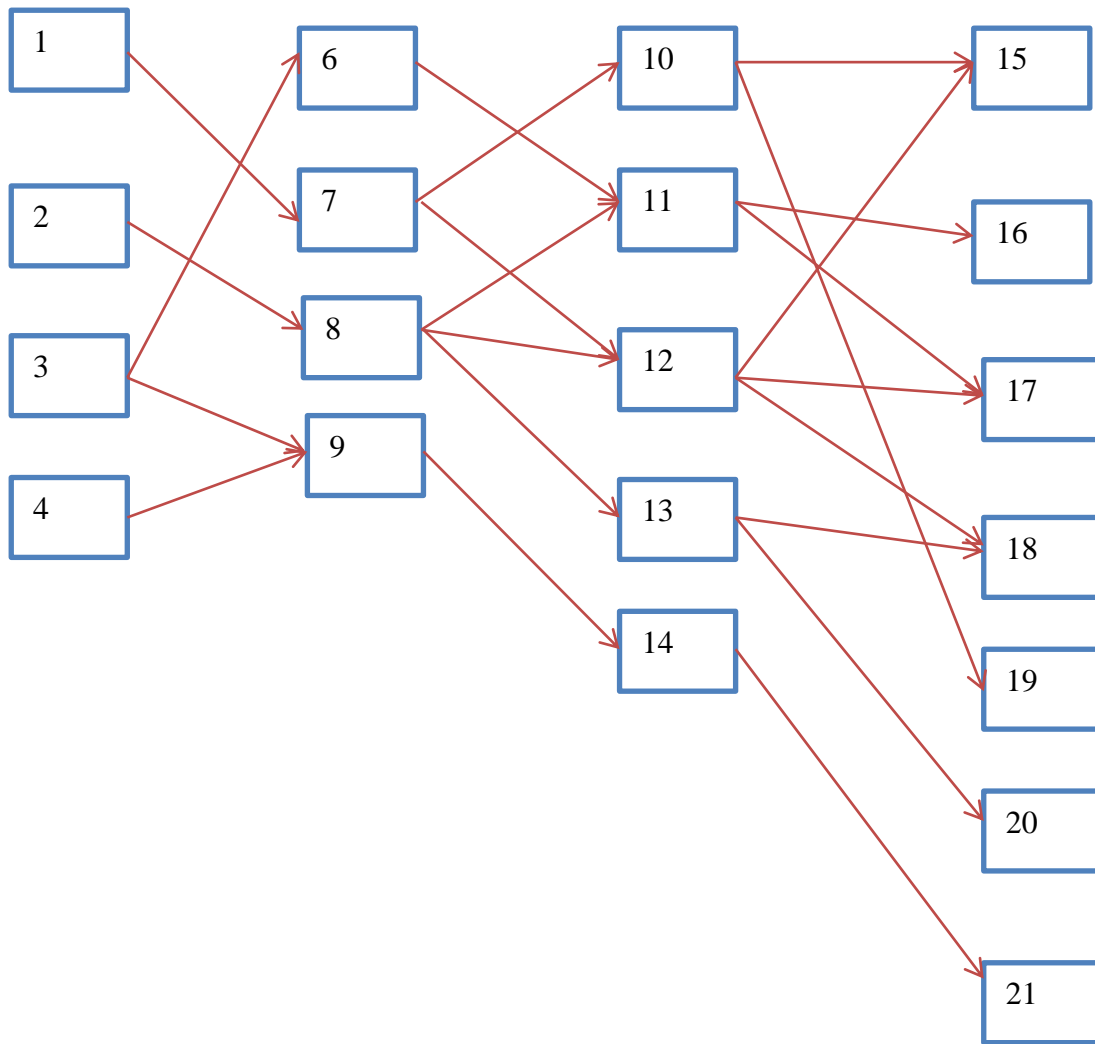


Figure 16: Restructured supply chain network diagram for the hypothetical testing

Based on the hypothetical data and solved as shown on its network diagram shown in Figure 15 , we can see that the developed stochastic linear programming (LP) model is consistent and applicable to this problem. Therefore once the model is fitted and tested using the hypothetical data the next part is to validate the model to the real situations by taking a case of Yirgalem Addis textile factory so as to fit with the problem statement.

5.9. Model Fitting for the Case Study

Once the model has been developed based on the network configurations, the next part is to optimize the configuration of the supply chain network. Jersey fabric product, product with high demand of the case company (Yirgalem Addis textile factory) shown in Table 5 , is selected for the purpose of model validation. It is important to note that though the author selects one kind of product for the sake of model fitting, the model has no restriction on the

type of the product, i.e. it can be applied to all product type. Using the primary data collected from Yirgalem Addis textile factory, characterized by five suppliers, single plant, single warehouse, and ten wholesalers as shown in Figure 17, the linear programming model (LP) was fitted to its input parameters.

Assuming that the plant have a single warehouse which is located in Addis Ababa outside the plant, the model fitted into its parameters is given as:

$$\begin{aligned} \text{Min } z: & 0.2 * X1 + 0.35 * X2 + 0.41 * X3 + 0.18 * X4 + 0.16 * X5 + 0.17 * X6 + \\ & 0.22 * X7 + 0.3 * X8 + 0.38 * X9 + 0.46 * X10 + 0.5 * X11 + 0.6 * X12 + 0.18 * \\ & X13 + 0.18 * X14 + 0.19 * X15 + 0.175 * X16 + 1.67 * \sum\{(D - C) + (E - D) + \\ & (F - E)\} \end{aligned}$$

Subjected To:

$$X1 + X2 + X3 + X4 + X5 \geq 13000$$

$$X1 \leq 7500$$

$$X2 \leq 1000$$

$$X3 \leq 4820.61$$

$$X4 \leq 5000$$

$$X5 \leq 4697.43$$

$$X6 \leq 10000$$

$$X6 \geq 9000$$

$$X7 \geq 800$$

$$X8 \geq 1000$$

$$X9 \geq 1500$$

$$X10 \geq 1300$$

$$X11 \geq 1100$$

$$X12 \geq 1200$$

$$X_{13} \geq 900$$

$$X_{14} \geq 750$$

$$X_{15} \geq 690$$

$$X_{16} \geq 560$$

$$X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} + X_{13} + X_{14} + X_{15} + X_{16} \leq 9000$$

$$X_1, X_2, X_3 \dots X_{16}, (D - C), (E - D), (F - E) \geq 0$$

Where the values of the differences in the last term in the objective function is constant, unmet demand at plant, warehouse and customer, is obtained from the result of the model and its result is added to the objective function. The interpretation of the variables in the model associate for the case study is shown below in Table 4.

Table 4: Interpretation of the variables in the model for the case study

Amount transported
x1 = amount transported from supplier 'Else' to plant
x2 = amount transported from supplier 'AS' to plant
x3 = amount transported from supplier 'SSTP' to plant
x4 = amount transported from supplier 'JWI' to plant
x5 = amount transported from supplier 'MNS' to plant
x6 = amount transported from plant 'i' to warehouse 'j'
x7 = amount transported from warehouse to wholesaler 'IRCS'
x8 = amount transported from warehouse to wholesaler 'IHI'
x9 = amount transported from warehouse to wholesaler 'USAID'
x10 = amount transported from warehouse to wholesaler 'GE'
x11 = amount transported from warehouse to wholesaler 'EA'
x12 = amount transported from warehouse to wholesaler 'TSI'
x13 = amount transported from warehouse to wholesaler 'KIKG'
x14 = amount transported from warehouse to wholesaler 'INP'
x15 = amount transported from warehouse to wholesaler 'DPS'
x16 = amount transported from warehouse to wholesaler 'CS'

5.10. Model Solving for the Case Study

Model validation is typically done by reconstructing the existing network configuration using the collected data, and comparing the output of the model to the existing data. To illustrate the validity and usefulness of the proposed model, a case study of Yirgalem Addis textile factory PLC have been undertaken, which is selected randomly among the five textile industry taken for survey analysis for the supply chain network optimization problem.

Yirgalem Addis textile factory PLC is formerly Adei Ababa yarn factory which was privatized by the government in Nov, 2010. The company had more than 50 years' experience in spinning, knitting, weaving, dyeing, garments and blanket activities. The factory is located on a prime and accessible location in the southern part of capital city Addis Ababa on Debrezeit road, Nifas Silk Lafto sub city. Yirgalem Addis Textile Factory PLC is owned by W/o Yirgalem Asfaw, a women entrepreneur, highly committed to transform the factory to one of the biggest textile and garment manufacturer in Ethiopia. Currently, the factory has more than 800 employees and 90% of the employees are women.

Production Facility and Capacity

The company is an integrated textile factory consisting of: Spinning, Knitting, Knit dyeing , Garment stone washing, Blanket weaving, blanket stitch bond (non-woven) and Garment production. Yirgalem Addis Textile factory PLC products are categorized in to the following. Various counts of cotton yarn, bleached yarn, Grieg Knitted fabric in various density and construction (including collar and cuff), stock net, Dyed knit fabrics, sportswear, woven blanket and non-woven blanket. In addition the company has 6 working days per week which implies 26 working days per month and about 312 working days per year.

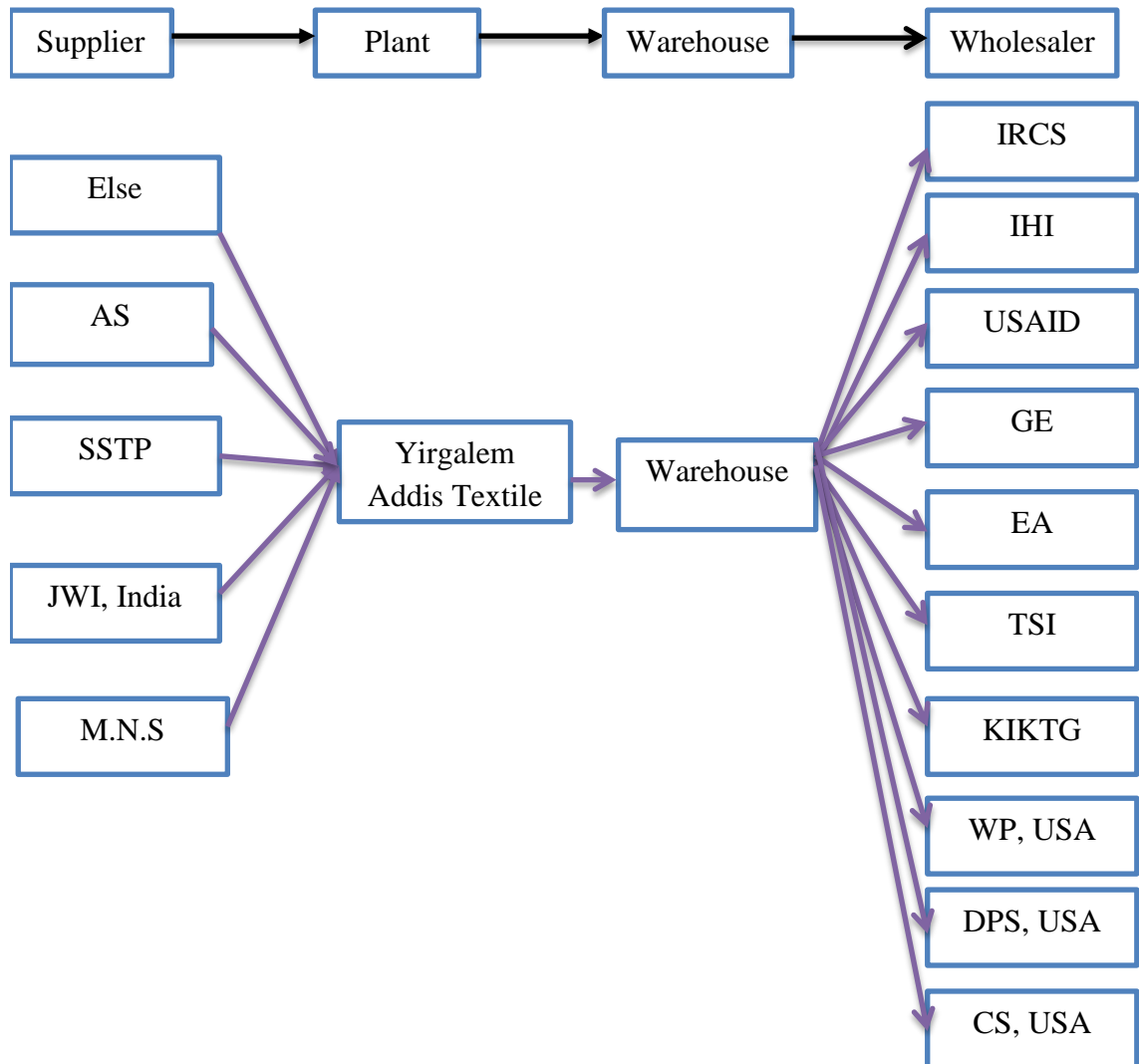
Table 5: Production capacity with its attainable capacity of Yirgalem Addis Textile

NO.	Section	Units	A.Production/year	Remark
1	Garment		1800000	1 shift
2	Knitting	Pcs.	1275000	3 shifts
3	Spinning	Kg.	1116000	3 shifts
4	Dyeing	Kg.	1200000	3 shifts
5	Blanket	Kg.	9600	3 shifts
6	Non-woven	Pcs.	300000	3 shifts
7	Jersey Fabric	Pcs.	120000	PHD, Product with High Demand
8	Pique fabric	Kg.	936000	PHD, Product with High Demand
9	Rib fabric	Kg.	187200	PMD, Product with Medium Demand

10	Stock net	Kg.	312000	PMD, Product with Medium Demand
----	-----------	-----	--------	---------------------------------

A firm is affected by long lasting decision strategy like plant, warehouse, transportation, and supplier and retailer location. According to the information obtained from yirgalem Addis textile factory, the demand for its product is increasing rapidly. However the existing supply chain network is not able to capture available demands at different location and means of selecting appropriate supplier of raw material and the customer service is not to the satisfactory level with the increased demand. As a result some segment of the market is experiencing shortage of outgoing product due to imbalance between incoming materials. Currently the company does not have well established means to sense the shortage in the market. Due to the existence of these problem the cost of shipping raw material and finished product is about 442,445.702 birr per year which is quite significant.

The figure below shows the existing supply chain of Yirgalem Addis textile factory PLC with the major international and local customers.



Key: AS = Adama spinning, SSTP= Shri Sai Textile Processor, JWI= Jindal Woolen Industries plc, M.N.S= M.N.S Textile, IRCS= International Red Cross Society, IHI = Intra Health International, GE= Goal Ethiopia, EA= Ethiopian Army, TSI= Teddy Spa Italy, KIKTG= KIK Textilien Germany, WP= Weather Proof USA, DPS = David payser sportswear USA, CS= Champro sports USA,

Figure 17: Existing supply chain structure of the case study

Positive variables $x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}$;

Free variable z ;

Equations

Con1, the sum of amount transported from each supplier to plant should be greater or equal to plant demand

Con2, amount transported from plant to warehouse should be greater or equal to warehouse demand

Con3, amount transported from warehouse to wholesaler '7' should be greater or equal to its demand

Con4, amount transported from warehouse to wholesaler '8' should be greater or equal to its demand

Con5, amount transported from warehouse to wholesaler '9' should be greater or equal to its demand

Con6, amount transported from warehouse to wholesaler '10' should be greater or equal to its demand

Con7, amount transported from warehouse to wholesaler '11' should be greater or equal to its demand

Con8, amount transported from warehouse to wholesaler '12' should be greater or equal to its demand

Con9, amount transported from warehouse to wholesaler '13' should be greater or equal to its demand

Con10, amount transported from warehouse to wholesaler '14' should be greater or equal to its demand

Con11, amount transported from warehouse to wholesaler '15' should be greater or equal to its demand

Con12, amount transported from warehouse to wholesaler '16' should be greater or equal to its demand

Con13, amount transported from supplier '1' should be less than or equal to its capacity

Con14, amount transported from supplier '2' should be less than or equal to its capacity

Con15, amount transported from supplier '3' should be less than or equal to its capacity

Con16, amount transported from supplier '4' should be less than or equal to its capacity

Con17, amount transported from supplier '5' should be less than or equal to its capacity

Con18, amount transported from plant to warehouse should be equal to its capacity

Con19, the sum of all amount from warehouse to wholesaler should be less than or equal to its capacity

Obj;

Con1.. $x_1 + x_2 + x_3 + x_4 + x_5 = G = 14800$;

Con2.. $x_6 = G = 9000$;

Con3.. $x_7 = G = 800$;

Con4.. $x_8 = G = 1000$;

Con5.. $x_9 = G = 1500$;

Con6.. $x_{10} = G = 1300$;

Con7.. $x_{11} = G = 1100$;

Con8.. $x_{12} = G = 1200$;

Con9.. $x_{13} = G = 900$;

Con10.. $x_{14} = G = 750$;

Con11.. $x_{15} = G = 690$;

Con12.. $x_{16} = G = 560$;

Con13.. $x_1 = L = 7500$;

Con14.. $x_2 = L = 1000$;

Con15.. $x_3 = L = 4820.61$;

Con16.. $x_4 = L = 5000$;

Con17.. $x_5 = L = 4697.43$;

Con18.. $x_6 = E = 10000$;

Con19.. $x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} = L = 9000$;

Obj.. $0.2 * x_1 + 0.35 * x_2 + 0.41 * x_3 + 0.18 * x_4 + 0.16 * x_5 + 0.17 * x_6 + 0.22 * x_7 + 0.3 * x_8 + 0.38 * x_9 + 0.46 * x_{10} + 0.5 * x_{11} + 0.6 * x_{12} + 0.18 * x_{13} + 0.18 * x_{14} + 0.19 * x_{15} + 0.175 * x_{16} = L = z$;

Model cost minimization /

Con1,

Con2,

Con3,

Con4,

Con5,

Con6,

Con7,

Con8,

Con9,

Con10,

Con11,

Con12,

Con13,

Con14,

Con15,

Con16,

Con17,

Con18,

Con19,

Obj /;

options LP = Cplex;

solve cost minimization using LP minimizing z;

Display x1.L, x2.L, x3.L, x4.L, x5.L, x6.L, x7.L, x8.L, x9.L, x10.L, x11.L, x12.L, x13.L, x14.L, x15.L, x16.L, z. L;

5.11. Result and Discussion of the Case Study Analysis

The result of the model solved and coded using GAMS build system is shown in Table 6 and based on this result the supply chain network is designed for the case study.

General Algebraic Modeling System Execution

Table 6: Result and discussion of the case study

Result in Kg	Interpretation/Description
71 VARIABLE x1.L = 281.960	Amount transported from supplier 'Else' to plant
VARIABLE x2.L = 0.000	Amount transported from supplier 'AS' to plant
VARIABLE x3.L = 4820.610	Amount transported from supplier 'SSTP' to plant
VARIABLE x4.L = 5000.000	Amount transported from supplier 'JWI' to plant
VARIABLE x5.L = 4697.430	Amount transported from supplier 'MNS' to plant
VARIABLE x6.L = 10000.000	Amount transported from plant 'i' to warehouse 'j'
VARIABLE x7.L = 800.000	Amount transported from warehouse to wholesaler 'IRCS'
VARIABLE x8.L = 1000.000	amount transported from warehouse to wholesaler 'IHI'
VARIABLE x9.L = 1500.000	Amount transported from warehouse to wholesaler 'USAID'
VARIABLE x10.L = 500.000	Amount transported from warehouse to wholesaler 'GE'
VARIABLE x11.L = 1100.000	Amount transported from warehouse to wholesaler 'EA'

VARIABLE x12.L = 1200.000	Amount transported from warehouse to wholesaler 'TSI'
VARIABLE x13.L = 900.000	Amount transported from warehouse to wholesaler 'KIKG'
VARIABLE x14.L = 750.000	Amount transported from warehouse to wholesaler 'INP'
VARIABLE x15.L = 690.000	Amount transported from warehouse to wholesaler 'DPS'
VARIABLE x16.L = 560.000	Amount transported from warehouse to wholesaler 'CS'
VARIABLE z. L = 8456.531	Optimal result of the model

Based on the result of the optimization problem, the penalty cost of unmet demand is then calculated. The result below shows unmet demand from plant to supplier, plant to warehouse and warehouse to wholesaler.

Total supplier capacity from optimal result = 14800

Plant demand = 14800

Unmet demand, D - C = 0

Plant capacity = 10000

Warehouse demand = 9000

Unmet demand, E - D = 0

Warehouse capacity = 9000

Wholesaler demand from optimal result

x7 = 800

x8 = 1000

x9 = 1500

x10 = 500

x11 = 1100

x12 = 1200

$$x_{13} = 900$$

$$x_{14} = 750$$

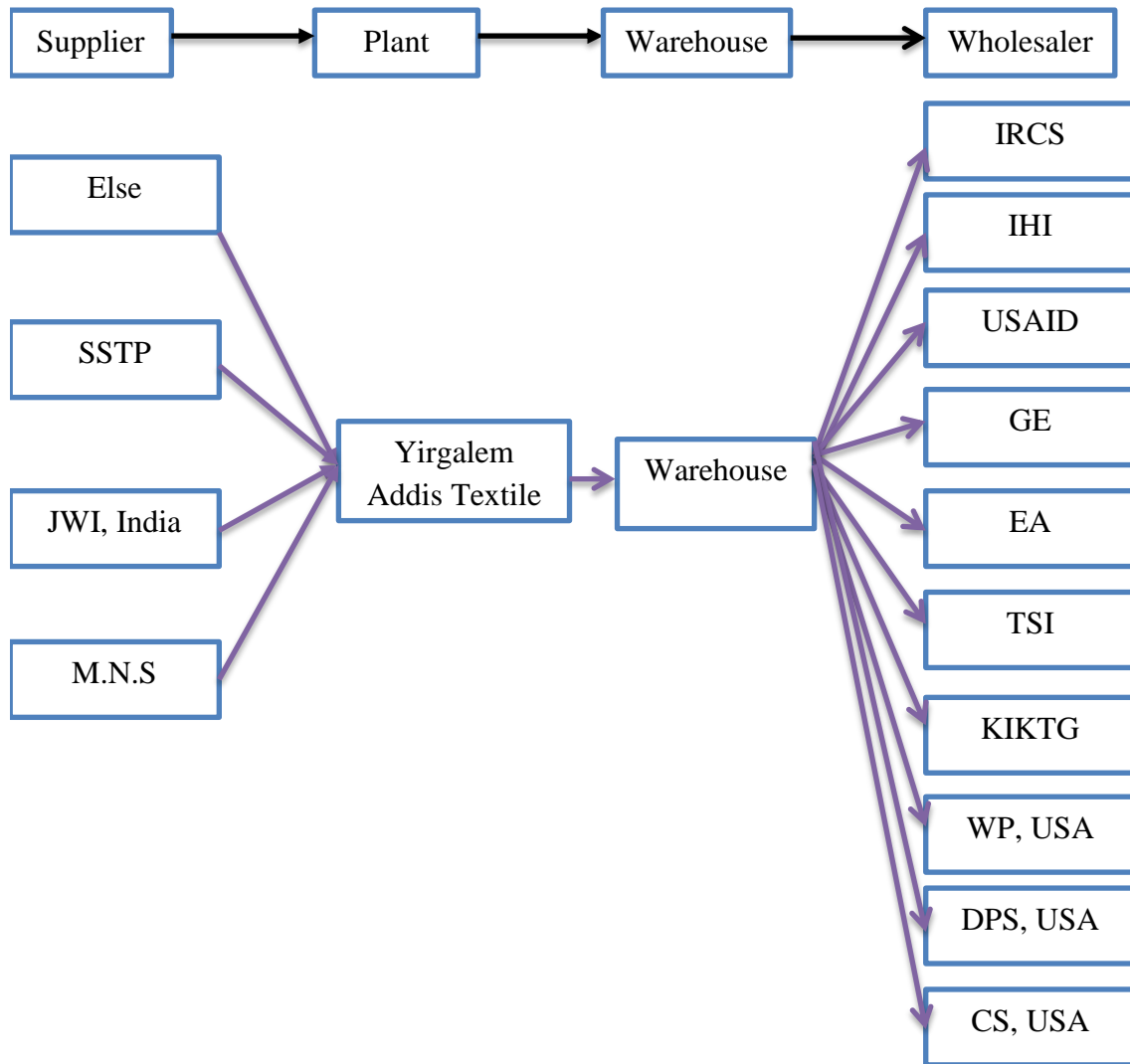
$$x_{15} = 690$$

$$x_{16} = 560$$

$$\text{Total wholesaler demand} = 8800$$

Stock remaining in the warehouse = $9000 - 8800 = 200$. Assuming that all wholesaler are satisfied at the same time, then there is stock in the warehouse equal to 200. i.e. the plant is enough to satisfy all wholesalers at the same time and it has an opportunity to sell to other wholesaler or to keep to the next period. Therefore unmet demand, $F-E = 0$ in the model. The cost associated with unmet demand, T_k , (opportunity cost), as obtained from the case study, is about 1.67 birr per kg. This implies that the total cost of unmet demand is equal to 0.00 birr ($1.67 \times (0 + 0 + 0)$). Therefore the optimal result of the transportation/shipment cost for the selected case study is about 8456.531 birr per shipment. According to the information obtained from the case company an average of 4 orders arrive from customers per month. i.e. the company have 48 orders or shipments per year. Which implies that the total cost of this company based on the result of the optimization model is about 405913.488 (8456.531×48) per year including the cost of risk or penalty cost which is comparatively optimal when we compare to the existing supply chain structure of the case company. Generally with the ideal application of the location – allocation optimization model proposed in this study about 9% cost reduction have been achieved from the existing supply chain structure which is quite significant for the sector.

Therefore since the obtained result is optimal solution compared to the existing structure of the supply chain of yirgalem Addis textile industry the network diagram is redesigned, which is depicted in Figure 18 shown below, based on the result of the optimization model.



Key: SSTP= Shri Sai Textile Processor, JWI= Jindal Woolen Industries plc, M.N.S= M.N.S Textile, IRCS= International Red Cross Society, IHI = Intra Health International, GE= Goal Ethiopia, EA= Ethiopian Army, TSI= Teddy Spa Italy, KIKTG= KIK Textilien Germany, WP= Weather Proof USA, DPS = David payser sportswear USA, CS= Champro sports USA,

Figure 18: Restructured supply chain network of the case company

5.12. Sensitivity Analysis of Supply and Demand Uncertainties for the Case Study

In this section a sensitivity analysis of the supply and demand uncertainty on the expected minimum cost will be presented. To do the sensitivity analysis three levels were considered for supply and demand uncertainty, high, medium and low which are shown below in Table 7 and Table 8 respectively.

Table 7: characteristics of supply uncertainty based on level of randomness

Level	Supply Uncertainty
1	High
2	Medium
3	Low

Table 8: Characteristics of demand uncertainty based on level of randomness

level	Demand Uncertainty
1	High
2	Medium
3	Low

The table below shows the supply and demand record for one year planning period together with the result of optimization model.

To see the impact of demand and supply uncertainty on the expected minimum cost, an average record for four month time period for a single product(jersey Fabric) is coded to the optimization model and solved using GAMS build system and the output of the model is observed which is summarized in Table 9 up to Table 25 . To see the impacts of the supply and demand uncertainty on the expected minimum cost a variations in the supplier capacity and wholesaler demand have been taken in to the sensitivity analysis using GAMS optimization model. C1, C2, C3, C4 and C5 are a supply for D6. C6 is a supply for D7, D8, D9, D10, D11, D12, D13, D14, D15, D16. Therefore in the supply uncertainty variations have been observed over C1 up to C6. The values of supply and demand for these variables have been depicted in the model fitting part for the case study. Therefore based on the input parameters a sensitivity analysis have been conducted on the GAMS build system so as to see the impacts of variations in the supply and demand uncertainty on the expected minimum

cost 'z'. The table from Table 9 to Table 25 shows the result of the expected minimum cost obtained from the result of the sensitivity analysis using GAMS build system. Though there is a variation on the expected minimum cost due to the supply and demand uncertainty no variations have been observed on the new supply chain network structure. This implies that the new supply chain network can be applied in the case study and the minimum cost they incurred for shipment of products for the capacity allocation-location problem is only the optimal value found in the GAMS tool. The expected cost reduction for all tables from Table 9 up to Table 25 is calculated using the following formula.

$$\text{expected cot reduction (\%)} = \left| \frac{Zs - Zo}{Zo} \right| * 100 \quad (9)$$

Where Zs = result of expected minimum cost at sensitive value

Zo = optimal expected minimum cost before sensitivity value

5.12.1. Sensitivity Analysis of Supply uncertainty on Expected Minimum Cost

According to the information obtained, the average supply for the warehouse 'yirgalem Addis Textile factory PLC' is about 9000. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 9.

Table 9: Sensitivity analysis of supply uncertainty 'C6' on expected minimum cost

Scenario	Supply level	Supply	Expected minimum cost 'z'	Percentage cost Reduction(%)
1	High	9300.98	8456.531	0.00
2	High	9250.87	8456.531	0.00
3	High	9240.56	8456.531	0.00
4	Medium	9220.69	8456.531	0.00
5	Medium	9200.34	8456.531	0.00
6	Medium	9180.45	8456.531	0.00
7	Low	9170.13	8456.531	0.00
8	Low	9160.21	8456.531	0.00
9	Low	9150.24	8456.531	0.00

According to the information obtained, the average supply for the supplier ‘Else’ is about 7500. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 10.

Table 10: Sensitivity analysis of supply uncertainty ‘C1’ on expected minimum cost

Scenario	Supply level	Supply	Expected minimum cost ‘z’	Percentage cost Reduction(%)
1	High	7600.75	8456.531	0.00
2	High	7560.47	8456.531	0.00
3	High	7558.74	8456.531	0.00
4	Medium	7520.42	8456.531	0.00
5	Medium	7518.69	8456.531	0.00
6	Medium	7516.13	8456.531	0.00
7	Low	7510.62	8456.531	0.00
8	Low	7507.12	8456.531	0.00
9	Low	7503.64	8456.531	0.00

According to the information obtained, the average supply for the supplier ‘Adama Spinning(AS)’ is about 1000. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 11.

Table 11: Sensitivity analysis of supply uncertainty ‘C2’ on expected minimum cost

Scenario	Supply level	Supply	Expected minimum cost ‘z’	Percentage cost Reduction(%)
1	High	990.57	8456.531	0.00
2	High	980.67	8456.531	0.00
3	High	970.75	8456.531	0.00

4	Medium	965.76	8456.531	0.00
5	Medium	960.68	8456.531	0.00
6	Medium	958.82	8456.531	0.00
7	Low	952.13	8456.531	0.00
8	Low	950.21	8456.531	0.00
9	Low	948.11	8456.531	0.00

According to the information obtained, the average supply for the supplier ‘Shri Sai Textile processor(SSTP)’ is about 4820.61. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 12.

Table 12: Sensitivity analysis of supply uncertainty ‘C3’ on expected minimum cost

Scenario	Supply level	Supply	Expected minimum cost ‘z’	Percentage cost Reduction(%)
1	High	4860.16	8464.836	0.098
2	High	4852.61	8463.251	0.079
3	High	4856.26	8464.017	0.089
4	Medium	4850.36	8462.778	0.074
5	Medium	4846.23	8461.911	0.064
6	Medium	4840.12	8460.628	0.048
7	Low	4832.11	8458.946	0.029
8	Low	4830.12	8458.528	0.024
9	Low	4827.51	8457.980	0.017

According to the information obtained, the average supply for the supplier ‘Jindal Woolen Industries(JWI)’ is about 5000. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 13.

Table 13: Sensitivity analysis of supply uncertainty ‘C4’ on expected minimum cost

Scenario	Supply level	Supply	Expected minimum cost ‘z’	Expected cost Reduction(%)
1	High	5060.42	8455.323	0.014
2	High	5055.26	8455.426	0.013
3	High	5050.47	8455.521	0.012
4	Medium	5047.53	8455.580	0.011
5	Medium	5042.37	8455.684	0.010
6	Medium	5040.72	8455.716	0.010
7	Low	5036.71	8455.797	0.009
8	Low	5032.13	8455.888	0.008
9	Low	5030.10	8455.929	0.007

According to the information obtained, the average supply for the supplier ‘M.N.S Textile (M.N.S)’ is about 4697.43. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 14.

Table 14: Sensitivity analysis of supply uncertainty ‘C5’ on expected minimum cost

Scenario	Supply level	Supply	Expected minimum cost ‘z’	Expected cost Reduction(%)
1	High	4720.15	8455.622	0.011
2	High	4715.13	8455.823	0.008

3	High	4710.21	8456.020	0.006
4	Medium	4708.12	8456.103	0.005
5	Medium	4705.50	8456.208	0.004
6	Medium	4702.61	8456.324	0.002
7	Low	4700.60	8456.404	0.002
8	Low	4699.70	8456.440	0.001
9	Low	4698.82	8456.475	0.001

As it is clear from Table 9 to Table 14 the impact of the supply uncertainty is high. When the supply uncertainty increase the percentage cost reduction also increases and remains constant in some sensitivity result when the taken data's are close to the actual data ,i.e. when the data's are less uncertain.

5.12.2. Sensitivity Analysis of Demand Uncertainty on Expected Minimum Cost

The sensitivity analysis of demand uncertainty on expected minimum cost is depicted in Table 15 to Table 25.

The demand for the company 'Yirgalem Addis Textile factory PLC (D6)' according to the information obtained is about 14800. Therefore by taking three levels as shown below we observed its impact on the minimum expected cost as shown in Table 15.

Table 15: Sensitivity analysis of demand uncertainty 'D6' on expected minimum cost

Scenario	Demand level	Demand	Expected minimum cost 'z'	Expected cost Reduction(%)
1	High	15000.37	8496.605	0.474
2	High	14999.67	8496.465	0.472
3	High	14997.35	8496.001	0.467
4	Medium	14996.21	8495.773	0.464
5	Medium	14993.35	8495.201	0.457
6	Medium	14991.62	8494.855	0.453
7	Low	14990.98	8494.727	0.452
8	Low	14989.68	8494.467	0.449

9	Low	14888.86	8474.303	0.210
----------	-----	----------	----------	-------

According to the information obtained, the average demand for the wholesaler ‘International Red Cross Society(IRCS)’ is about 800. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 16.

Table 16: Sensitivity analysis of demand uncertainty ‘D7’ on expected minimum cost

Scenario	Demand level	Demand	Expected minimum cost ‘z’	Expected cost Reduction(%)
1	High	900.42	8432.430	0.199
2	High	880.24	8437.273	0.228
3	High	870.13	8439.700	0.199
4	Medium	850.69	8444.365	0.144
5	Medium	845.36	8445.645	0.129
6	Medium	840.35	8446.847	0.115
7	Low	830.32	8449.254	0.086
8	Low	826.43	8450.188	0.075
9	Low	820.54	8451.601	0.058

According to the information obtained, the average demand for the wholesaler ‘Intra Health Organization(IHI)’ is about 1000. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 17.

Table 17: Sensitivity analysis of demand uncertainty ‘D8’ on expected minimum cost

Scenario	Demand level	Demand	Expected minimum cost ‘z’	Expected cost Reduction(%)
1	High	1200.78	8424.406	0.380
2	High	1150.69	8432.421	0.285
3	High	1145.98	8433.174	0.276
4	Medium	1100.56	8440.441	0.190
5	Medium	1090.42	8442.064	0.171

6	Medium	1060.32	8446.880	0.114
7	Low	1050.24	8448.493	0.095
8	Low	1047.54	8448.925	0.090
9	Low	1030.64	8451.628	0.058

According to the information obtained, the average demand for the wholesaler ‘United State Agency for International Development(USAID)’ is about 1500. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 18.

Table 18: Sensitivity analysis of demand uncertainty ‘D9’ on expected minimum cost

Scenario	Demand level	Demand	Expected minimum cost ‘z’	Expected cost Reduction(%)
1	High	1594.58	8448.965	0.089
2	High	1570.85	8450.863	0.067
3	High	1565.42	8451.297	0.062
4	Medium	1560.66	8451.678	0.057
5	Medium	1558.72	8451.833	0.056
6	Medium	1552.46	8452.334	0.050
7	Low	1550.16	8452.518	0.047
8	Low	1545.61	8452.882	0.043
9	Low	1534.28	8453.789	0.032

According to the information obtained, the average demand for the wholesaler ‘Goal Ethiopia(GE)’ is about 1300 . Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 19.

Table 19: Sensitivity analysis of demand uncertainty 'D10' on expected minimum cost

Scenario	Demand level	Demand	Expected minimum cost 'z'	Expected cost Reduction(%)
1	High	1224.42	8474.303	0.210
2	High	1228.46	8474.303	0.210
3	High	1230.68	8474.303	0.210
4	Medium	1235.98	8474.303	0.210
5	Medium	1238.49	8474.303	0.210
6	Medium	1240.38	8474.303	0.210
7	Low	1260.82	8474.303	0.210
8	Low	1270.88	8474.303	0.210
9	Low	1280.89	8474.303	0.210

According to the information obtained, the average demand for the wholesaler 'Ethiopian army(EA)' is about 1100. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 20.

Table 20: Sensitivity analysis of demand uncertainty 'D11' on expected minimum cost

Scenario	Demand level	Demand	Expected minimum cost 'z'	Percentage cost Reduction(%)
1	High	1190.12	8477.908	0.253
2	High	1175.21	8477.311	0.246
3	High	1160.32	8476.716	0.239
4	Medium	1242.23	8479.992	0.277
5	Medium	1140.45	8475.921	0.229
6	Medium	1138.56	8475.845	0.228
7	Low	1130.78	8475.534	0.225
8	Low	1124.89	8475.299	0.222
9	Low	1116.48	8474.962	0.218

According to the information obtained, the average demand for the wholesaler ‘Teddy spa Italy(TSI)’ is about 1200. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 21.

Table 21: Sensitivity analysis of demand uncertainty ‘D12’ on expected minimum cost

Scenario	Demand level	Demand	Expected minimum cost ‘z’	Expected cost Reduction(%)
1	High	1290.82	8487.018	0.361
2	High	1275.38	8484.856	0.335
3	High	1270.43	8484.163	0.327
4	Medium	1260.52	8482.776	0.310
5	Medium	1252.56	8481.661	0.297
6	Medium	1250.49	8481.372	0.294
7	Low	1248.20	8481.051	0.290
8	Low	1240.40	8479.959	0.277
9	Low	1231.13	8478.661	0.262

According to the information obtained, the average demand for the wholesaler ‘KIK Textilien Germany(KIKTG)’ is about 900. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 22.

Table 22: Sensitivity analysis of demand uncertainty ‘D13’ on expected minimum cost

Scenario	Demand level	Demand	Expected minimum cost ‘z’	Expected cost Reduction(%)
1	High	960.63	8439.555	0.201
2	High	956.27	8440.775	0.186
3	High	954.62	8441.237	0.181
4	Medium	950.85	8442.293	0.168
5	Medium	948.48	8442.957	0.161
6	Medium	939.62	8445.437	0.131
7	Low	930.26	8448.058	0.100
8	Low	924.25	8449.741	0.080
9	Low	920.32	8450.841	0.067

According to the information obtained, the average demand for the wholesaler ‘weather proof(WP)’ is about 750. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 23.

Table 23: Sensitivity analysis of demand uncertainty ‘D14’ on expected minimum cost

Scenario	Demand level	Demand	Expected minimum cost ‘z’	Expected cost Reduction(%)
1	High	800.26	8442.458	0.166
2	High	790.28	8445.253	0.133
3	High	780.84	8447.896	0.102
4	Medium	770.46	8450.802	0.068
5	Medium	768.63	8451.315	0.062
6	Medium	760.32	8453.641	0.034
7	Low	759.29	8453.930	0.031
8	Low	756.98	8454.577	0.023
9	Low	755.78	8454.913	0.019

According to the information obtained, the average demand for the wholesaler ‘David payser sportswear(DPS)’ is about 690. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 24.

Table 24: Sensitivity analysis of demand uncertainty ‘D15’ on expected minimum cost

Scenario	Demand level	Demand	Expected minimum cost ‘z’	Expected cost Reduction(%)
1	High	732.86	8444.959	0.137
2	High	730.38	8445.628	0.130
3	High	728.72	8446.076	0.124
4	Medium	720.47	8448.304	0.097
5	Medium	716.54	8449.365	0.085
6	Medium	710.48	8451.001	0.065
7	Low	700.64	8453.658	0.034
8	Low	693.27	8455.648	0.010
9	Low	692.52	8455.851	0.008

According to the information obtained, the average demand for the wholesaler ‘Champro sports(CS)’ is about 560. Therefore by taking three levels as shown below an observation have been made on its impact on the minimum expected cost as shown in Table 25.

Table 25: Sensitivity analysis of demand uncertainty ‘D16’ on expected minimum cost

Scenario	Demand level	Demand	Expected minimum cost ‘z’	Expected cost Reduction(%)
1	High	600.75	8444.917	0.137
2	High	590.35	8447.881	0.102
3	High	578.83	8451.164	0.063
4	Medium	570.62	8453.504	0.036
5	Medium	568.36	8454.148	0.030
6	Medium	565.54	8454.952	0.0189
7	Low	564.25	8455.320	0.014
8	Low	563.48	8455.539	0.017
9	Low	562.36	8455.858	0.008

5.13. Result and Discussion Regarding to the Sensitivity Analysis

As it is clear from Table 16 up to Table 25 the impact of the demand uncertainty is high. When the demand uncertainty increase the percentage cost reduction also increases and remains constant in some sensitivity result due the reliability of data. Generally the result of the sensitivity analysis shows that highest percentage cost reduction is obtained when supply is highly uncertain regardless to the level of demand uncertainty and when the supply uncertainty is low, regardless to the demand uncertainty level, the percentage cost reduction is low. we observed that when demand uncertainty is low the percentage cost reduction is also low regardless to the supply uncertainty and the impact of the demand uncertainty increases when the demand uncertainty is medium or high regardless to the level of supply uncertainty. In some of the sensitivity analysis the expected cost reduction is constant and this is due to the reason that the level of demand and supply uncertainty are close to the actual demand and supply values, i.e. the taken values are less uncertain(see: Table 9 up to Table 11 for example).

Finally it is worth noting that, when supply is highly uncertain, regardless to the level of demand uncertainty, the percentage cost reduction is highest and when the supply uncertainty is low, regardless to the demand uncertainty, the percentage cost reduction is low. In contrast

when demand is highly uncertain, regardless to the level of supply uncertainty, the percentage cost reduction is highest and when the demand uncertainty is low, regardless to the supply uncertainty level, the percentage cost reduction is low. In general the result of the various scenarios have shown that supply and demand uncertainty have significant impact on the expected minimum cost. Though there is impact on the cost reduction ratio (expected minimum cost) due to the supply and demand uncertainty (high variation of expected minimum cost due to highly uncertain supply and demand values) the sensitivity result shows that there is no clear variation on the new network structure and which implies the network diagram is tolerable for these variations and we can see that the developed model under the assumption of supply and demand uncertainty is feasible and consistent even though there is a slight increment/decrement on the expected cost reduction.

CHAPTER SIX

6. Conclusion, Recommendation and Future Research Direction

6.1. Conclusion

Depending on the supply chain area, risks can be related to supply, demand, product, system delay, inventory, capacity, or information. These risks can be modeled so as to optimize the supply chain network.

This thesis aims at designing a four echelon supply chain while considering risk and uncertainty especially supply and demand uncertainty. A quantitative model is developed which mainly focuses on supply chain network design with supplier and wholesaler location as well as capacity allocations while considering risk (penalty cost) and uncertainty (supply and demand uncertainty). Underestimating the impact of uncertainties of supply chain and optimizing under the assumptions of deterministic parameters is risky. Uncertainties of supply chain should be explicitly included in the decision making process. In this paper, a stochastic single objective optimization model have been considered for the supply chain network optimization problem under risk and uncertainty and finally cost effective supply chain network is forwarded. The main contribution of this paper is threefold: First it is the one among the few that develops an optimization model and based on the result of the optimization model a supply chain network have been designed particularly for the case study that aims at location allocation decision with the incorporation of risk and uncertainty into the model. Second sensitivity analysis of these uncertainty on the expected minimum cost have been conducted so as to generalize the impact of these uncertainty on the expected minimum cost. Third the study also contributes to the body of knowledge by developing a forward supply chain network and analysis of the real case study of textile industry (Yirgalem Addis textile factory in particular) in Addis Ababa. An illustrative case study, to illustrate the applicability and efficiency of the model was taken. With the application of the location – allocation optimization model proposed in this study about 9% cost reduction have been achieved from the existing supply chain structure which is quite significant for the sector.

The paper also conducted a sensitivity analysis of supply and demand uncertainty to make generalization on the impact of the minimum expected cost. The result of the sensitivity analysis shows that highest percentage cost reduction is obtained when supply is highly uncertain regardless to the level of demand uncertainty and when the supply uncertainty is

low, regardless to the demand uncertainty level, the percentage cost reduction is low. The result of the sensitivity analysis also shows that, when demand is highly uncertain, regardless to the level of supply uncertainty, the percentage cost reduction is high and when the demand uncertainty is low, regardless to the supply uncertainty level, the percentage cost reduction is low. The developed model as well as the sensitivity analysis is coded and solved using GAMS 24.8.3 build system.

Finally it is worth nothing that the author refined the problem statement by defining supply chain network design and related concepts and introduced the relevant back ground to decision making approach under risk and uncertainty. The author identified three methodological requirements to support decision making in supply chain network design under risk and uncertainty: a methodology to identify risk and uncertainty relevant to the decision problem, a methodology to handle these risk and uncertainty by using the different frameworks suggested in the literature(to mitigate risk and uncertainty since risk and uncertainty are difficult to avoid and accept) and optimization model to optimize the supply chain network under risk and uncertainty. In general the author concludes that designing a cost effective supply chain network by developing a mathematical model such as LP model with the incorporation of risk and uncertainty is a critical issues in today's competitive world and this may lead to the future research direction on the development of optimization model that incorporates the other risk and uncertainty types forwarded in this paper.

6.2.Recommendation

Supply Chain network design (SCND) is a principle emphasizing the utilization of an efficient integrated system of suppliers, producers, warehouses, retailers and customers, so that items can be produced and distributed system-wide at the right quantities, locations, and time to minimize costs and maximize services. Handling of the inherent supply chain risk and uncertainties as well as structuring the supply chain network while considering these issues is now the emerging point of today's competitive sectors. Underestimating the impact of uncertainties of supply chain and optimizing under the assumptions of deterministic parameters is risky. Uncertainties of supply chain should be explicitly included in the decision making process. Based on the findings of this study, the following major recommendations may be given.

- ✚ Though, the research is applied to textile industries, (Yirgalem Addis textile factory PLC in particular for model validation purpose), any kind of sector that is characterized with four echelon: supplier, plant, warehouse and wholesaler, can be adopted to his/her enterprise for a better performance on the location- allocation of their supplier, warehouse and wholesalers.
- ✚ The developed model is simple for implementation , and redesigning of the supply chain network may come up with a radical improvement on the performance of an enterprise(textile industries found in Addis Ababa in general and yirgalem Addis textile factory in particular).
- ✚ In this paper the author identified a methodology to handle risk and uncertainty in the supply chain network process(either to use avoid risk and uncertainty, accept risk and uncertainty or mitigate risk and uncertainty) together with the conceptual framework to manage risk and uncertainty in the supply chain network and it is the recommendation of the author for the company to use the later one since the first- two are difficult to apply together with the conceptual framework identified in the literature part.

6.3.Future Research Direction

This study has some limitations that represent opportunities for future research. Therefore in line with this study, the following future research direction can be forwarded so as to extend the work of this paper.

- The focus of this paper was on the development of single objective optimization model and further research can be done on the development of multi-objective optimization model with the objectives of transportation lead time minimization as well as maximizing risk reduction.
- This study was based on the supply chain network design under risk and uncertainty and it has not seen the causal relationship between the various risk and uncertainty identified in the study. Therefore a future research can be done on the identification of the causal relationship between these risk and uncertainty using different approaches like interpretive structural modeling(ISM) so that a model considering these risk and uncertainty with the highest causal relationship and increasing the complexity of the model by extending the model to include other risk and uncertainty can be developed for the supply chain network design problem.

Bibliography

- Amin, S. H. (2013). multi-objective facility location model for closed-loop supply chain network under uncertain demand and return. . *Applied Mathematical Modelling*, 37(6):, 4165- 4176.
- Aqlan, F. (2015). Supply chain optimization under risk and uncertainty: A case study for high end server manufacturing. *Computers & Industrial Engineering*.
- Aqlan, F. a. (2014). Integrating Lean Principles and Fuzzy Bow-Tie Analysis for Risk assessment in chemical industry. *Journal of Loss Prevention in the Process Industries Vol. 29* , 39-48.
- Aqlan, F. a. (2015). A Fuzzy-based Integrated Framework for Supply Chain Risk assessment. *International Journal of Production Economics, Vol. 161*., 54-63.
- Arlbjorn, J. S. (2002). Logistics knowledge creation: reflections on content context and processes. *International Journal of Physical Distribution and logistics management 32 (1)* , 22-40.
- Azad, N. a. (2013). Designing a Stochastic Distribution Network Model under Risk. *The International Journal of advanced manufacturing technology 64* , 23–40.
- Azaron, A. K. (2008). A Multi-objective Stochastic Programming Approach for Supply chain design considering risk. . *International Journal of Production Economics 116*: , 129–138.
- Badri, H. B. (2013). Integrated strategic and tactical planning in a supply chain network design with a heuristic solution method. *Comput. Oper. Res 40(4)*: , 1143-1154.
- Baghalian, A. S. (2013). Robust Supply Chain Network Design with Service Level against Disruptions and demand uncertainty A Real-life Case.”. *European Journal of Operational Research 227*: , , 199–215.
- Behnam Fahimnia, C. S. (2015). Quantitative Models for Managing supply chain Risks: A review. *euopean journal of operation research*,, 4-5.
- Blessing, L., & Chakrabarti, A. (2009). *DRM, a design research methodology* . london: Springer.
- Brewer, P. &. (2000). Using the balanced scorecard to measure supply chain performance. *Journal of Business Logistics*, , 75-79.
- Campuzano, F., & Mula, J. (2011). *Supply Chain Simulation: A System Dynamics Approach for improving performance*. New York:: Springer London Dordrecht Heidelberg.
- Carter, C.R., Rogers, D.S., (2008). A framework of sustainable supply chain management:moving toward new theory. *International Journal of Physical Distribution and logistics management 38(5)*., 360-387.
- Chen, I. P. (2004). Towards a theory of supply chain management : the constructs and measurements. *Journal of Operations Management* , 119-150.
- Chen, W.-S. &.-F. (2007). Modeling Product Diffusion by System Dynamics Approach. . *Journal of the Chinese Institute of Industrial Engineers, 24(5)* , 397-413.
- Chopra, S., Sodhi, M.S., (2004). Managing risk to avoid supply-chain breakdown. *MIT Sloan management Review*, 53-62.

- Christopher, M. and Towill, D. (2001). An integrated model for the design of agile supply chain. *International Journal of Physical Distribution & Logistics Management*, Vol. 31 No. 4,, 235-46.
- Christopher, M. L. (2004). Mitigating supply chain risk through improved confidence. *International Journal of Physical Distribution and Logistics Management*,, 388-396.
- Christopher, M. P. (2004). Building the resilient supply chain. . *International Journal of logistics management* 15 (2), , 1-13.
- Claypool, E. N. (2014). Modeling Risk in a Design for Supply Chain problem. . *Computers and Industrial Engineering*, Vol. 78, , 44-54.
- Colicchia, C. a. (2012). Supply chain risk management: a new methodology for a systematic Literature review. *international journal of supply chain management*,, 404-418.
- Cooper Martha c., D. M. (1997). supply chain management: More than new name for Logistics. *International journal of logistics management* , 1-14.
- Correia, I. M.-d.-G. (2013). Comparing classical performance measures for a multi-period, two echelon supply chain network design problem with sizing decisions. . *Comput. Ind. Eng.*, 64(1): , 366-380.
- Craighead, C. (2007). The severity of supply chain disruptions; design characteristics and mitigation capabilities. *Decision Science*, 131-156.
- Croxton, K. L.-D. (2001). the supply chain management process. . *The International Journal of Logistics management*, 13-36.
- Davenport, T. H. (1995). Managing Information about Processes. . *Journal of management information system*, 57-80.
- Davis., T. (1993). Effective Supply Chain Management. *Sloan Management sciences*, 35-46.
- Finch, P. (2004). “Supply chain risk management”, Supply Chain Management: . *An International journal*. Vol. 9 No. 2,, 183-96.
- G., Chaudhry H. and Hodge. (2012). Postponement and supply chain structure: cases from the textile industry and apparel industry. *Journal of Fashion Marketing and Management*, Vol. 16 (1), 64-80.
- Garrick, S. Kaplan and B. J. (1981). On the quantitative definition of risk. *Risk Analysis*, 1 risk Analysis, 1(1). 11-27.
- Georgiadis, M. C. (2011). Optimal Design of Supply Chain Networks under Uncertainty transient demand Variation. . *Omega* 39: , , 254–272.
- Goetschalckx, M. H. (2013). Trading off supply chain risk and efficiency through supply chain design . *Procedia Comput. Sci.*, 16:, , 658-667.
- Goh, M. L. (2007). A Stochastic model for Risk Management in Global Supply chain Networks. *European Journal of Operational Research*, Vol. 182(1), 164-173.

- Gordon, L. A.-Y. (2009). Enterprise risk management and firm performance. . *Journal of Accounting and public policy*, 301-327.
- Gunasekaran, A. a. (2004). "Virtual supply chain management". ., *Taylor & Francis Ltd., vol. 15, No. 6* , 584–595.
- Hahn, C. D. (2000). Supply chain synchronization:. lessons from Hyundai Motor Company”, *Interfaces*, Vol. 30 No. 4,, . 32-45.
- Hahn, G.J., Kuhn, H. (2012). Value-based performance and risk management in supply chains: a robust optimization approach. *Int. J. Prod. Econ.* , 139(1), 135-144.
- Hailu, Asseb. (2009). Model development of supply chain management system for textile and garment industry. *Addis Ababa University, thesis*.
- Handfield, R. B. (2002). *Supply chain redesign: Transforming supply chains into integrated value system*. FT Press.
- He, Y. a. (2012). Coordination in multi-echelon supply chain under supply and demand uncertainty. *International Journal of Production Economics* 139(1):, 106-115.
- Heckmann, I. (2015). A critical review on supply chain risk definition , measure and modeling. *Omega* , 119-132.
- Hendricks, K., and Singhal, V. (2005). Association between Supply Chain Glitches and Operation performance. *Management Science* Vol. 51, No. 5,, 695-711.
- Henriott, L. (1999). Transforming supply chains into e-chains”, . *Supply Chain Management review., Global Supplement, Spring* , , 15-8.
- Jüttner., U. (2003). supply chain risk management:Understanding the business requirements from a practitioner perspective. *International journal of logistics management* , 120-141.
- Johnson, M. (2001). Learning from toys: lessons in managing supply chain risk from the toy. . *California Management Review* 43 (3), 106-124.
- Kaebnick, S. K. (2008). "Reverse logistics Strategies for end-of-life products. *Logistic management, vol. 19* , 367-388.
- Khan, O. and Burnes, B.,. (2007). Risk and supply chain management: Creating a research agenda. *International Journal of Logistics Management* 18 (2),, 197-216.
- Khor, K. U. (2012). Impact of reverse logistics product disposition towards business performance in Malaysian E&E companies. . *J. Supply Chain. Management science* , 1.
- Kleindorfer, P. S. (2005). Managing disruption risks in supply chains. . *Journal of Production and operation management* , 53-68.
- Kouvelis, P., Chambers, C., Wang, H.,. (2006). Supply chain management research and operation management review. *Production and operation management,15(3)*, 449-469.
- Kumar, S. K. (2013). Supply Chain System Design Integrated with Risk Pooling. ” . *Computers & Industrial Engineering* 64,, 580–588.

- Lambert, D. M. (2004). *Supply Chain Management: Processes, Partnerships, Performance*, Sarasota,. *Supply Chain Management Institute*.
- Lambert, D. M.-D. (2005). An Evaluation of Process oriented supply chain management framework. *International Journal of Business Logistics*, , 25-51.
- Lee, H. (2002). Aligning supply chain strategies with product uncertainties. . *California management review*, 105-119.
- Lee, H. (2004). The triple supply chain . *Harvard Business Review*, 102-112.
- Liu, Z. (2009). Risk Mitigation of Supply Chain Disruptions PhD Dissertation, Northwestern University.
- M. A. Vonderembse, M. U. (2006). Designing supply chain. towards Theory development. *International Journal of Production Economics*, ., 223–238.
- Mak, H. Y. (2012). Risk Diversification and Risk Pooling in Supply Chain Design. *IIE Transactions* 44:., 603-621.
- Mentzer, I. M. (2008). Global supply chain risk management strategies. . *International journal of distributions and logistics management*, , 192-223.
- Mentzer, J. a. (1994). Logistics control system in 21st century. *Journal of business logistics*, , 215-227.
- Mentzer, J. T. (2001). Defining supply chain management. *Journal of business logistics*, , 1-25.
- Merna, T., & Al-Thani, F. F. . (2005). *Corporate risk management*. England: England.
- Meyr., S. K. (2009.). Strategic network planning for an international automotive manufacturer. *OR Spectrum*, 31(3):, 507–532,.
- Miller., K. D. (1992). A Framework for integrated risk management in international bussiness. *Journal of International Business Studies*,, 311-331.
- Nima H., M. A. (2014). Supply chain network optimization considering assembly line balancing and demand uncertainty. *International Journal of Production Research*.
- Norrman, A. a. (2002). Supply chain risk management: purchasers' vs planners' views on sharing capacity investment risks in the telecom industry". 577-595.
- Pan, F. N. (2010). Robust supply chain design under uncertain demand in agile manufacturing. . *Comput. Oper Res.* 37(4):, 668-683.
- Park, S. T. (2010). "A Three-level Supply Chain Network Design Model with Risk-pooling and Lead times.". *Transportation Research Part E: Logistics and Transportation Review* 46: , , 563–581.
- Paulson, U. (2005). Developing a supply chain flow risk model. *NOFOMA 2005 Conference* . Copenhagen,.

- Pishvae, M. a. (2010). A possibilistic programming approach for closed loop supply chain network design under uncertainty. *Fuzzy Sets and Systems* 161(20):, , 2668-2683.
- Pishvae, M. S. (2011). a robust optimization approach to closed-loop supply chain network design under uncertainty . *Mathematical Modelling*, 35(2):, , 637-649.
- Poojari, C. A. (2008). Robust Solutions and Risk Measures for a Supply Chain Planning Problem under uncertainty. . *Journal of the Operational Research Society* 59: , , 2–12.
- Qiang, P. a. (2012). A bi-criteria Indicator to Assess Supply Chain Network Performance for Critical Needs under capacity and demand disruptions. *Transportation Research Part A* 46, , 801–812.
- Quinn, F. (2006). Risk business. . *Supply Chain Management Review*, 5.
- R.Sridharan, S. a. (2014). Reverse logistics; A review of literature,". *Research in engineering and technology*.
- Rice, J. C. (2003). Building a secure and resilient supply network. *Supply chain management review* 7 (5),, 22-30.
- Ross, A. M. (1998). Reconfiguring the Supply Network Using Current Performance Data. *Decision Science*, 707-728.
- Sahay, B. a. (2002). “Supply chain: a shift from transactional to collaborative partnership”,. *Decision sCIENCE*, Vol. 29 No. 2, , 67-88.
- Salem, R. W. (2015). Supply Chain Network Design Under Supply and Demand uncertainties.
- Salema, M. I-P. (2007). an optimization model for the design of a capacitated multi-product reverse logistics network with uncertainty. *European Journal of Operational Research*, 179(3):, , 1063-1077.
- Santoso, T. A. (2005). a stochastic programming approach for supply chain network design under uncertainty. *European Journal of Operational Research*, 167(1):, 96- 115.
- Sarkar, A., and Mohapatra, P.K. (2009). Determining the Optimal Size of Supply Base with the consideration of risks of supply disruptions. *International Journal of Production Economics* Vol. 122(1), 122-135.
- Schutz, P. T. (2009). Supply chain design under uncertainty using sample average approximation and dual decomposition. *European journal of Operational Research*, 199(2):, , 409-419.
- Shad, D. a. (2000). "Developing a Theory of Reverse logistics,". . *ProQuest Science Journal*, , 143.
- Sheffi, Y. (2005). A supply chain view of the resilient enterprise. . *MIT slogan management review* .
- Sinha, P. W. (2004). Methodology to mitigate supplier risk in an aerospace supply chain”,. Supply Chain Management: . *An International Journal*, Vol. 9 No. 2,, , 154-168.
- Snyder, L. V. (2010). operation research or management science models for supply chain disruptions: A review. *SSRN eLibrary*.

- Spekman, R. D. (2004). Risky business: expanding the discussion on risk and the extended enterprise. *International Journal of Physical Distribution and Logistics management* 34 (5), , 414-433.
- Spekman, R. D. (2006). Risk Business: expanding the discussion on risk and the extended enterprise. *International Journal of Physical Distribution and Logistics management*, , 414-433.
- Stewart., T. J. (2005). Dealing with uncertainties in multi criteria decision analysis(MCDA). . *international journal*, 445–470.
- Tabrizi, B. R. (2013). Introducing a mixed-integer nonlinear fuzzy model for risk management in designing supply chain network. *J. Manuf. Syst.*, 32(2), , 295-307.
- Tang, C. (2006). Perspectives in supply chain risk management. *International Journal of Production Economics*, 451-488.
- Tang, C. (2008). The power of Flexibility for mitigating supply chain risks . *International journal of production economics* ,, 12-27.
- Thanh, P. P. (2010.). A linear relaxation based approach for logistics network design. *Comput. Ind. engineering* 59(4), , 964-975.
- Tiwari, M. R. (2010). A hybrid taguchi-immune approach to optimize an integrated supply chain design problem with multiple ship. . *Eur. J. Oper. Res.*, 203(1): , 95-106.
- Tummala, R., Schoenherr, T. (2011). Assessing and managing risks using the supply risk management process (SCRMP). *Supply Chain Manag. . An Int. J.* 16 (6),, 474-483.
- Van der Vorst, J. G. (2000). Identifying sources of uncertainty to generate supply chain redesign strategies. *International Journal of Physical distribution and logistics management* 32(6):, 409- 430.
- Venkatesan, S. a. (2012). Multi-Objective Supply Chain Sourcing Strategy Design under Risk Using PSO and Simulation. *International Journal of Advanced Manufacturing Technology, Vol. 61, No. 3-4* , , 325-337.
- Verdegay, D. P. (2009). Fuzzy optimization for supply chain planning under supply,demand and process uncertainty. *Fuzzy Sets and Systems*160, 2640–2657.
- Viduto, V. M.-P. (2012). A Novel Risk Assessment and Optimization Model for a Multi-Objective Network Security Countermeasure Selection problem. . *Decision Support Systems, Vol. 53(3)*, 599-610.
- Wagner, S. M. (2008). An Empirical Examination of Supply Chain Performance along Several Dimensions of Risk Vol.29 No.1. . *Journal of business logistics* , 307-325.
- Wang, C. X. (2007). Channel Coordination for a Supply Chain with a Risk-Neutral Manufacturer and a Loss-Averse Retailer. . *Decision Sciences*, 38, ., 361-389.
- Waters, D. (2007). *Supply Chain Risk Management: Vulnerability and Resilience in Logistics*,. London UK: : KoganPage Ltd.
- William Ho, T. Z. (2015). Supply chain Risk Management: a Literature Review. . *International journal production Research*, 5059-5061.

- Wu, T., & Blackhurst, J. (2009). *Managing supply chain risk and vulnerability:Tools and methods for supply chain decision makers.* : . London, UK: Springer-Verlag.
- Zairi, M. (1997). Business Process Management: A Boundaryless Approach to Modern competitiveness. *Business process Re engineering and management journal*,, 64.
- Zhang, G. S. (2011). Collaborative production planning of supply under price and demand uncertainty. . *European Journal of Operational Research* 215(3),, 590-603.
- Zsidisin, G. .. (2003). Managerial Perception of Supply risk. . *Journal of Supply Chain management*, 14-26.
- Zsidisin, G. a. (2009). *Supply Chain Risk: A Handbook of Assessment, management and performance.* New York, NY: : Springer.
- Zsidisin, G. A. (2000). Purchasing organization involvement in risk assessments, contingency plans, and risk management: an exploratory study. *Supply Chain Management: 5(4):. An International Journal* , 187-198.

Appendix

Annex A: Result of the Optimization Model for the Hypothetical Testing

1GAMS 24.8.3 r60202 Released Jan 28, 2017 WEX-WEI x86 64bit/MS Windows 06/08/17 18:07:59
Page 1

General Algebraic Modeling System

Compilation

1 positive variables y1, y2, y3, y4, y5, y6, y7, y8, y9, y10, y11, y12, y13, y14, y15, y16, y17, y18, y19, y20, y21, y22, y23, y24, y25, y26, y27, y28, y29, y30, y31, y32, y33, y34, y35, y36, y37, y38, y39, y40, y41, y42, y43, y44;

2 free variable z;

3 equations

4 Con1,

5 Con2,

6 Con3,

7 Con4,

8 Con5,

9 Con6,

10 Con7,

11 Con8,

12 Con9,

13 Con10,

14 Con11,

15 Con12,

16 Con13,

17 Con14,

18 Con15,

19 Con16,

20 Con17,

21 Con18,

- 22 Con19,
23 Con20,
24 Con21,
25 Con22,
26 Con23,
27 Con24,
28 Con25,
29 Con26,
30 Con27,
31 Con28,
32 Con29,
33 Con30,
34 obj;
35 Con1.. $y_1 + y_3 + y_6 = G = 300$;
36 Con2.. $y_2 + y_4 + y_8 = G = 350$;
37 Con3.. $y_5 + y_{10} = G = 400$;
38 Con4.. $y_7 + y_9 + y_{11} = G = 450$;
39 Con5.. $y_{12} + y_{14} + y_{18} = G = 500$;
40 Con6.. $y_{13} + y_{15} + y_{19} = G = 550$;
41 Con7.. $y_{17} + y_{20} + y_{23} = G = 600$;
42 Con8.. $y_{21} + y_{24} = G = 650$;
43 Con9.. $y_{16} + y_{22} + y_{25} = G = 700$;
44 Con10.. $y_{26} + y_{32} + y_{36} = G = 750$;
45 Con11.. $y_{27} + y_{29} = G = 800$;
46 Con12.. $y_{30} + y_{33} + y_{37} = G = 850$;
47 Con13.. $y_{34} + y_{38} + y_{41} = G = 900$;
48 Con14.. $y_{31} + y_{28} + y_{42} = G = 950$;
49 Con15.. $y_{35} + y_{39} + y_{43} = G = 100$;

-
- 50 Con16.. $y_{40} + y_{44} = G = 1050$;
- 51 Con17.. $y_1 + y_2 = L = 400$;
- 52 Con18.. $y_3 + y_4 + y_5 = L = 500$;
- 53 Con19.. $y_6 + y_7 = L = 600$;
- 54 Con20.. $y_8 + y_9 = L = 700$;
- 55 Con21.. $y_{10} + y_{11} = L = 800$;
- 56 Con22.. $y_{12} + y_{13} = L = 900$;
- 57 Con23.. $y_{14} + y_{15} + y_{16} + y_{17} = L = 1000$;
- 58 Con24.. $y_{18} + y_{19} + y_{20} + y_{21} + y_{22} = L = 1100$;
- 59 Con25.. $y_{23} + y_{24} + y_{25} = L = 1200$;
- 60 Con26.. $y_{26} + y_{27} + y_{28} = L = 1300$;
- 61 Con27.. $y_{29} + y_{30} + y_{31} = L = 1400$;
- 62 Con28.. $y_{32} + y_{33} + y_{34} + y_{35} = L = 1500$;
- 63 Con29.. $y_{36} + y_{37} + y_{38} + y_{39} + y_{40} = L = 1600$;
- 64 Con30.. $y_{41} + y_{42} + y_{43} + y_{44} = L = 1700$;
- 65 obj.. $0.6*y_1 + 0.35*y_2 + 0.4*y_3 + 0.71*y_4 + 0.3*y_5 + 0.21*y_6 + 0.16*y_7 + 0.49$
 $*y_8 + 0.25*y_9 + 0.63*y_{10} + 0.8*y_{11} + 0.68*y_{12} + 0.81*y_{13} + 0.18*y_{14} + 0.62$
 $*y_{15} + 0.5*y_{16} + 0.2*y_{17} + 0.3*y_{18} + 0.42*y_{19} + 0.3*y_{20} + 0.15*y_{21} + 0.51*$
 $y_{22} + 0.7*y_{23} + 0.6*y_{24} + 0.4*y_{25} + 0.32*y_{26} + 0.87*y_{27} + 0.19*y_{28} + 0.6*y$
 $29 + 0.2*y_{30} + 0.33*y_{31} + 0.35*y_{32} + 0.21*y_{33} + 0.16*y_{34} + 0.6*y_{35} + 0.8*y_3$
 $6 + 0.6*y_{37} + 0.52*y_{38} + 0.28*y_{39} + 0.73*y_{40} + 0.71*y_{41} + 0.68*y_{42} + 0.86*y_{43} + 0.56*y_{44}$
 $= L = z$;
- 66 model hypothetical testing /
- 67 Con1,
- 68 Con2,
- 69 Con3,
- 70 Con4,
- 71 Con5,
- 72 Con6,
-

73 Con7,
74 Con8,
75 Con9,
76 Con10,
77 Con11,
78 Con12,
79 Con13,
80 Con14,
81 Con15,
82 Con16,
83 Con17,
84 Con18,
85 Con19,
86 Con20,
87 Con21,
88 Con22,
89 Con23,
90 Con24,
91 Con25,
92 Con26,
93 Con27,
94 Con28,
95 Con29,
96 Con30,
97 obj/;
98 options LP = Cplex;
99 solve hypothetical testing using LP minimizing z;
100 Display y1.L, y2.L, y3.L, y4.L, y5.L, y6.L, y7.L, y8.L, y9.L, y10.L, y11.L , y12.L, y13.L,
y14.L, y15.L, y16.L, y17.L, y18.L, y19.L, y20.L, y21.L, y22.L, y23.L, y24.L, y25.L, y26.L, y27.L,

y28.L, y29.L, y30.L, y31.L, y32.L, y33.L, y34.L, y35.L, y36.L, y37.L, y38.L, y39.L, y40.L, y41.L, y42.L, y43.L, y44.L, z. L;

COMPILATION TIME = 0.000 SECONDS 2 MB 24.8.3 r60202 WEX-WEI

1GAMS 24.8.3 r60202 Released Jan 28, 2017 WEX-WEI x86 64bit/MS Windows 06/08/17 18:07:59
Page 2

General Algebraic Modeling System

Equation Listing SOLVE hypothetical testing Using LP From line 99

---- Con1 =G=

Con1.. $y_1 + y_3 + y_6 = G = 300$; (LHS = 0, INFES = 300 *****)

---- Con2 =G=

Con2.. $y_2 + y_4 + y_8 = G = 350$; (LHS = 0, INFES = 350 *****)

---- Con3 =G=

Con3.. $y_5 + y_{10} = G = 400$; (LHS = 0, INFES = 400 *****)

---- Con4 =G=

Con4.. $y_7 + y_9 + y_{11} = G = 450$; (LHS = 0, INFES = 450 *****)

---- Con5 =G=

Con5.. $y_{12} + y_{14} + y_{18} = G = 500$; (LHS = 0, INFES = 500 *****)

---- Con6 =G=

Con6.. $y_{13} + y_{15} + y_{19} = G = 550$; (LHS = 0, INFES = 550 *****)

---- Con7 =G=

Con7.. $y_{17} + y_{20} + y_{23} = G = 600$; (LHS = 0, INFES = 600 *****)

---- Con8 =G=

Con8.. $y_{21} + y_{24} = G = 650$; (LHS = 0, INFES = 650 *****)

---- Con9 =G=

Con9.. $y_{16} + y_{22} + y_{25} = G = 700$; (LHS = 0, INFES = 700 *****)

---- Con10 =G=

Con10.. $y_{26} + y_{32} + y_{36} = G = 750$; (LHS = 0, INFES = 750 *****)

---- Con11 =G=

Con11.. $y_{27} + y_{29} = G = 800$; (LHS = 0, INFES = 800 *****)

---- Con12 =G=

Con12.. $y_{30} + y_{33} + y_{37} = G = 850$; (LHS = 0, INFES = 850 *****)

---- Con13 =G=

Con13.. $y_{34} + y_{38} + y_{41} = G = 900$; (LHS = 0, INFES = 900 *****)

---- Con14 =G=

Con14.. $y_{28} + y_{31} + y_{42} = G = 950$; (LHS = 0, INFES = 950 *****)

---- Con15 =G=

Con15.. $y_{35} + y_{39} + y_{43} = G = 100$; (LHS = 0, INFES = 100 *****)

---- Con16 =G=

Con16.. $y_{40} + y_{44} = G = 1050$; (LHS = 0, INFES = 1050 *****)

---- Con17 =L=

Con17.. $y_1 + y_2 = L = 400$; (LHS = 0)

---- Con18 =L=

Con18.. $y_3 + y_4 + y_5 = L = 500$; (LHS = 0)

---- Con19 =L=

Con19.. $y_6 + y_7 = L = 600$; (LHS = 0)

---- Con20 =L=

Con20.. $y_8 + y_9 = L = 700$; (LHS = 0)

---- Con21 =L=

Con21.. $y_{10} + y_{11} = L = 800$; (LHS = 0)

---- Con22 =L=

Con22.. $y_{12} + y_{13} = L = 900$; (LHS = 0)

---- Con23 =L=

Con23.. $y_{14} + y_{15} + y_{16} + y_{17} = L = 1000$; (LHS = 0)

---- Con24 =L=

Con24.. $y_{18} + y_{19} + y_{20} + y_{21} + y_{22} = L = 1100$; (LHS = 0)

---- Con25 =L=

Con25.. $y_{23} + y_{24} + y_{25} = L = 1200$; (LHS = 0)

---- Con26 =L=

Con26.. $y_{26} + y_{27} + y_{28} =L= 1300$; (LHS = 0)

---- Con27 =L=

Con27.. $y_{29} + y_{30} + y_{31} =L= 1400$; (LHS = 0)

---- Con28 =L=

Con28.. $y_{32} + y_{33} + y_{34} + y_{35} =L= 1500$; (LHS = 0)

---- Con29 =L=

Con29.. $y_{36} + y_{37} + y_{38} + y_{39} + y_{40} =L= 1600$; (LHS = 0)

---- Con30 =L=

Con30.. $y_{41} + y_{42} + y_{43} + y_{44} =L= 1700$; (LHS = 0)

---- obj =L=

obj.. $0.6*y_1 + 0.35*y_2 + 0.4*y_3 + 0.71*y_4 + 0.3*y_5 + 0.21*y_6 + 0.16*y_7 + 0.49*y_8 + 0.25*y_9 + 0.63*y_{10} + 0.8*y_{11} + 0.68*y_{12} + 0.81*y_{13} + 0.18*y_{14} + 0.62*y_{15} + 0.5*y_{16} + 0.2*y_{17} + 0.3*y_{18} + 0.42*y_{19} + 0.3*y_{20} + 0.15*y_{21} + 0.51*y_{22} + 0.7*y_{23} + 0.6*y_{24} + 0.4*y_{25} + 0.32*y_{26} + 0.87*y_{27} + 0.19*y_{28} + 0.6*y_{29} + 0.2*y_{30} + 0.33*y_{31} + 0.35*y_{32} + 0.21*y_{33} + 0.16*y_{34} + 0.6*y_{35} + 0.8*y_{36} + 0.6*y_{37} + 0.52*y_{38} + 0.28*y_{39} + 0.73*y_{40} + 0.71*y_{41} + 0.68*y_{42} + 0.86*y_{43} + 0.56*y_{44} - z =L= 0$; (LHS = 0)

1GAMS 24.8.3 r60202 Released Jan 28, 2017 WEX-WEI x86 64bit/MS Windows 06/08/17 18:07:59
Page 3

General Algebraic Modeling System

Column Listing SOLVE hypothetical testing Using LP From line 99

---- y1

y1

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con1

1 Con17

0.6 obj

---- y2

y2

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con2

```
1   Con17
0.35 obj
---- y3
y3
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con1
1   Con18
0.4  obj
---- y4
y4
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con2
1   Con18
0.71 obj
---- y5
y5
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con3
1   Con18
0.3  obj
---- y6
y6
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con1
1   Con19
0.21 obj
---- y7
y7
```

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con4

1 Con19

0.16 obj

---- y8

y8

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con2

1 Con20

0.49 obj

---- y9

y9

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con4

1 Con20

0.25 obj

---- y10

y10

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con3

1 Con21

0.63 obj

---- y11

y11

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con4

1 Con21

0.8 obj

---- y12

y12

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con5

1 Con22

0.68 obj

---- y13

y13

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con6

1 Con22

0.81 obj

---- y14

y14

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con5

1 Con23

0.18 obj

---- y15

y15

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con6

1 Con23

0.62 obj

---- y16

y16

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con9

```
1   Con23
0.5 obj
---- y17
y17
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con7
1   Con23
0.2 obj
---- y18
y18
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con5
1   Con24
0.3 obj
---- y19
y19
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con6
1   Con24
0.42 obj
---- y20
y20
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con7
1   Con24
0.3 obj
---- y21
y21
```

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con8

1 Con24

0.15 obj

---- y22

y22

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con9

1 Con24

0.51 obj

---- y23

y23

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con7

1 Con25

0.7 obj

---- y24

y24

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con8

1 Con25

0.6 obj

---- y25

y25

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con9

1 Con25

0.4 obj

---- y26

y26

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con10

1 Con26

0.32 obj

---- y27

y27

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con11

1 Con26

0.87 obj

---- y28

y28

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con14

1 Con26

0.19 obj

---- y29

y29

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con11

1 Con27

0.6 obj

---- y30

y30

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con12

```
1   Con27
0.2  obj
---- y31
y31
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con14
1   Con27
0.33 obj
---- y32
y32
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con10
1   Con28
0.35 obj
---- y33
y33
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con12
1   Con28
0.21 obj
---- y34
y34
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con13
1   Con28
0.16 obj
---- y35
y35
```

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con15

1 Con28

0.6 obj

---- y36

y36

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con10

1 Con29

0.8 obj

---- y37

y37

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con12

1 Con29

0.6 obj

---- y38

y38

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con13

1 Con29

0.52 obj

---- y39

y39

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con15

1 Con29

0.28 obj

---- y40

y40

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con16

1 Con29

0.73 obj

---- y41

y41

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con13

1 Con30

0.71 obj

---- y42

y42

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con14

1 Con30

0.68 obj

---- y43

y43

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con15

1 Con30

0.86 obj

---- y44

y44

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con16

1 Con30

0.56 obj

---- z

z

(.LO, .L, .UP, .M = -INF, 0, +INF, 0)

-1 obj

1GAMS 24.8.3 r60202 Released Jan 28, 2017 WEX-WEI x86 64bit/MS Windows 06/08/17 18:07:59
Page 4

General Algebraic Modeling System

Model Statistics SOLVE hypothetical testing Using LP From line 99

MODEL STATISTICS

BLOCKS OF EQUATIONS 31 SINGLE EQUATIONS 31

BLOCKS OF VARIABLES 45 SINGLE VARIABLES 45

NON ZERO ELEMENTS 133

GENERATION TIME = 0.031 SECONDS 3 MB 24.8.3 r60202 WEX-WEI

EXECUTION TIME = 0.031 SECONDS 3 MB 24.8.3 r60202 WEX-WEI

1GAMS 24.8.3 r60202 Released Jan 28, 2017 WEX-WEI x86 64bit/MS Windows 06/08/17 18:07:59
Page 5

General Algebraic Modeling System

Solution Report SOLVE hypothetical testing Using LP From line 99

SOLVE SUMMARY

MODEL hypothetical testing OBJECTIVE z

TYPE LP DIRECTION MINIMIZE

SOLVER CPLEX FROM LINE 99

**** SOLVER STATUS 1 Normal Completion

**** MODEL STATUS 1 Optimal

**** OBJECTIVE VALUE 3160.5000

RESOURCE USAGE, LIMIT 0.000 1000.000

ITERATION COUNT, LIMIT 22 2000000000

IBM ILOG CPLEX 24.8.3 r60202 Released Jan 28, 2017 WEI x86 64bit/MS Windows

Cplex 12.7.0.0

Space for names approximately 0.00 Mb

Use option 'names no' to turn use of names off

LP status(1): optimal

Cplex Time: 0.00sec (det. 0.07 ticks)

Optimal solution found.

Objective : 3160.500000

	LOWER	LEVEL	UPPER	MARGINAL
--- EQU Con1	300.000	300.000	+INF	0.300
--- EQU Con2	350.000	350.000	+INF	0.350
--- EQU Con3	400.000	400.000	+INF	0.300
--- EQU Con4	450.000	450.000	+INF	0.250
--- EQU Con5	500.000	500.000	+INF	0.670
--- EQU Con6	550.000	550.000	+INF	0.810
--- EQU Con7	600.000	600.000	+INF	0.690
--- EQU Con8	650.000	650.000	+INF	0.540
--- EQU Con9	700.000	700.000	+INF	0.400
--- EQU Con10	750.000	750.000	+INF	0.710
--- EQU Con11	800.000	800.000	+INF	0.970
--- EQU Con12	850.000	850.000	+INF	0.570
--- EQU Con13	900.000	900.000	+INF	0.520
--- EQU Con14	950.000	950.000	+INF	0.580
--- EQU Con15	100.000	100.000	+INF	0.280
--- EQU Con16	1050.000	1050.000	+INF	0.560
--- EQU Con17	-INF	350.000	400.000	.
--- EQU Con18	-INF	400.000	500.000	.

---- EQU Con19	-INF	600.000	600.000	-0.090
---- EQU Con20	-INF	150.000	700.000	.
---- EQU Con21	-INF	.	800.000	.
---- EQU Con22	-INF	200.000	900.000	.
---- EQU Con23	-INF	1000.000	1000.000	-0.490
---- EQU Con24	-INF	1100.000	1100.000	-0.390
---- EQU Con25	-INF	700.000	1200.000	.
---- EQU Con26	-INF	1300.000	1300.000	-0.390
---- EQU Con27	-INF	1400.000	1400.000	-0.370
---- EQU Con28	-INF	1500.000	1500.000	-0.360
---- EQU Con29	-INF	150.000	1600.000	.
---- EQU Con30	-INF	1050.000	1700.000	.
---- EQU obj	-INF	.	.	-1.000

LOWER LEVEL UPPER MARGINAL

---- VAR y1	.	.	+INF	0.300
---- VAR y2	.	350.000	+INF	.
---- VAR y3	.	.	+INF	0.100
---- VAR y4	.	.	+INF	0.360
---- VAR y5	.	400.000	+INF	.
---- VAR y6	.	300.000	+INF	.
---- VAR y7	.	300.000	+INF	.
---- VAR y8	.	.	+INF	0.140
---- VAR y9	.	150.000	+INF	.
---- VAR y10	.	.	+INF	0.330
---- VAR y11	.	.	+INF	0.550
---- VAR y12	.	.	+INF	0.010

----	VAR y13	.	200.000	+INF	.
----	VAR y14	.	500.000	+INF	.
----	VAR y15	.	.	+INF	0.300
----	VAR y16	.	.	+INF	0.590
----	VAR y17	.	500.000	+INF	.
----	VAR y18	.	.	+INF	0.020
----	VAR y19	.	350.000	+INF	.
----	VAR y20	.	100.000	+INF	.
----	VAR y21	.	650.000	+INF	.
----	VAR y22	.	.	+INF	0.500
----	VAR y23	.	.	+INF	0.010
----	VAR y24	.	.	+INF	0.060
----	VAR y25	.	700.000	+INF	.
----	VAR y26	.	350.000	+INF	.
----	VAR y27	.	.	+INF	0.290
----	VAR y28	.	950.000	+INF	.
----	VAR y29	.	800.000	+INF	.
----	VAR y30	.	600.000	+INF	.
----	VAR y31	.	.	+INF	0.120
----	VAR y32	.	400.000	+INF	.
----	VAR y33	.	250.000	+INF	.
----	VAR y34	.	850.000	+INF	.
----	VAR y35	.	.	+INF	0.680
----	VAR y36	.	.	+INF	0.090
----	VAR y37	.	.	+INF	0.030
----	VAR y38	.	50.000	+INF	.
----	VAR y39	.	100.000	+INF	.
----	VAR y40	.	.	+INF	0.170

```

---- VAR y41      .      .      +INF    0.190
---- VAR y42      .      .      +INF    0.100
---- VAR y43      .      .      +INF    0.580
---- VAR y44      .    1050.000  +INF      .
---- VAR z        -INF  3160.500  +INF      .
**** REPORT SUMMARY :    0  NONOPT

```

0 INFEASIBLE

0 UNBOUNDED

1GAMS 24.8.3 r60202 Released Jan 28, 2017 WEX-WEI x86 64bit/MS Windows 06/08/17 18:07:59
Page 6

General Algebraic Modeling System

Execution

```

---- 100 VARIABLE y1.L      =    0.000
      VARIABLE y2.L      =   350.000
      VARIABLE y3.L      =    0.000
      VARIABLE y4.L      =    0.000
      VARIABLE y5.L      =   400.000
      VARIABLE y6.L      =   300.000
      VARIABLE y7.L      =   300.000
      VARIABLE y8.L      =    0.000
      VARIABLE y9.L      =   150.000
      VARIABLE y10.L     =    0.000
      VARIABLE y11.L     =    0.000
      VARIABLE y12.L     =    0.000
      VARIABLE y13.L     =   200.000
      VARIABLE y14.L     =   500.000
      VARIABLE y15.L     =    0.000
      VARIABLE y16.L     =    0.000
      VARIABLE y17.L     =   500.000

```

VARIABLE y18.L	=	0.000
VARIABLE y19.L	=	350.000
VARIABLE y20.L	=	100.000
VARIABLE y21.L	=	650.000
VARIABLE y22.L	=	0.000
VARIABLE y23.L	=	0.000
VARIABLE y24.L	=	0.000
VARIABLE y25.L	=	700.000
VARIABLE y26.L	=	350.000
VARIABLE y27.L	=	0.000
VARIABLE y28.L	=	950.000
VARIABLE y29.L	=	800.000
VARIABLE y30.L	=	600.000
VARIABLE y31.L	=	0.000
VARIABLE y32.L	=	400.000
VARIABLE y33.L	=	250.000
VARIABLE y34.L	=	850.000
VARIABLE y35.L	=	0.000
VARIABLE y36.L	=	0.000
VARIABLE y37.L	=	0.000
VARIABLE y38.L	=	50.000
VARIABLE y39.L	=	100.000
VARIABLE y40.L	=	0.000
VARIABLE y41.L	=	0.000
VARIABLE y42.L	=	0.000
VARIABLE y43.L	=	0.000
VARIABLE y44.L	=	1050.000
VARIABLE z. L	=	3160.500

EXECUTION TIME = 0.000 SECONDS 2 MB 24.8.3 r60202 WEX-WEI

USER: GAMS Development Corporation, Washington, DC G871201/0000CA-ANY

Free Demo, 202-342-0180, sales@gams.com, www.gams.com DC0000

**** FILE SUMMARY

Input C:\Users\user\Documents\gamsdir\projdir\Hypothetical Testing.gms

Output C:\Users\user\Documents\gamsdir\projdir\Hypothetical Testing.lst

Appendix B: Result of the Optimization Model for the Case Study

1GAMS 24.8.3 r60202 Released Jan 28, 2017 WEX-WEI x86 64bit/MS Windows 06/06/17 20:27:47

Page 1

General Algebraic Modeling System

Compilation

1 Positive variables x1, x2, x3, x4, x5, x6, x7, x8, x9, x10, x11, x12, x13, x14, x15, x16; 2 Free variable z;

3 Equations

4 Con1, the sum of amount transported from each supplier to plant should be greater or equal to plant demand

5 Con2, amount transported from plant to warehouse should be greater or equal to warehouse demand

6 Con3, amount transported from warehouse to wholesaler '7' should be grater or equal to its demand

7 Con4, amount transported from warehouse to wholesaler '8' should be grater or equal to its demand

8 Con5, amount transported from warehouse to wholesaler '9' should be grater or equal to its demand

9 Con6, amount transported from warehouse to wholesaler '10' should be grater or equal to its demand

10 Con7, amount transported from warehouse to wholesaler '11' should be grater or equal to its demand

11 Con8, amount transported from warehouse to wholesaler '12' should be grater or equal to its demand

12 Con9, amount transported from warehouse to wholesaler '13' should be grater or equal to its demand

13 Con10, amount transported from warehouse to wholesaler '14' should be grater or equal to its demand

14 Con11, amount transported from warehouse to wholesaler '15' should be greater or equal to its demand

15 Con12, amount transported from warehouse to wholesaler '16' should be greater or equal to its demand

16 Con13, amount transported from supplier '1' should be less than or equal to its capacity

17 Con14, amount transported from supplier '2' should be less than or equal to its capacity

18 Con15, amount transported from supplier '3' should be less than or equal to its capacity

19 Con16, amount transported from supplier '4' should be less than or equal to its capacity

20 Con17, amount transported from supplier '5' should be less than or equal to its capacity

21 Con18, amount transported from plant to warehouse should be equal to its capacity

22 Con19, the sum of all amount from warehouse to wholesaler should be less than or equal to its capacity

23 Obj;

24 Con1.. $x_1 + x_2 + x_3 + x_4 + x_5 = G = 14800$;

25 Con2.. $x_6 = G = 9000$;

26 Con3.. $x_7 = G = 800$;

27 Con4.. $x_8 = G = 1000$;

28 Con5.. $x_9 = G = 1500$;

29 Con6.. $x_{10} = G = 1300$;

30 Con7.. $x_{11} = G = 1100$;

31 Con8.. $x_{12} = G = 1200$;

32 Con9.. $x_{13} = G = 900$;

33 Con10.. $x_{14} = G = 750$;

34 Con11.. $x_{15} = G = 690$;

35 Con12.. $x_{16} = G = 560$;

36 Con13.. $x_1 = L = 7500$;

37 Con14.. $x_2 = L = 1000$;

38 Con15.. $x_3 = L = 4820.61$;

39 Con16.. $x_4 = L = 5000$;

40 Con17.. $x_5 = L = 4697.43$;

41 Con18.. $x_6 = E = 10000$;

42 Con19.. $x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} = L = 9000$;

43 Obj.. $0.2*x_1 + 0.35*x_2 + 0.41*x_3 + 0.18*x_4 + 0.16*x_5 + 0.17*x_6 + 0.22*x_7 + 0.3*x_8 + 0.38*x_9 + 0.46*x_{10} + 0.5*x_{11} + 0.6*x_{12} + 0.18*x_{13} + 0.18*x_{14} + 0.19*x_{15} + 0.175*x_{16} = L = z$;

45 Model cost minimization /

46 Con1,

47 Con2,

48 Con3,

49 Con4,

50 Con5,

51 Con6,

52 Con7,

53 Con8,

54 Con9,

55 Con10,

56 Con11,

57 Con12,

58 Con13,

59 Con14,

60 Con15,

61 Con16,

62 Con17,

63 Con18,

64 Con19,

65 Obj /;

67 options LP = Cplex;

69 solve cost minimization using LP minimizing z;

71 Display $x_{1.L}, x_{2.L}, x_{3.L}, x_{4.L}, x_{5.L}, x_{6.L}, x_{7.L}, x_{8.L}, x_{9.L}, x_{10.L}, x_{11.L}$
 $, x_{12.L}, x_{13.L}, x_{14.L}, x_{15.L}, x_{16.L}, z.L$;

COMPILATION TIME = 0.000 SECONDS 2 MB 24.8.3 r60202 WEX-WEI

1GAMS 24.8.3 r60202 Released Jan 28, 2017 WEX-WEI x86 64bit/MS Windows 06/06/17 20:27:47
Page 2

General Algebraic Modeling System

Equation Listing SOLVE cost minimization Using LP From line 69

---- Con1 =G=

Con1.. $x_1 + x_2 + x_3 + x_4 + x_5 =G= 14800$; (LHS = 0, INFES = 14800 *****)

---- Con2 =G=

Con2.. $x_6 =G= 9000$; (LHS = 0, INFES = 9000 *****)

---- Con3 =G=

Con3.. $x_7 =G= 800$; (LHS = 0, INFES = 800 *****)

---- Con4 =G=

Con4.. $x_8 =G= 1000$; (LHS = 0, INFES = 1000 *****)

---- Con5 =G=

Con5.. $x_9 =G= 1500$; (LHS = 0, INFES = 1500 *****)

---- Con6 =G=

Con6.. $x_{10} =G= 1300$; (LHS = 0, INFES = 1300 *****)

---- Con7 =G=

Con7.. $x_{11} =G= 1100$; (LHS = 0, INFES = 1100 *****)

---- Con8 =G=

Con8.. $x_{12} =G= 1200$; (LHS = 0, INFES = 1200 *****)

---- Con9 =G=

Con9.. $x_{13} =G= 900$; (LHS = 0, INFES = 900 *****)

---- Con10 =G=

Con10.. $x_{14} =G= 750$; (LHS = 0, INFES = 750 *****)

---- Con11 =G=

Con11.. $x_{15} =G= 690$; (LHS = 0, INFES = 690 *****)

---- Con12 =G=

Con12.. $x_{16} =G= 560$; (LHS = 0, INFES = 560 *****)

```

---- Con13 =L=
Con13.. x1 =L= 7500 ; (LHS = 0)

---- Con14 =L=
Con14.. x2 =L= 1000 ; (LHS = 0)

---- Con15 =L=
Con15.. x3 =L= 4820.61 ; (LHS = 0)

---- Con16 =L=
Con16.. x4 =L= 5000 ; (LHS = 0)

---- Con17 =L=
Con17.. x5 =L= 4697.43 ; (LHS = 0)

---- Con18 =E=
Con18.. x6 =E= 10000 ; (LHS = 0, INFES = 10000 *****)

---- Con19 =L=
Con19.. x7 + x8 + x9 + x10 + x11 + x12 + x13 + x14 + x15 + x16 =L= 9000 ;
(LHS = 0)

---- Obj =L=
Obj.. 0.2*x1 + 0.35*x2 + 0.41*x3 + 0.18*x4 + 0.16*x5 + 0.17*x6 + 0.22*x7 + 0.3*x8 + 0.38*x9 +
0.46*x10 + 0.5*x11 + 0.6*x12 + 0.18*x13 + 0.18*x14 + 0.19*x15 + 0.175*x16 - z =L= 0 ; (LHS =
0)

```

1GAMS 24.8.3 r60202 Released Jan 28, 2017 WEX-WEI x86 64bit/MS Windows 06/06/17 20:27:47
Page 3

General Algebraic Modeling System

Column Listing SOLVE cost minimization Using LP From line 69

---- x1

x1

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con1

1 Con13

0.2 Obj

---- x2

x2

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con1

1 Con14

0.35 Obj

---- x3

x3

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con1

1 Con15

0.41 Obj

---- x4

x4

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con1

1 Con16

0.18 Obj

---- x5

x5

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con1

1 Con17

0.16 Obj

---- x6

x6

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con2

1 Con18

0.17 Obj

---- x7

x7

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con3

1 Con19

0.22 Obj

---- x8

x8

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con4

1 Con19

0.3 Obj

---- x9

x9

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con5

1 Con19

0.38 Obj

---- x10

x10

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con6

1 Con19

0.46 Obj

---- x11

x11

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

```
1   Con7
1   Con19
0.5 Obj
---- x12
x12
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con8
1   Con19
0.6 Obj
---- x13
x13
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con9
1   Con19
0.18 Obj
---- x14
x14
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con10
1   Con19
0.18 Obj
---- x15
x15
      (.LO, .L, .UP, .M = 0, 0, +INF, 0)
1   Con11
1   Con19
0.19 Obj
---- x16
```

x16

(.LO, .L, .UP, .M = 0, 0, +INF, 0)

1 Con12

1 Con19

0.175 Obj

---- z

Z

(.LO, .L, .UP, .M = -INF, 0, +INF, 0) -1 Obj

1GAMS 24.8.3 r60202 Released Jan 28, 2017 WEX-WEI x86 64bit/MS Windows 06/06/17
20:27:47 Page 4

General Algebraic Modeling System

Model Statistics SOLVE cost minimization Using LP From line 69

MODEL STATISTICS

BLOCKS OF EQUATIONS 20 SINGLE EQUATIONS 20

BLOCKS OF VARIABLES 17 SINGLE VARIABLES 17

NON ZERO ELEMENTS 49

GENERATION TIME = 0.047 SECONDS 3 MB 24.8.3 r60202 WEX-WEI

EXECUTION TIME = 0.047 SECONDS 3 MB 24.8.3 r60202 WEX-WEI

1GAMS 24.8.3 r60202 Released Jan 28, 2017 WEX-WEI x86 64bit/MS Windows 06/06/17 20:27:47
Page 5

General Algebraic Modeling System

Solution Report SOLVE cost minimization Using LP From line 69

SOLVE SUMMARY

MODEL cost minimization OBJECTIVE z

TYPE LP DIRECTION MINIMIZE

SOLVER CPLEX FROM LINE 69

**** SOLVER STATUS 1 Normal Completion

**** MODEL STATUS 4 Infeasible

**** OBJECTIVE VALUE 8456.5309

RESOURCE USAGE, LIMIT 0.015 1000.000

ITERATION COUNT, LIMIT 15 2000000000

IBM ILOG CPLEX 24.8.3 r60202 Released Jan 28, 2017 WEI x86 64bit/MS Windows

Cplex 12.7.0.0

Space for names approximately 0.00 Mb

Use option 'names no' to turn use of names off

LP status(3): infeasible

Cplex Time: 0.00sec (det. 0.00 ticks)

Rerunning with pre solve turned off and solving with LPMETHOD=0

LP status(3): infeasible

Cplex Time: 0.00sec (det. 0.02 ticks)

Model has been proven infeasible.

	LOWER	LEVEL	UPPER	MARGINAL	
---- EQU Con1	14800.000	14800.000	+INF	EPS	
---- EQU Con2	9000.000	10000.000	+INF	.	
---- EQU Con3	800.000	800.000	+INF	1.000	
---- EQU Con4	1000.000	1000.000	+INF	1.000	
---- EQU Con5	1500.000	1500.000	+INF	1.000	
---- EQU Con6	1300.000	500.000	+INF	1.000	INFES
---- EQU Con7	1100.000	1100.000	+INF	1.000	
---- EQU Con8	1200.000	1200.000	+INF	1.000	
---- EQU Con9	900.000	900.000	+INF	1.000	
---- EQU Con10	750.000	750.000	+INF	1.000	
---- EQU Con11	690.000	690.000	+INF	1.000	
---- EQU Con12	560.000	560.000	+INF	1.000	
---- EQU Con13	-INF	281.960	7500.000	.	
---- EQU Con14	-INF	.	1000.000	.	
---- EQU Con15	-INF	4820.610	4820.610	EPS	

```

---- EQU Con16      -INF  5000.000  5000.000  EPS
---- EQU Con17      -INF  4697.430  4697.430  EPS
---- EQU Con18      10000.000 10000.000 10000.000  EPS
---- EQU Con19      -INF  9000.000  9000.000  -1.000
---- EQU Obj        -INF  .      .      EPS
    
```

LOWER LEVEL UPPER MARGINAL

```

---- VAR x1        .  281.960  +INF  .
---- VAR x2        .  .      +INF  EPS
---- VAR x3        .  4820.610  +INF  .
---- VAR x4        .  5000.000  +INF  .
---- VAR x5        .  4697.430  +INF  .
---- VAR x6        .  10000.000  +INF  .
---- VAR x7        .  800.000  +INF  .
---- VAR x8        .  1000.000  +INF  .
---- VAR x9        .  1500.000  +INF  .
---- VAR x10       .  500.000  +INF  .
---- VAR x11       .  1100.000  +INF  .
---- VAR x12       .  1200.000  +INF  .
---- VAR x13       .  900.000  +INF  .
---- VAR x14       .  750.000  +INF  .
---- VAR x15       .  690.000  +INF  .
---- VAR x16       .  560.000  +INF  .
---- VAR z         -INF  8456.531  +INF  .
    
```

**** REPORT SUMMARY : 0 NONOPT

1 INFEASIBLE (INFES)

```

SUM  800.000
MAX  800.000
MEAN 800.000
    
```

0 UNBOUNDED

1GAMS 24.8.3 r60202 Released Jan 28, 2017 WEX-WEI x86 64bit/MS Windows 06/06/17 20:27:47
Page 6

General Algebraic Modeling System

Execution

```
---- 71 VARIABLE x1.L      = 281.960
      VARIABLE x2.L      = 0.000
      VARIABLE x3.L      = 4820.610
      VARIABLE x4.L      = 5000.000
      VARIABLE x5.L      = 4697.430
      VARIABLE x6.L      = 10000.000
      VARIABLE x7.L      = 800.000
      VARIABLE x8.L      = 1000.000
      VARIABLE x9.L      = 1500.000
      VARIABLE x10.L     = 500.000
      VARIABLE x11.L     = 1100.000
      VARIABLE x12.L     = 1200.000
      VARIABLE x13.L     = 900.000
      VARIABLE x14.L     = 750.000
      VARIABLE x15.L     = 690.000
      VARIABLE x16.L     = 560.000
      VARIABLE z. L      = 8456.531
```

EXECUTION TIME = 0.000 SECONDS 2 MB 24.8.3 r60202 WEX-WEI

USER: GAMS Development Corporation, Washington, DC G871201/0000CA-ANY

Free Demo, 202-342-0180, sales@gams.com, www.gams.com DC0000

**** FILE SUMMARY

Input C:\Users\user\Documents\gamsdir\projdir\Cost Model Minimization Problem.gms

Output C:\Users\user\Documents\gamsdir\projdir\Cost Model Minimization Problem.lst

Appendix C: Supply Chain Risk and Uncertainty Survey Questionnaire

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF MECHANICAL and INDUSTRIAL ENGINEERING
Supply Chain Risk and Uncertainty survey Questionnaire

Greetings from Addis Ababa University, Institute of technology! With the approval of the Addis Ababa Institute of Technology, I am conducting a research entitled “**Modeling Supply Chain Network under Risk and Uncertainty**” for the partial fulfillment of my M.Sc. degree program in mechanical engineering, industrial Engineering specialization in the school of mechanical and industrial engineering. The purpose of this research is to assess the existing risks and uncertainty in textile and Garment industries at each stage of the supply chain and to increase competitive advantage. Therefore, I would like to request you to participate in this research because I believe that your experience in your industry would help me much to understand the risks and uncertainty within the supply chain. Please answer the questions freely. **Note:** The information obtained here will be held in a strictly confidential manner. Neither your name nor the name of your business will be used in any document based on this survey.

Direction: please don't write your name on any page of the questionnaire, and please answer each question by putting ‘X’ mark on the box provided.

For any enquiry, please contact:

Researcher: Gebrewold Teklay +251913953429

Supervisor: Dr.-Ir. Eshetie Berhan (PhD) +251912632735

Co-Supervisor: Fitsum Getachew +251913952163

Thank you for your time and genuine response and corporation.

Facility Information

Name of the Firm /company	
Office phone number	
Email	
Company web page	
Year of establishment	

Section I. General Information of your company

Question1. What is your organizational level? (Choose one)

Chair, Owner, CEO, President Director, Senior Manager

Managing Director, VP, General Manager, chief executive

- Analyst, Specialist, Coordinator, Consultant Production manager
- Marketing manager Other

Question2. What is your functional area within the company?

- General Management
- Supply chain management (Incl. Procurement, Logistics, and Transportation)
- Financial Management (Inc. Accounting and IT)
- Sales and Marketing management
- Production and manufacturing management
- Engineering and product development
- Human Resources management
- Other

Question3. In which country is your company’s global headquarters located?

- Ethiopia Other than Ethiopia

Question4. What is your company’s Ownership?

- Fully Ethiopian Fully Foreign Mixed

Question 5. What is your company’s annual global sales (in birr)?

- Less than 1,000,000 between 1,000, 000-10,000,000 between 10,000, 000- 100,000,000 More than 100,000,000

Question6. How many persons does your company employ?

- 1-10 1-100 1-1000 More than 1000

Question7. What percentage of your company’s products sourced or produced in Ethiopia is exported out of Ethiopia from the total sales?

- 100% 5-99% 74% 49% 1-4% 0% Don’t Know

Question8. Where are the locations of your major suppliers? (Please write the location with Kilometers)

Question9. Where are the locations of your major distributors? (Please write the location with Kilometers)

Question10. For how many years has your company sourcing or producing?

- Less than 3 years 3-8 years 8-16 years More than 16 years don’t know

Question11. What is the production time of the facility?

Production Hrs./day	
Production days/ week	
Production days/ year	

Work shifts/day	
-----------------	--

Section II: The following categories of risks and uncertainty are some of the risk and uncertainty gathered from literature review that could affect the supply chain in your company. These risks and uncertainty are no to the end, and are made based on my knowledge and some of them may not get in your company, but if there are other kind of risk and uncertainty in your company that I didn't include please write by your own on the space provided and answer the questions correspondingly. ("Risk and Uncertainty can be defined as an unexpected event that throws the supply chain into minor or major disorder".)

Question1. How many times from the previous record was your company affected by the following supply chain risks and uncertainty?

If there are other significant disruptions rather than the listed one, I have left a space to fill at the end of this table specified in numbers. Tick '**X**' mark on the corresponding box

1: **Never** 2: **Rarely** 3: **Sometimes** 4: **Often** 5: **Always**

Lack of trust:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Heterogeneity of partners:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Inadequate collaboration and agreement:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Forecasting problem:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Information flow risk:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Process risk:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Delay of material:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Exchange rate volatility:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Quality failure:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Short product life cycle:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Rapid products turnover:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Seasonal changes:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Procurement risk:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Management commitment:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Knowledge about risk:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Wrong partner selection:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Geographic location:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>

Delivery of wrong material:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	<input type="checkbox"/>	
Delivery process risk:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Excessive inventory	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Scarcity of resources:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Supplier problem:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Lack of coordination:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Infrastructure risk:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Demand shortage:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Supply shortage:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Financial risk:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>
Security and safety:	1	<input type="checkbox"/>	2	<input type="checkbox"/>	3	<input type="checkbox"/>	4	<input type="checkbox"/>	5	<input type="checkbox"/>

Appendix D: Interview Questions

1. Can you briefly describe the existing structure of your company supply chain?
2. What are the major product of the company?
3. How many available warehouse do you have?
4. Could you tell me the capacity (production capacity) and warehouse capacity of your plant?
5. What amount of quantity in kg are your company expected from each supplier?
6. Could you explain the average demand of your wholesaler from past record?
7. What is the approximate unit transportation cost of raw material and finished product?
8. Is there shortage of supply in your plant?
9. What is the number of order per month?
10. What is the planned/designed production capacity of each product listed in the above?
11. Finally could you tell me the opportunity cost of unmet demand?