DESIGN OF MULTI-ECHELON SUPPLY CHAIN SYSTEMS TO OPTIMIZE COST AND SERVICE LEVELS

A Thesis by

Vatsal Maru

Bachelor of Engineering in Mechanical Engineering, Marwadi Engineering College, GTU, 2013

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science with a major in Industrial Engineering.

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Krishna Krishnan, Committee Chair

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Pingfeng Wang, Committee Member

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Rajeev Nair, Committee Member

DEDICATION

To my parents

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It is my pleasure to acknowledge the continuous help and support of Dr. Krishna Krishnan. There were variety of thoughts and ideas, and it was necessary to guide the research into something tangible. His knowledge and experience are behind the framework of this thesis to meet the mark. A special thanks to the committee members, Dr. Pingfeng Wang and Dr. Rajeev Nair, for their valuable comments and time to be a part of this research. Finally, I would like to thank my family and friends for being patient and supportive through-out my masters. It has been a long and fruitful journey which has motivated me to carry further with the same motivation.

ABSTRACT

Primarily found basic uncertainties in the supply chain design are supply and demand, later there are many more uncertainties added in the literature of the field, e.g., control. For an organization there are many options available to implement in the area of supply chain design and uncertainty, whether to find the root cause of the uncertainty, or to reduce the risk, or to optimize the process to handle the uncertainty more conveniently, etc. From all these alternatives, this thesis is concentrated on the reduction of uncertainties by answering with the available resources. Therefore, the focus is on optimization of cost and service levels with proper utilization of the network echelons. There is a mathematical model presented in the paper, which is a mixed integer linear programming (MILP). Along with the cost reduction and service level maximization, this research is also directed towards variability reduction by aggregating the customer zones to reduce the volatility in service levels, and in turn higher service levels. The research has future scope to be explored and identified to add dynamic factors.

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CHAPTER 1

INTRODUCTION

In this era of manufacturing and service industry, the need to serve the end customer and to save the cost associated while serving the customers are two important factors. For an organization, these factors can act as trade-offs – since, higher the service level, higher the cost, and vice versa. Although, manufacturers target to maximize service levels, and while achieving the maximum service levels, manufacturers also want to reduce the supply chain cost. This requires the effective design of supply chains such that it achieves these dual conflicting objectives of maximizing service levels while keeping supply chain costs low.

Recent developments in the supply chain research suggest a necessity to link the Supply Chain Network (SCN) more efficiently. Concepts such as Industrial Internet of Things (IIoT), Vendor Managed Inventory (VMI), Just-In-Time Distribution (JITD), etc. suggest the importance of SCN functioning and operating as a single enterprise. To create an integrated network of the supply chain, the integration of information in the network, and utilizing that information to effectively analyze the SCN is necessary. Thus a holistic approach to supply chain design which can provide the actionable results is necessary for an effective supply chain.

1.1 Supply Chain Design

Supply chain design is a very important criteria of decision making for any organization. Supply chain design requires an organization to decide on the number of echelons within the supply chain system. Echelon refers to the number of stages for a product to travel between the manufacturer and the final customer. Along with the decision on the number of echelons, the subsequent decision is to recognize the number of entities required in a particular echelon. Entities in a supply chain can be defines as the number of units of each type is added in any given echelon.

For example, at the last echelon, 6 retailers may be assigned to be served by a given entity, a ware house, in the previous echelon. On the other hand, another ware house may serve 8 entities in the last echelon. To give a brief view on the scenario, let us assume an organization is operating on the chain of manufacturing plant, distribution centers, regional warehouses, and consumer retail stores. Therefore, the organization consists four echelons. Moreover, there is only one manufacturing plant, two distribution centers, four warehouses, and eight retail stores. So, in this case, the first echelon consist one entity, the second echelon consists two entities, and so on.

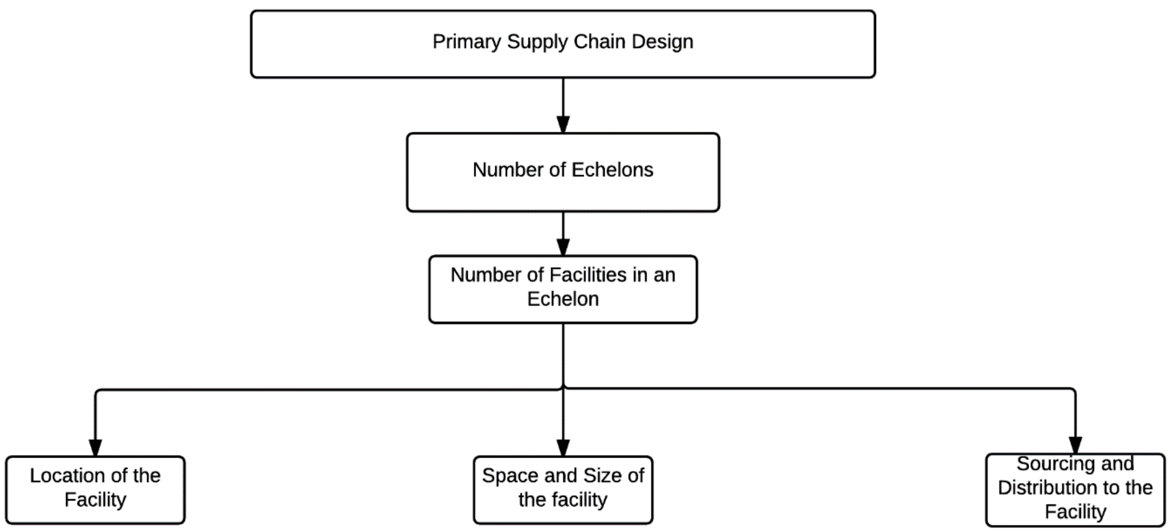

Figure 1.1: Structure of supply chain design

The location of the entities within the respective echelons must be considered along with the costs of opening facilities at these locations. Costs associated with opening a facility can be higher or lower depending on the location. After the consideration of location, facility sourcing becomes a vital point for the supply chain design problem. Assigning the sourcing of the right distribution center to the right warehouse is important as it affects the supply chain cost and the customer service levels.

Distribution strategies are decided based on whether the network is operating on a make-to-stock or make-to-order production methodology. Make-to-order production strategy is used in low volume industry, and make-to-stock production strategy is widely used in the mass production industry. Consumer goods markets, apparel industry, automobile industry etc. are examples of mass production industry. Because of that reason, in make-to-stock production strategy, production starts well in advance, and hence the uncertainty in customer demand develops.

As discussed in the above paragraph, the important areas of supply chain design this thesis attends are the space and capacity of the entities, and sourcing and distribution strategies of the network. In the literature of supply chain design, the concept of manufacturer controlling and/or owning the retail stores is not attended thoroughly. For instance, in their supply chain design mixed integer linear programming (MILP) model, Farhani and Elahipanah (2008) considered the implementation of Just-In-Time Distribution (JITD). However, they had not considered the make-to-stock production methodology. Their distribution strategy was to send the exact quantity of products to the store as much the distributor had asked for.

After understanding the above points regarding the make-to-stock and JITD, this research has taken a step towards matching the current supply chain trend. The recent trend is to make the products available to customers by the organization themselves, while avoiding the distributors and third party retailers. This concept of distribution strategy is known as Direct to Consumer (DTC). DTC provides a scope for companies to control and organize the supply chain network to be more compatible with the market uncertainty. There are many advanced manufacturing companies implementing DTC, such as Tesla, Nike, Under Armor, etc.

In the literature review, there is a detailed discussion on what are the areas of progression in the supply chain design field, when there is risk and uncertainty associated with the supply chain. Simchi-Levi et al. (1999) categorized the supply chain risks into more substantial entities: controllable and uncontrollable. For example, natural disasters, epidemics, etc. are uncontrollable at any given time. On the other hand, the risks raised due to execution problems, communication delays, forecasting accuracy, etc. are controllable. The major improvement area in the supply chain design part is to understand and respond well to the controllable risks. As stated earlier, the controllable risks can be avoided efficiently compared to the uncontrollable, however, it is not an easy task to accomplish. Furthermore, Simangunsong et al. (2010) reviewed the supply chain design models and sources associated with the uncertainty, and they categorized the entire literature to provide the better understanding of the problem and improvement areas.

The objectives of this research are to investigate the design of the supply chain system to optimize the cost and service levels. This research explores the concept of reducing service level uncertainty even when the network experiences demand uncertainty. The primary motivation for this research is the need for supply chain designs which can reduce costs when there is demand uncertainty. The sequence of this report is as follows: Chapter 2 details the relevant literature associated with this research; Chapter 3details the methodology, the mathematical formulation of the cost minimization, and service level maximization; In Chapter 4 case studies with scenarios are used to provide validation of the models and examples of its use. The first case study is used to demonstrate the objective function and constraints evolve and affect the network objectives. Case study has an alternative scenario of higher demand volatility to analyze its effect on service levels and the cost. Chapter 5 is discussion about the analysis of the results. And in the end, conclusion and future study summarize the research.

CHAPTER 2

LITERATURE REVIEW

This section discusses the detailed review on the related concepts, idea generation, and research to validate this thesis. There are many areas of the supply chain framework are being discussed throughout the span of this research, therefore, the effort is given to carefully categorize the topics relevant to the research. This chapter examines the literature in the following topics: supply chain design, supply chain design and service levels, closed loop supply chain design, and risk and uncertainty in supply chain framework.

2.1 Supply Chain Design

Tsiakis et al. (2001) proposed a Mixed Integer Linear Programming (MILP) model for supply chain design of multi echelon network with demand uncertainty. Model was targeted towards the location of the facilities and the associated transportation and inventory costs. Zanjani et al. (2010) developed a multi-period, multi-product stochastic model for production planning with demand uncertainty. Petridis (2013) proposed a mixed integer non-linear programming model to find the optimal network design. The major extension of the model than the earlier literature was in terms of lead time using probabilities for overstocking and understocking.

2.2 Supply Chain Design and Service Levels

Baghalian et al. (2013) argued on the importance of the supply chain network design in relation with the service level consideration. They considered a supply chain network that consists of three echelons: manufacturers, distribution centers, and retail outlets. In the model, the demand was assumed to be random with a known distribution function, and it was assumed that the retailers order their goods before the beginning of each period. They developed cut-set models (MINLP) and did a sensitivity analysis of those models to find the optimal facility locations, which are important in the strategic decision making of the organization.

Sabri and Beamon (2000) noted the categorization of the supply chain into two terms: strategic and operational. Strategic planning is more related to the design aspect of the supply chain, e.g., where to locate the network facilities are strategic for any organization. Furthermore, production, delivery, etc., are operational level decisions. Sabri and Beamon (2000) integrated both the supply chain terms, strategic and operational, as they used two sub-models in their solution approach. They considered four echelons: suppliers, plants, distribution centers, and customer zones. The uncertainty related with demand, and lead time made their models stochastic. They used ε- constraint method, and a Mixed Integer Linear Programming (MILP) objective function. The objective functions attempts to minimize the fixed and variable costs.

Shen et al. (2003) developed a cost based location inventory model. Using this model as a reference, Shen and Daskin (2005) further enhanced the mdoel by adding the customer service element. The model Shen and Daskin (2005) developed was to evaluate the cost and service trade-offs. They used a weighting method with a genetic algorithm based heuristic solution approach. The non-linear model determines the distribution center location for the demand nodes to optimize the allocation considering cost and service. The observation of their model is that the conventional location model which does not include the variable (inventory) cost tends to give a higher fixed cost as the total cost would be underestimated. Therefore, an organization is believed to invest more on fixed capital cost as not considering the actual total cost. For that reason, the location models give more distribution centers than an organization actually needs or can feasibly open with the available finances. The reason Shen and Daskin (2005) gave for the inclusion of the customer service factor is fundamentally important. As IBM developed their supply chain network keeping customer service factor in mind with the competitive threshold (Ma & Wilson 2002). Farhani and Elahipanah (2008) contributed in the supply chain design by concentrating on the service levels. They attributed the Just-in-Time Distribution (JITD) in supply chain network. The constructed genetic algorithm was a Mixed Integer Linear Programming (MILP).

2.3 Closed Loop Supply Chain

Fleischmann et al. (2001) introduced a Recovery Network Model (RNM) which was developed for a closed loop supply chain network, both forward and reverse supply chains. Both forward and reverse models were Mixed Integer Linear Programming (MILP). In their models, flow starting from the factory and directing towards the warehouse, and from there to the customer is defined as a forward flow. However, in the reverse flow, the links are not necessarily the same as from the customer to the warehouse and then from the warehouse to the factory, instead the flow followed the path: customer to disassembly centers to the factory. The major flaw the network had was that Fleischmann et al. (2001) did not consider the uncertainties in the reverse logistics, most of the times, product need not go to the factory, and instead they can have a different links after disassembly. Salema et al. (2007) extended the RNM by generalizing the model with three additional areas: distribution and planning, multi-products, and uncertainties with reverse logistics.

Listes (2007) developed a mixed integer linear programming model for closed loop network to further understand the reverse flow uncertainties. Overall, Listes (2007) model was run on several scenarios, and the results were consistent over the uncertainty to determine the conclusion. This research also aims to develop different scenarios which will help to clarify the consistency of reduced volatility of the service levels over high demand volatility.

2.4 Risk and Uncertainty in Supply Chain

Simangunsong et al. (2010) performed a comprehensive literature review in the area of supply chain risk and uncertainty. The main focus was on the uncertainty involved with the supply chain. Simangunsong et al. (2010) argued on the research they reviewed on supply chain risk and uncertainty that supply chain risk and uncertainty can be assessed on basis of the outcome. Research on supply chain risk and uncertainty is extensive, and divided into two sides. One side of the argument insists that supply chain risk and uncertainty are not the same (Hillson, 2006), while some argue that there is little difference between the two. Hillson (2006) stated that supply chain risk represents two areas: upside and downside. Upside represents the area for process improvement. Upside is the opportunity in the supply chain which can be improved. Upside is the part believed by Hillson (2006) as the uncertainty. Contrary, downside is the area where risk is caused by the external risk factors or the causes that could not be controlled by humans. For example, the natural disasters, or an epidemic, would be considered as a downside. Thus it is far more important to deal with uncertainties in the design than to merely concentration on the risks.

Simangunsong et al. (2010) categorized the uncertainty approach of the research so far in supply chain management. They separated the uncertainty research as: 1) the models of supply chain uncertainty, which provide the *source of the uncertainty*, and 2) *the management of the uncertainty*. Sources of uncertainties are important, as early as in 1993, Davis identified the three critical sources of uncertainty which are supply, demand, and manufacturing process. These three primary uncertainty sources became the base for furthur research. Mason-Jones and Towill (1998) added control uncertainty in the supply chain field as a vital phenomenon.

Management of the supply chain is necessary for the effective functioning of an organization especially when dealing with uncertainty. More importantly, the strategies of an organization are visible here as they are trying to reduce the uncertainty or to build the infrastructure which can withstand the uncertainty posed by the environment. Simangunsong et al. (2010) stretched the importance of further categorizing the managing the uncertainty task into *i) reducing* and *ii) coping with uncertainty*. Reducing uncertainty, as discussed in the supply chain design elements, means to control the factors responsible for uncertainty such as, the number of facilities and their location, size, and sourcing. In the modern supply chain setting, uncertainty reduction requires substantial investment on the infrastructure and higher capital investments. Simangunsong et al. (2010) identified 10 such strategies, ranging from application of lean operations, new product design, to pricing strategy.

On the other hand, improve the response strategy of an organization to handle the uncertainty is a strategy to cope with the supply chain uncertaintya to. Primarily, it is associated with the implementation of operational costs, which varies but can be identified and minimized with improvement techniques. They categorized 11 such techniques including postponement, multiple suppliers, strategic stocks, etc. The research emphasized reduction of variability in customer service levels, even if there is high customer demand uncertainty. Data aggregation concepts are utilized to reduce the service level volatility.

In our research, service levels are considered as the product fill rates. However, as Slack (1987) suggested, there are flexibilities associated with the fill rates, which are of two kinds: volume and delivery. There is a considerable amount of research on the flexibility of volume, but less importance to the delivery flexibility. Delivery flexibility for this research can be defined as as the ability to fill back-orders. Thus, when a supply chain network could not meet the demand in a time period, it may lead to a stock-out; but in this supply chain network design, customers can be provided their product in the subsequent time period. The stock-out cost usually is two to three times the product cost. The high cost for stock-out occurs because when the customer demand is not met, the company losses market value in terms of image and responsibility, as well as there is a chance of losing out that customers in future. Usually, to avoid the stock-outs, companies tend to keep high inventory buffers in terms of safety stocks. As there is an extensive amount of research on the inventory management. Companies have tried to avoid stock-outs by keeping higher inventories, which in turn leads to higher costs associated with holding and handling the excessive inventory.

As a manager or researcher, when dealing with the demand uncertainties, there is no bright side, because if the inventory is higher than inventory holding and handling cost increases, and if there is a dependency on the forecast and the inventory is kept at the expected amount, then the stock out cost increases. As all the studies related with forecast and the concept of forecast suggest the 'forecast is never accurate'. Therefore, after careful thinking and much consideration, Slack (1987) realized the need of service level delivery flexibility. Therefore, in this research, the stock-outs are considered as back orders, and the parameters represent this area are overage inventory and stock-outs. In Table 2.1, categorization of the literature review can be found with the timeline and objective functions addressed by each paper.

Table 2.1: Literature review

				Objective Function		
Year	**Article**	**No. of Echelons**	**Model Type**	**Storage Cost**	**Transportation Cost**	**Service Level**
2000	Sabri & Beamon	3	Demand and facilities constraints		*	*
2005	Shen and Daskin	3	Weighting method amd geneic algorithm		*	*
2007	Listes	3	L- shaped method	*	*	
2007	Qi & Shen	2	Langragian relaxation	*	*	
2007	Salema et al.	3	Branch and bound	*	*	
2008	Xu et al.	3	Spanning tree based genetic algorithm	*		*
2008	Li et al.	3	Game theory	*		
2010	Zanjani et al.	N/A	Fuzzy approach			*
2011	Pishvaee et al.	5	MINLP	*		
2013	Baghalian et al.	3	regression	*		*
2017	This thesis	4	MINLP	*	*	*

CHAPTER 3

METHODOLOGY

This chapter provides the general idea of cost minimization in the supply chain paradigm, as well as the service level importance via product fill rates. In the later part of this chapter, there is an elaborate explanation on this research's mathematical formulation as well as the importance of the optimization of the objective functions selected in this research.

In supply chain, a product can be produced at multiple manufacturing facilities, and then move forward in the direction towards the customer. Usual supply chain network consist the multi echelon structure placed in scattered locations which will be responsible for the product to reach to the end customer. For instance, according to the size of the organization, there must be a strategy to locate the distribution centers and warehouses. Moreover, organization's customer area also play a part in the decision making of network creation.

When organization have the network installed with the operational facilities, the decisions will be taken to prioritize the objectives which are align with the vision and mission of the company, e.g., whether to set the customer service as the main priority or to reduce risk or to reduce the costs, or the timing of the delivery, etc. In the supply chain design, there are various network distribution strategies, depending on whether the network is operating on make to stock or make to order production methodology. Make-to-stock production technique is widely used in the mass production industry as the customer demand is uncertain throughout the time, and the production of the product is before the demand period.

Noting these points, there is one more important notation is that the manufacturer is controlling and/or owning the facilities. This business model plays vital part in the model building phase, while deciding the distribution strategy of the network. If the manufacturer is controlling and/or owning the stores, which implicates that the distribution centers or warehouses do not send the products to the store according to their demand, rather the sent products are based on the policy followed by the organization. Generally in supply chain management, store's demand is the store or retailer's asking quantity of the products. Entire literature has followed the distribution strategy, where the amount of products transported to the store is equal to the store's demand.

This model serves the major change in the distribution, and promotes the Just-in-Time Distribution (JITD) strategy. In JITD, there are two important considerations. The first, retailers and stores must provide the details of amount of inventory they are left with, and the second, customer demand of the last time period(s). When a manufacturing organization understands the available on hand inventory at the store, and what will be the likely demand for the time period (from historical data), the amount of products transported becomes a calculated forecast for the organization. Moreover, the inventory amount and historical data will leave little scope for optimization, the forecast predicts the situation but do not optimize it. Therefore, in this thesis, the importance is given to the concept of manufacturer handling the decision on the amount of products transported with the optimized numbers (rather calculated forecast). Therefore, the objective functions of this research are to minimize the costs and maximize the service levels with the help of mixed integer linear programming (MILP).

Apart from that, the reason behind keeping the Direct to Consumer (DTC) distribution strategy and not building the model where the stores are independent (as in the case of franchise or distributorship) is due to the new developments in the field as there are companies investing in and preferring to have their own stores, rather than having a third party. For instance, the companies such as Tesla do not have any distributor, instead they own all the stores. Another example will be Nike, company's financial forecast in 2016 was that the company will improve their DTC sales by three times in the next five years to approximately around $20 billion. After carefully considering and evaluating all the above decision making aspects and frameworks, developed mathematical formulation of the problem is as following:

3.1 Mathematical Formulation

Indices:

i = number of echelons (or levels) = 1,…, I

n = number of entities in the echelon = 1,…, J

m = number of entities in the echelon for the subsequent echelon (i+1) in the link = n = 1, …, J

p = product index = 1,…, P

t = time period index = 1,…, T

Variables:

$V_{pin(i+1)mt}$ = amount of product p transported between the echelons (i) and their respective entities (n and m) in time period t

Parameters:

C_{pint} = manufacturer i's capacity to produce product p in time period t

D_{pint} = demand for product p at store (echelon I) in time period t

T_p = unit transportation cost of product p for unit distance

$E_{in(i+1)m}$ = distance between echelons (i) and their entities (n and m)

I_{pint} = inventory at store (echelon I) in time period t = $V_{pin(i+1)t}$ +$O_{pin(t-1)}$ – $M_{pin(t-1)}$

h_{pin} = unit holding cost of product p at retail stores (echelon I) for each time period

A_{pin} = holding capacity for product p at stores (echelon I) for each time period

O_{pint} = Overage inventory at store (echelon I) = I_{pint} - D_{pint}

M_{pint} = Stock-out at the store (echelon I) = D_{pint} - I_{pint}

Objective Functions:

Objective 1: Minimize the total cost: Z1=

$\sum_{i=1}^{I}\sum_{m=n=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T}(\boldsymbol{V}_{\mathbf{pin(i+1)mt}} \cdot \mathbf{T_p} \cdot \mathbf{e}_{\mathbf{in(i+1)m}} + \mathbf{h}_{\mathbf{pin}} \cdot \mathbf{O}_{\mathbf{pint}})$

Objective 2: Maximize the service level Z2 $=\sum_{i=1}^{I}\sum_{m=n=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T}(\boldsymbol{I}_{\mathbf{pijt}} / \mathbf{D}_{\mathbf{pijt}})$

Objective 3: Minimize the overage and stock out to increase the service level and decrease the cost

Z3 $= \sum_{i=1}^{I}\sum_{m=n=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T}(\boldsymbol{O}_{\mathbf{pijt}} + \mathbf{M}_{\mathbf{pijt}})$

Subject to,

1. Total transported amount of product p echelons i and entities j do not exceed the manufacturer's production capacity.

   $\sum_{i=1}\sum_{m=n=1} V_{\text{pin(i+1)mt}} = \sum_{i=1}\sum_{m=n=1} C_{\text{pint}}\ \forall p,t$

2. Balance between the incoming and outgoing product flows.

   $\sum_{i=1}^{I}\sum_{m=n=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} V_{\text{pin(i+1)mt}} = \sum_{i=1}^{I}\sum_{m=n=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} V_{\text{p(i+1)n(i+2)mt}}\ \forall p,t$

3. Total transported amount of product p transported to stores (echelon I) should not be more than the store's storage capacity.

   $\sum_{i=1}^{I}\sum_{m=n=1}^{J}\sum_{p=1}^{P}\sum_{t=1}^{T} V_{\text{pin(i+1)mt}} \le \sum_{i=1}^{I}\sum_{n=1}^{J}(A_{\text{pin}} - O_{\text{pin(t-1)}})\ \forall p,t$

4. Total amount of inventory at stores (echelon I) also have to abide to the same constraint as the previous one that it cannot be more than the store's storage capacity.

   $\sum_{i=1}^{I}\sum_{n=1}^{J}(I_{\text{pint}} \le A_{\text{pin}})\ \forall p,t$

5. Non-negativity constraint:

   $V_{\text{pin(i+1)mt}}, O_{\text{pint}}, M_{\text{pint}}, I_{\text{pint}} \ge 0\ \forall p,i,j,t$

As stated in the formulation, the objective function Z1 is to minimize the cost associated with transportation and holding of any product in the supply chain design, where $V_{\text{pin(i+1)mt}}$ is the amount of products transported to the store multiplied by unit transportation cost (T_p) and the distance ($E_{in(i+1)m}$). Objective function Z2 is the ratio of available inventory and actual demand, which shows exactly how much customer demand was served in a particular time period and how much customer demand was left without service. In this research, the stock-out (M_{pint}) will be calculated as a back-order because of the assumption that the unserved customers are available with their orders in the following time period.

In the model, there is a storage capacity at the stores (A_{pin}), which have the holding cost (h_{pin}) associated with it. Holding cost is considered when there are excessive products in the inventory than the actual demand, which is called an overage (O_{pint}), because the overage is the quantity of products are staying at the store from one time period to another. Therefore, the product of holding cost and overage for the respective time period is added in the first objective function of cost minimization.

Demand (D_{pint}) at the retail stores is unknown, and therefore considered as stochastic, which is another important criterion. In this research, the design of supply chain considers the amount of products transported from one echelon to another. Therefore, the amount of flow transported from the manufacturer to the distribution center is less than or equal the amount manufacturing facility can produce (C_{pint}), and the amount transported to the distribution center should not be less than the amount going out-bound (from distribution center to warehouse) from distribution center. Trend continues till the last links between echelons of the network.

As the amount of products transported from the warehouse to the store ($V_{pin(i+1)mt}$), and the overage from the last time period ($O_{pin(t-1)}$) builds the inventory, $V_{pin(i+1)t} + O_{pin(t-1)}$. Inventory at the store will be responsible to satisfy the actual demand (D_{pint}) at the store. Moreover, as discussed earlier that the stock-outs are considered as back orders, the amount of last time period's stock-out will be deducted from the inventory. Therefore, the inventory can be calculated as: $I_{pint} = V_{pin(i+1)t} + O_{pin(t-1)} – M_{pin(t-1)}$.

Above description is true for the wide variety of industries and their supply chain. The aim of the research is to minimize cost and improve the service levels. Demand uncertainty is one of the many reasons for high cost and low service levels. As variability in demand changes from store to store, the same is true for the service levels, in other words, service level volatility is due to demand uncertainty. Therefore, solving the problem in the direction of maintaining higher service levels, and maintaining higher service levels under volatility are different things. Earlier research have shown the ways to reduce the service level volatility, in terms of lead time reduction (Prater et al. 2001), agile manufacturing (Braunscheidel and Suresh 2009), safety and buffer stocks (Davis 1993, Helms et al. 2000, Wong and Arlbjorn 2008), or a modern concept such as internet of things (IoT). However, collaboration of the specific entities of the supply chain to create a cluster and reduce the effect of demand variability on the service levels is shown in this research to introduce the new way of reducing the volatility. To give a practical understanding of our model, the following chapter consists the case study with two scenarios. Both the scenarios are performed over different set of conditions. The optimization tools used in this thesis are MS Excel and General Algebraic Modeling System (GAMS). Particularly in GAMS, the solver used to optimize is BARON.

CHAPTER 4

CASE STUDY

In traditional make-to-stock production strategy, continuous or periodic review of inventory is set as a replenishment strategy. This case study consist the periodic replenishment as a basis to conceptualize. The supply chain network of the company is distributed in 4 echelons (levels), and the entities in those echelons differ from one another. Manufacturing facility, distribution centers, warehouses, and retail stores create 4 echelons. There is only one manufacturing facility, two distribution centers, 4 warehouses and 8 retail stores. The flow of products in the network is considered uniform as products travel from a manufacturing plant to the distribution centers, from the distribution centers to the warehouses, and from the warhorses to finally the stores. This supply chain network can be considered for the small to medium scale industry. However, the location of the stores still can be assumed to be in the single state or a nearby region. In the case study, a single distribution center transports the products to two warehouses, and a single warehouse transports the products to two stores. To understand the supply chain network thoroughly, see the figure 4.1.

As discussed earlier and can be seen from the above figure 4.1, that the amount of products is being transported to the distribution center 1 and 2 from the manufacturing plant. In turn, distribution center 1 transport the products to warehouses 1 and 2, where distribution center 2 transport the products to warehouses 3 and 4. Reaching to the last two echelons, warehouse 1, 2, 3, and 4 are responsible to transport the products to stores 1 and 2, 3 and 4, 5 and 6, 7 and 8, respectively.

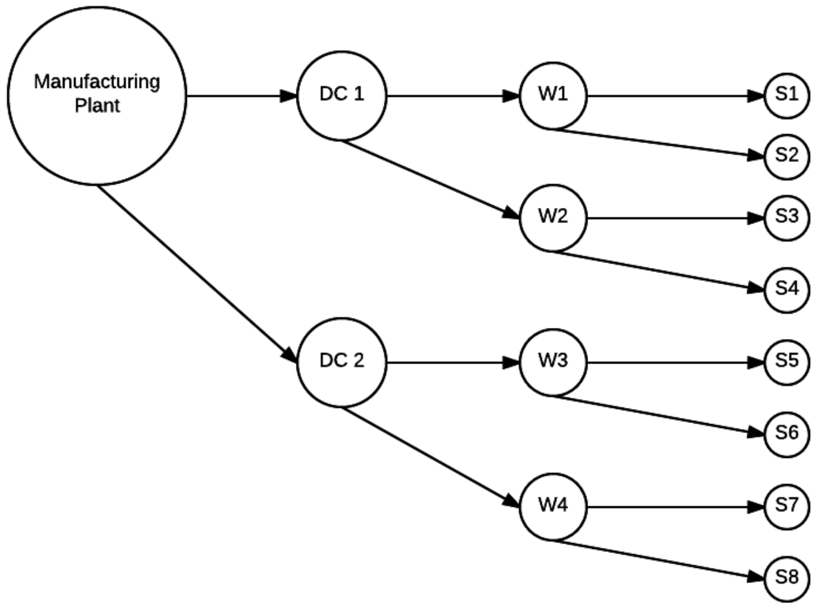

Figure 4.1: Supply Chain Network

This case study is simulated for 4 time periods. And the organization is assumed to operate on make-to-stock distribution and replenishment strategy. For all the following tables and data, follow the matrix representation of links in terms of arcs. For example, manufacturing plant is number 11, two distribution centers are numbers 21 and 22, warehouses will become numbers 31, 32, 33, 34, and stores are numbers from 41, 42,…, 48. Therefore, the interpretation of this matrix shows the number 11 is supplying the products to number 21 and 22. Number 21 (distribution center 1) is supplying the products to number 31 and 32 (warehouses 1 and 2 respectively.). Number 22 (distribution center 2) is supplying products to number 33 and 34 (warehouses 3 and 4).Holding cost at stores and the storage capacity is given below.

Table 4.1: Store holding cost and storage capacity

Store Location	Holding Cost in $	Storage Capacity in # of products
41	5	1050
42	5	1050
43	5	1050
44	5	1050
45	5	1050
46	5	1050
47	5	1050
48	5	1050

Considering the scope of this research and very low variability associated with the transportation cost and distance, both of them is assumed constant for all the time periods. Reason behind prioritizing unit transportation cost is that organizations have variety of distance between the echelons, but when this distance is multiplied with the transportation cost, it usually provides the approximate measure of the total transportation cost. Due to objective function 1, which is to reduce the total cost associated with the supply chain design, the total transportation cost is important to be minimized as well. Unit transportation cost and the distances between the echelons are given in the following tableau.

Table 4.2: Distance and unit transportation cost

Entity locations			Distance between entity column 1 and 2 in mi	Distance between entity column 1 and 3 in mi	Transportation cost between entity column 1 and 2 in $	Transportation cost between entity column 1 and 3 in $
11	21	22	500	800	20	22
21	31	32	255	307	15	16
22	33	34	221	326	14	15
31	41	42	124	70	8	9
32	43	44	139	165	8	6
33	45	46	63	174	7	8
34	47	48	89	132	6	5

In the case study, there are two scenarios presented. Scenario creation is based on the volatility in the demand. Volatility can be defined as the standard deviation being fraction of the mean, i.e., if the standard deviation is 10 and the mean is 100, volatility will become 10%. Therefore, if the volatility is less than 10%, then volatility is low, and if volatility is greater than 15%, volatility is high. Moreover, each scenario is presented in three categories: a) base value of the SCN, b) optimized values of the SCN (Excel and GAMS), and c) aggregation of customer zones to reduce the volatility in service levels.

4.1 Scenario 1

Table below shows the customer demand for the first scenario. And with the demand data, there is a sample standard deviation and mean are given, which suggest the customer demand volatility is at 6.087%. Volatility categorization in this research further enhances that the scenario is low volatile. A usual circumstance of a SCN is to be low volatile, and high volatility is the uncertainty. Therefore, for better understanding purposes, the low volatile scenario is first and followed with the base value calculations.

Table 4.3: Customer demand at the stores with low volatility

Store Location	**Demand (in # of products) for time period 1**	**Demand (in # of products) for time period 2**	**Demand (in # of products) for time period 3**	**Demand (in # of products) for time period 4**
41	980	1068	1018	1060
42	907	1012	966	969
43	1042	1013	1073	984
44	1072	920	996	910
45	1005	1014	1072	1091
46	1001	974	911	1082
47	1067	1023	920	968
48	914	970	1017	902
Sample standard deviation	63.12	44.13	61.56	74.07
Mean	998.5	999.25	996.62	995.75

4.1.1 Scenario 1- Base Values

After understanding the above description for demand, distance, and unit transportation cost, base value calculations are performed for the scenario 1. Base value calculations are important in a way that the improvement due to the optimization, then that improvement is visible if there is an initial point to match the improvement with. To calculate the base values, the capacity constraints are implemented, however, organization is believed to carrying a periodic replenishment and the reordering quantity will try to maximize the inventory amount to match the demand and improve the service levels. Therefore, the variable amount of products transported are given in the following table 4.4 as base values for scenario 1.

Table 4.4: Variable amount of products transported: base values scenario 1

Store Location (entity links)	Amount of products (in #) transported for time period 1	Amount of products (in #) transported for time period 2	Amount of products (in #) transported for time period 3	Amount of products (in #) transported for time period 4
41(31→41)	1050	980	1036	1036
42(31→42)	1050	907	1012	966
43(32→43)	1050	1042	1013	1050
44(32→44)	1050	1050	942	996
45(33→45)	1050	1005	1014	1050
46(33→46)	1050	1001	974	911
47(34→47)	1050	1050	1040	920
48(34→48)	1050	914	970	1017

And after the calculations of the variable amount of products transported, the subsequent calculations are for the overage inventory (table 4.5), stock-outs (table 4.6), and total inventory (table 4.7). And in the end, achieved service levels and the objective function values are given in table 4.8, and table 4.9.

Table 4.5: Overage inventory: base values- scenario 1

Store Location	Overage (in #) for time period 1	Overage (in #) for time period 2	Overage (in #) for time period 3
41	70	0	14
42	143	38	84
43	8	37	0
44	0	108	54
45	45	36	0
46	49	76	139
47	0	10	130
48	136	80	33

Table 4.6: Stock-outs: base values- scenario 1

Store Location	Stock-out (in #) for time period 1	Stock-out (in #) for time period 2	Stock-out (in #) for time period 3
41	0	18	0
42	0	0	0
43	0	0	23
44	22	0	0
45	0	0	22
46	0	0	0
47	17	0	0
48	0	0	0

Table 4.7: Total inventory: base values- scenario 1

Store Location	Inventory (in #) for time period 1	Inventory (in #) for time period 2	Inventory (in #) for time period 3	Inventory (in #) for time period 4
41	1050	1050	1032	1050
42	1050	1050	1050	1050
43	1050	1050	1050	1027
44	1050	1028	1050	1050
45	1050	1050	1050	1028
46	1050	1050	1050	1050
47	1050	1033	1050	1050
48	1050	1050	1050	1050

Table 4.8: Service levels: base values scenario 1

Store Location	Service levels for time period 1	Service levels for time period 2	Service levels for time period 3	Service levels for time period 4
41	1	0.98	1	0.99
42	1	1	1	1
43	1	1	0.97	1
44	0.97	1	1	1
45	1	1	0.97	0.94
46	1	1	1	0.97
47	0.98	1	1	1
48	1	1	1	1

Table 4.9: Objective functions: base values- scenario 1

Objective Function	Value
Z1	$607,594,294
Z2	1.052
Z3	1392 (in #)

4.1.2 Scenario 1- Optimization

And as the base values are calculated, optimization was run with the case study data. The step-wise implementation of the mathematical model is given in this section. The first part was to assign the upper bound limits to the network flow. In our case, the network flow is interpreted in terms of the amount of products transported. Therefore, the upper bound constraint which stats the amount of products transported subtracted by the overage inventory store held from the last time period, and that number must be less than the store's storage capacity. This constraint calculation is given in the following table 4.10 for all 4 time periods.

Table 4.10: Upper bound constraint values

Store Location	Upper bound (in # of products) for time period 1	Upper bound (in # of products) for time period 2	Upper bound (in # of products) for time period 3	Upper bound (in # of products) for time period 4
41	1050	1020	1050	1050
42	1050	907	1012	966
43	1050	1050	1013	1050
44	1050	1050	942	996
45	1050	1007	1014	1050
46	1050	1002	974	911
47	1050	1050	1040	928
48	1050	914	970	1050

The lower bound in the model is considered as the manufacturer's production capacity. However, in this case study, production capacity is assumed that it can fulfill the customer demand, therefore, research has taken the liberty to have higher production capacity than the demand. But the model can still be implemented if the demand is higher than the production capacity. Therefore, the variable values for the amount of products transported for all time periods from warehouse to store is as following:

Table 4.11: Variable amount of products transported

Store Location (entity links)	Amount of products (in #) transported for time period 1	Amount of products (in #) transported for time period 2	Amount of products (in #) transported for time period 3	Amount of products (in #) transported for time period 4
41(31→41)	1010	1020	1036	1050
42(31→42)	1050	907	1012	966
43(32→43)	1042	1050	1013	1050
44(32→44)	1050	1050	942	996
45(33→45)	1048	1007	1014	1050
46(33→46)	1049	1002	974	911
47(34→47)	1050	1050	1032	928
48(34→48)	1050	914	937	1050

Moreover, the overage inventory is the excess (more than the actual demand) inventory sent by warehouse to store. Overage is calculated as the inventory subtracted by actual customer demand, which is given in the following table 4.12. The calculation for stock-out is also the same as overage, where the actual customer demand is subtracted by inventory. Stock-out data is in the table 4.13. The calculated overage and stock-out are for the time periods 1 to 3, as both are always used for the last time periods'.

Table 4.12: Overage Inventory at the stores for different time periods

Store Location	Overage (in #) for time period 1	Overage (in #) for time period 2	Overage (in #) for time period 3
41	30	0	0
42	143	38	84
43	0	37	0
44	0	108	54
45	43	36	0
46	48	76	139
47	0	10	122
48	136	80	0

Table 4.13: Stock-outs at the stores for different time periods

Store Location	Stock-out (in #) for time period 1	Stock-out (in #) for time period 2	Stock-out (in #) for time period 3
41	0	18	0
42	0	0	0
43	0	0	23
44	22	0	0
45	0	0	22
46	0	0	0
47	17	0	0
48	0	0	0

Inventory is calculated by adding the amount of products transported and the overage inventory of the last time period. Moreover, stock-out is assumed as back orders, meaning customers are willing to buy the product on subsequent time period. Therefore, the inventory of the store also becomes an important parameter to be constrained lower than the store's storage capacity. Table 4.14 provides the calculated inventory for all four time periods.

Table 4.14: Inventory amount at the stores for different time periods

Store Location	**Inventory (in #) for time period 1**	**Inventory (in #) for time period 2**	**Inventory (in #) for time period 3**	**Inventory (in #) for time period 4**
41	1050	1020	1050	1050
42	1050	907	1012	966
43	1050	1050	1013	1050
44	1050	1050	942	996
45	1050	1007	1014	1050
46	1050	1002	974	911
47	1050	1050	1040	928
48	1050	914	970	1050

All above variables and parameters are critical in the calculation of objective functions. The first objective function of this research is to minimize the total cost associated with the design. The objective function Z1's values are shown in the following table 4.15. The sample calculation is as following.

Table 4.15: Objective function Z1 values

Entity locations			Objective function values in $ between entity links (column 1 and 2)	Objective function values in $ between entity links (column 1 and 3)
11	21	22	159,500,000	275,369,600
21	31	32	27,715,950	38,028,704
22	33	34	23,653,630	34,679,880
31	41	42	4,082,080	2,478,420
32	43	44	4,620,360	3,996,630
33	45	46	1,816,479	5,478,912
34	47	48	2,139,738	2,607,660

Cumulative of the above table is our objective function Z1 value, which is **$586,168,043**. This value is after minimizing the cost. However, our second objective function Z2 to maximize the service levels. The service level is considered as the product fill rate, for this research, service levels is the cumulative ratio of the inventory at the stores and the actual customer demand. Below table 4.16 gives the service level for all time periods at each store.

Table 4.16: Service levels for all time periods at each store

Store Location	Service levels for time period 1	Service levels for time period 2	Service levels for time period 3	Service levels for time period 4
41	1	0.98	1	0.98
42	1	1	1	1
43	1	1	0.97	1
44	0.97	1	1	1
45	1	1	0.97	0.94
46	1	1	1	0.97
47	0.98	1	1	1
48	1	1	1	1

Therefore our objective function Z2 value is **1.00875**. And objective function 3 is the summation of stock-out and overage, which is **1286** (number of products). After maximizing the objective function 2 and minimizing the objective function 3, all the variable and parameter values change. Therefore, following the same sequence of the data, the new upper bound values are as shown in the table 4.17 below.

Table 4.17: New upper bound values

Store Location	**Upper bound (in #) for time period 1**	**Upper bound (in #) for time period 2**	**Upper bound (in #) for time period 3**	**Upper bound (in #) for time period 4**
41	1050	1050	1050	1050
42	1050	907	1050	1050
43	1050	1050	1050	1050
44	1050	1050	1050	1050
45	1050	1050	1050	1050
46	1050	1050	1050	1050
47	1050	1050	1041	1050
48	1050	1050	1050	1050

And the new variable values are given in the following table 4.18. Again, this is after the optimization of objective functions 2, and 3.

Table 4.18: New Variable values of amount of product transported

Store Location (entity links)	Amount of products (in #) transported for time period 1	Amount of products (in #) transported for time period 2	Amount of products (in #) transported for time period 3	Amount of products (in #) transported for time period 4
41(31→41)	980	1050	1036	1049
42(31→42)	1050	868	967	1049
43(32→43)	1042	1013	1050	1050
44(32→44)	1050	941	997	1049
45(33→45)	1004	1015	1050	1050
46(33→46)	1000	975	911	1049
47(34→47)	1050	1049	910	1049
48(34→48)	913	970	1018	1017

The new overage inventory and stock-out values are in the following two tables. Overage inventory and stock-outs are the main input in objective function 3, which is to be minimized. Therefore, both, the overage and stock-outs, will have reduced values to optimize the overall value of the objective function Z3.

Table 4.19: New overage inventory

Store Location	Overage (in #) for time period 1	Overage (in #) for time period 2	Overage (in #) for time period 3
41	0	0	0
42	143	0	0
43	0	0	0
44	0	0	0
45	0	0	0
46	0	0	0
47	0	9	0
48	0	0	0

Table 4.20: New stock-out values

Store Location	Stock-out (in #) for time period 1	Stock-out (in #) for time period 2	Stock-out (in #) for time period 3
41	0	18	0
42	0	1	0
43	0	0	23
44	22	1	0
45	1	0	22
46	1	0	0
47	17	0	1
48	1	1	0

Therefore, as visible, the new optimized value of the objective function Z3 will be 261 (number of products). And as discussed earlier while calculating the inventory, overage and stock-outs will change the value of inventory of the store. The new optimized values of the inventory are in the following table 4.21.

Table 4.21: New inventory values

Store Location	Inventory (in #) for time period 1	Inventory (in #) for time period 2	Inventory (in #) for time period 3	Inventory (in #) for time period 4
41	980	1050	1018	1049
42	1050	1011	966	1049
43	1042	1013	1050	1027
44	1050	919	996	1049
45	1004	1014	1050	1028
46	1000	974	911	1049
47	1050	1032	919	1048
48	913	969	1017	1017

After understanding the new data, the objective function Z1 value and the service levels are in the below two tables.

Table 4.22: New objective function values

Entity locations			Objective function values in $ between entity links (column 1 and 2)	Objective function values in $ between entity links (column 1 and 3)
11	21	22	159,500,000	275,158,400
21	31	32	27,715,950	38,004,144
22	33	34	23,409,204	34,674,990
31	41	42	4,082,080	2,479,135
32	43	44	4,620,360	3,996,630
33	45	46	1,816,479	5,477,520
34	47	48	2,167,017	2,585,880

Table 4.23: New service levels at the stores

Store Location	Service levels for time period 1	Service levels for time period 2	Service levels for time period 3	Service levels for time period 4
41	1	0.98	1	0.98
42	1	0.9990	1	1
43	1	1	0.97	1
44	0.97	0.99	1	1
45	0.99	1	0.97	0.94
46	0.99	1	1	0.96
47	0.98	1	1	1
48	0.98	0.99	1	1

The service level values of the aggregated customer zones are given below in table 4.24. The stores which are sourced by a single warehouse are treated as a single customer zone and then the service levels are calculated. The detailed discussion is done in chapter 5 to understand the concept further.

Table 4.24: Service levels after aggregation

Store Location	**Service levels for time period 1**	**Service levels for time period 2**	**Service levels for time period 3**	**Service levels for time period 4**
41	1	1	1	1
42	1	1	1	1
43	0.98	1	1	1
44	0.99	1	1	1
45	1	1	1	0.95
46	1	1	1	0.96
47	1	1	1	1
48	1	1	1	1

Therefore all three objective values:

Table 4.25: Objective function values

Objective Function	**Value**
Z1	$585,114,823
Z2	1.0142
Z3	261 (in #)

From the above table, it is clear that all three objectives are important to reduce cost, overage and stock-out, and to improve the service levels. After optimizing the above three objective functions in sequence in MS Excel, the values of the objective functions are decreasing, but they reduce on the basis of optimization of one function at any time. To optimize all three objective functions, and see the impact of cost reduction with the service level maximization, General Algebraic Modeling System (GAMS) is used. Preliminary use of Excel served as a platform to validate the process and model, and the GAMS provide us the highly optimized values with its solver BARON. The program can be found in the appendix of the report, and the values are given in the below table 4.26.

Table 4.26: Objective function values in GAMS

Objective Function Value in GAMS	**Value**
Z1	$108,644,578
Z2	0.96304
Z3	34 (in #)

In the following section, the volatility in the demand is being increased and the model is implemented.

4.2 Scenario 2

In scenario 1, demand did not fluctuate more (low volatility), and therefore, to analyze the model with higher volatility in customer demand, scenario 2 was simulated. The customer demand and standard deviation for scenario 2 are given in table 4.27. Higher volatility has an impact on the overall service level achieved or the increased cost, or there is an unusual increment in the store's storage, all this questions can be answered with careful observation of the case study. And discussion points can be derived with the scenario 1 and scenario 2 comparisons of the case study.

Table 4.27: Customer demand at the stores with high volatility Scenario 2

Store Location	**Demand for time period 1**	**Demand for time period 2**	**Demand for time period 3**	**Demand for time period 4**
41	1155	830	1054	1024
42	1110	867	791	1284
43	714	1133	996	862
44	975	881	1300	957
45	1271	784	1255	1272
46	1095	1148	738	710
47	802	973	1211	1115
48	1010	840	859	1128
Sample standard deviation	184.44	139.55	216.95	197.96
Population standard deviation	172.53	130.54	202.94	185.17
Mean	1016.5	932	1025.5	1044

As discussed in the scenario 1, the volatility less than 10% is low and more than 15% is considered high volatility. Scenario 2 has 18.39% volatility, which is very high. The calculation of the model for scenario 2 in sequence below.

4.2.1 Scenario 2- Base Values

To go through the base values quickly for the second scenario, the calculations for the variable amount transported, service levels, and the objective function values are given in the following three consecutive tables.

Table 4.28: Variable base values for the scenario 2

Store Location (entity links)	Amount of products (in #) transported for time period 1	Amount of products (in #) transported for time period 2	Amount of products (in #) transported for time period 3	Amount of products (in #) transported for time period 4
41(31→41)	1050	1050	935	1050
42(31→42)	1050	1050	927	791
43(32→43)	1050	714	1050	1050
44(32→44)	1050	975	881	1050
45(33→45)	1050	1050	1005	1050
46(33→46)	1050	1050	1050	881
47(34→47)	1050	802	973	1050
48(34→48)	1050	1010	840	859

Table 4.29: Service levels- Base values scenario 2

Store Location	Service levels for time period 1	Service levels for time period 2	Service levels for time period 3	Service levels for time period 4
41	0.909	1.00	0.996	1.00
42	0.946	1.00	1.00	0.818
43	1.00	0.927	0.971	1.00
44	1.00	1.00	0.808	0.836
45	0.826	1.00	0.837	0.664
46	0.959	0.875	1.00	1.00
47	1.00	1.00	0.867	0.797
48	1.00	1.00	1.00	0.931

Table 4.30: Objective function- Base values scenario 2

Objective Function	Value
Z1	$596,315,669
Z2	1.03
Z3	3363 (in #)

4.2.2 Scenario 2- Optimization

Now, there is a scenario 2 optimization is performed with the stepwise calculations. The upper bound values for the scenario 2 by calculating the constraint, which is the subtraction of overage from capacity to create a periodic replenishment, is in the table 4.31. After upper bound calculation, the variable values for the amount of products transported are in the table 4.32.

Table 4.31: Upper bound value for scenario 2

Store Location	**Upper bound (in #) for time period 1**	**Upper bound (in #) for time period 2**	**Upper bound (in #) for time period 3**	**Upper bound (in #) for time period 4**
41	1050	1050	1050	1050
42	1050	1050	927	791
43	1050	974	1050	1050
44	1050	975	1050	1050
45	1050	1050	1050	1050
46	1050	1050	1050	1050
47	1050	802	983	1050
48	1050	1049	840	909

Table 4.32: Variable values for the scenario 2

Store Location (entity links)	Amount of products (in #) transported for time period 1	Amount of products (in #) transported for time period 2	Amount of products (in #) transported for time period 3	Amount of products (in #) transported for time period 4
41(31→41)	1050	935	1050	1050
42(31→42)	1050	1050	927	791
43(32→43)	790	974	1050	1050
44(32→44)	1050	806	1050	1050
45(33→45)	1050	1005	1050	1050
46(33→46)	1050	1050	881	1050
47(34→47)	1050	792	983	1050
48(34→48)	1011	1049	790	909

Calculation are in as same order as scenario 1. Therefore, the overage, stock-outs and the inventory are calculated next for the high volatile demand. Scenario 2 has the simulated data after optimization of all three objective functions. The overage, stock-outs, and inventory are shown in the following tables 4.33, 4.34, and 4.35, respectively. As the demand has higher standard deviation, one can assume the overage or stock-outs will have higher value when attained.

Table 4.33: Overage for the scenario 2

Store Location	**Overage (in #) for time period 1**	**Overage (in #) for time period 2**	**Overage (in #) for time period 3**
41	0	0	0
42	0	123	259
43	76	0	0
44	75	0	0
45	0	0	0
46	0	0	0
47	248	67	0
48	1	210	141

Table 4.34: Stock-outs for the scenario 2

Store Location	**Stock-out (in #) for time period 1**	**Stock-out (in #) for time period 2**	**Stock-out (in #) for time period 3**
41	105	0	4
42	60	0	0
43	0	83	29
44	0	0	250
45	221	0	205
46	45	143	0
47	0	0	161
48	0	0	0

Table 4.35: Inventory values for scenario 2

Store Location	Inventory (in #) for time period 1	Inventory (in #) for time period 2	Inventory (in #) for time period 3	Inventory (in #) for time period 4
41	1050	830	1050	1046
42	1050	990	1050	1050
43	790	1050	967	1021
44	1050	881	1050	800
45	1050	784	1050	845
46	1050	1005	738	1050
47	1050	1040	1050	889
48	1011	1050	1000	1050

Objective function values for scenario 2 are given as in scenario 1, and the calculations are in the table 4.36. After objective function values, the calculations for the service levels are given in the table 4.37. Service level in the higher volatility scenario is an important factor to observe. And as done in scenario 1, the aggregated service levels are also calculated in the table 4.38 where the stores sourced by a single warehouse are clustered together to form a single customer zone.

Table 4.36: Objective function 1 values for scenario 2

Entity locations			Objective function values in $ between entity links (column 1 and 2)	Objective function values in $ between entity links (column 1 and 3)
11	21	22	155,200,000	269,121,600
21	31	32	26,606,700	35,710,240
22	33	34	22,691,396	33,530,730
31	41	42	4,052,320	2,407,250
32	43	44	4,297,148	3,916,815
33	45	46	1,832,355	5,611,152
34	47	48	2,070,825	2,482,700

Table 4.37: Service levels for scenario 2

Store Location	Service levels for time period 1	Service levels for time period 2	Service levels for time period 3	Service levels for time period 4
41	0.90	1	0.99	1
42	0.94	1	1	0.81
43	1	0.92	0.97	1
44	1	1	0.80	0.83
45	0.82	1	0.83	0.66
46	0.95	0.87	1	1
47	1	1	0.867	0.797
48	1	1	1	0.931

Table 4.38: Service levels after aggregation for scenario 2

Store Location	Service levels for time period 1	Service levels for time period 2	Service levels for time period 3	Service levels for time period 4
41	0.93	1	1	0.92
42	0.92	1	1	0.91
43	1	0.96	0.89	1
44	1	0.95	0.88	1
45	0.89	0.93	0.92	1
46	0.90	0.94	0.91	1
47	1	1	1	0.87
48	1	1	1	0.86

Calculating all the steps and values, all three objective function values are in the following table 4.39.

Table 4.39: Objective function values for scenario 2

Objective Function	Value
Z1	$569,531,231
Z2	1.003
Z3	2506 (in #)

Optimization values in GAMS are given in the below table 4.40. And as in scenario 1, it consist the optimization of all three objective functions at the same time which has significant change and improvement. Objective function value comparisons and extended analysis are in the following chapter 5, discussion.

Table 4.40: Objective function values in GAMS for scenario 2

Objective Function	**Value**
Z1	$108,282,720
Z2	0.98023
Z3	1040 (in #)

CHAPTER 5

CONCLUSION AND DISCUSSION

5.1 Sequential Optimization

In this research, there are three objective functions, and therefore, the optimization is carried out with the sequence followed as the objective function Z1, Z2, and Z3 in MS Excel. However, to analyze further, the sequence in descending order, i.e., objective functions starting from Z3, then Z2, and ending with Z1, is also tested. The following table 5.1 shows that there is a difference in values, which suggest that the values were not globally optimal and changes every time. The following analysis created a need to use the platform to optimize all three objective functions together.

Table 5.1: Sequential Optimization

	Sequence 1 →2→3	**Sequence 3→2→1**
Objective function 1 value	$585,114,823	$585,283,781
Objective function 2 value	1.014	1.012
Objective function 3 value	261 (in #)	286 (in #)

5.2 Objective Function Value Analysis

In this section, the brief analysis is performed on how the objective function values have changed throughout the course of optimization. For the scenario 1, the objective function 1 values changed for all the optimization runs for all three objective functions. The table 5.2 further shows that the values are decreasing but they are not globally optimal, as the optimization is only of one objective function at a time. On contrary, when optimized all the objective functions together to find the global optimal by the use of GAMS, the value is significantly lower.

Table 5.2: Objective function 1 values through optimization- Scenario 1

	Obj. Fun. 1 values in $ for scenario 1
Base Value	607,594,294
While Optimizing of 1st Obj. Fun.	586,168,043
While Optimizing of 2nd Obj. Fun.	585,687,789
While Optimizing of 3rd Obj. Fun.	585,114,823
All three Obj. Fun. Optimized (GAMS)	108,280,170

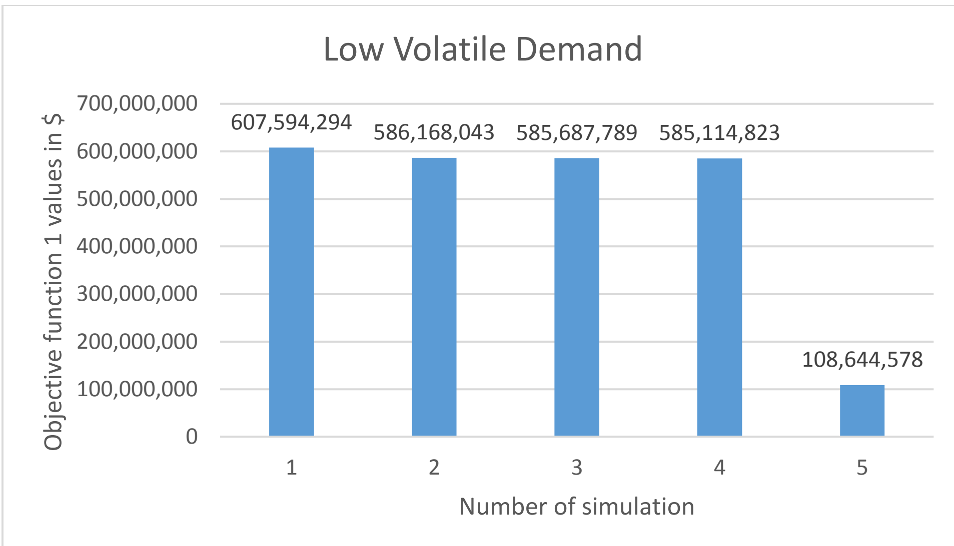

Figure 5.1: Bar chart- objective function 1 scenario 1

As can be visualized from the above graph that optimization of all three objective functions at the same time, reduces the cost drastically as well as finds the global optimal values. And the same is done for the scenario 2. The objective function 1 values for the consequent optimization of the objective functions (1, 2, 3) is given in the following table 5.3, which is followed by the line chart.

Table 5.3: Objective function 1 values through optimization- Scenario 2

	Obj. fun 1 values in $ for scenario 2
Base Value	596,315,669
While Optimizing of 1st Obj. Fun.	572,109,559
While Optimizing of 2nd Obj. Fun.	569,531,231
While Optimizing of 3rd Obj. Fun.	569,531,221
All three Obj. Fun. Optimized (GAMS)	108,282,720

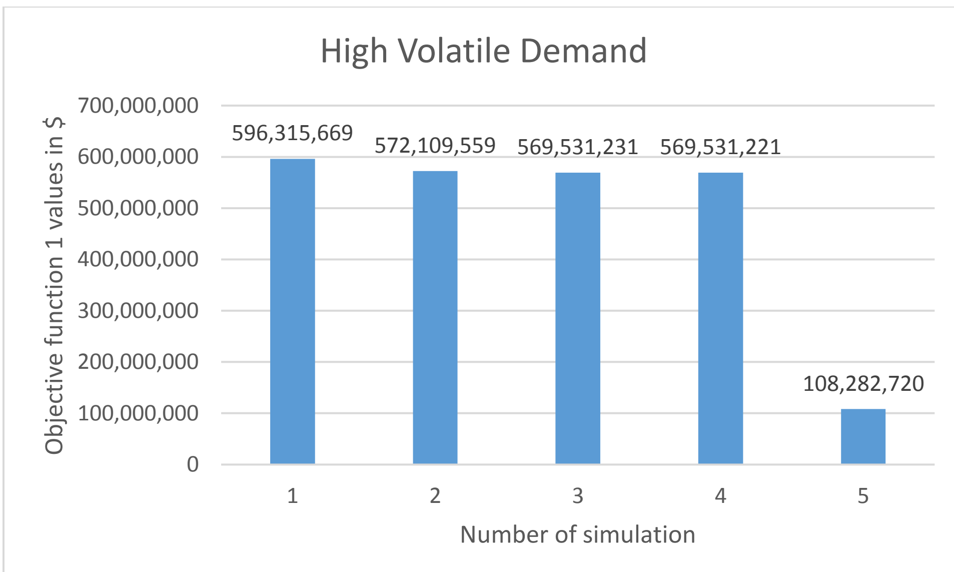

Figure 5.2: Bar Chart- objective function 1 scenario 2

5.3 Relationship between the Objective Functions

To further understand the relationship between the objective functions and why the need to have the third objective function can be understand by the below two graphs. The graphs are objective function 1 (Z1) vs objective function 3 (Z3). Both the graphs suggest that higher the total amount of overage and stock-outs at the store, higher the supply chain cost and vice versa. Z1 is a vertical axes and Z3 is the horizontal axes with the corresponding values.

Table 5.4: Relationship between the objective functions- Scenario 1

Simulation Run	**Obj. Fun. 1 values in $ for scenario 1**	**Obj. Fun. 3 values (in #) for scenario 1**
Base Value	607,594,294	1392
While Optimizing 1st Obj. Fun.	586,168,043	1286
While Optimizing 2nd Obj. Fun.	585,687,789	261
While Optimizing 3rd Obj. Fun.	585,114,823	102
All three Obj. Fun. Optimized (GAMS)	108,644,578	34

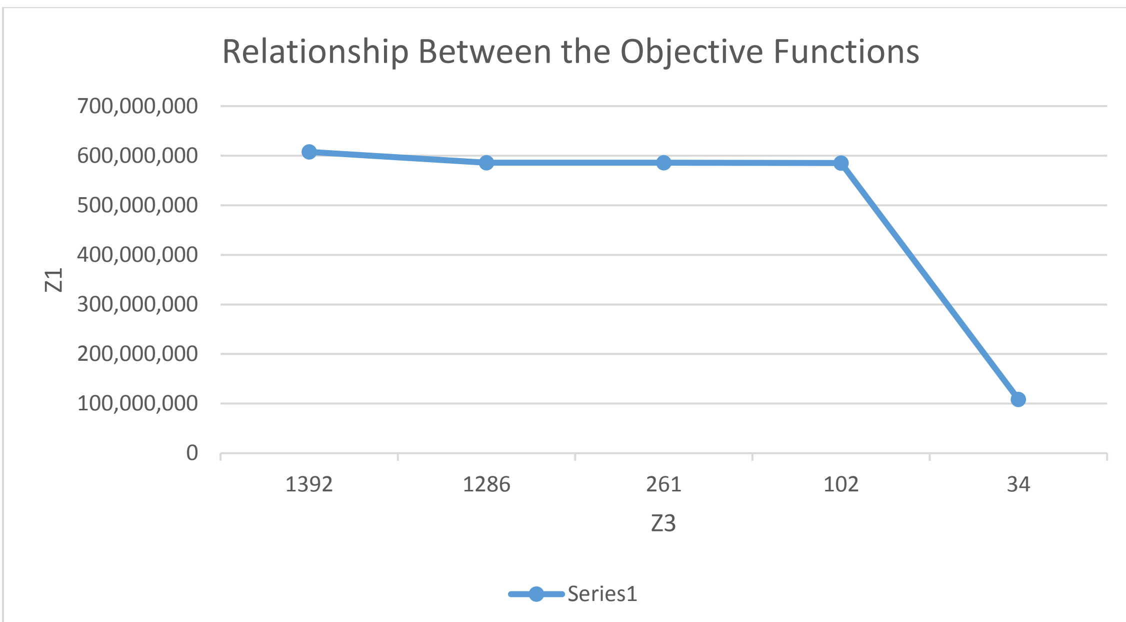

Figure 5.3: Relationship between the objective functions for scenario 1

Table 5.5: Relationship between the objective functions- Scenario 2

Simulation Run	Obj. Fun. 1 values in $ for scenario 2	Obj. Fun. 3 values (in #) for scenario 2
Base Value	596,315,669	3363
While Optimizing 1st Obj. Fun.	572,109,559	1308
While Optimizing 2nd Obj. Fun.	569,531,231	2504
While Optimizing 3rd Obj. Fun.	569,531,221	2506
All three Obj. Fun. Optimized (GAMS)	108,282,720	1040

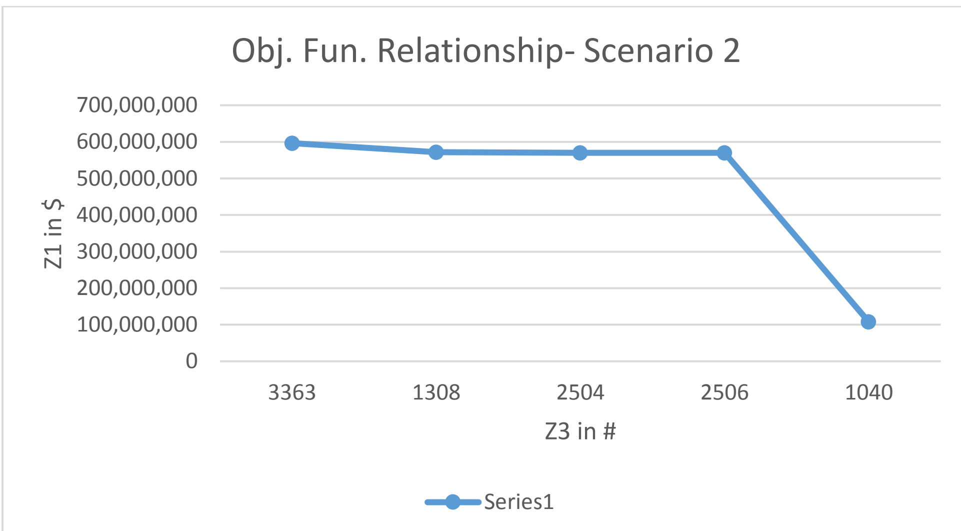

Figure 5.4: Relationship between the objective functions for scenario 2

Moreover, the reduction in the objective functions are apparent and after knowing the relationship, the use of GAMS signifies the importance to have solved both the objective functions optimized together. The cost associated with the overage and stock-outs are higher and relevant in the form of overall supply chain cost reduction with the minimization of the quantity. However, while analyzing, important notation was that the overall service levels are higher but at the store level, service levels may differ and could be lower as in the case of high volatile scenario. So, objective function 2 maximizes the service levels, but to bring that maximization impact to the individual store level, research promotes the aggregation concept in the supply chain design. Next section follows the analysis on data aggregation.

5.4 Customer Zone Aggregation to Reduce Service Level Volatility

Service level volatility depends on the volatility in customer demand. In chapter 4, there are two scenarios developed specifically to analyze the change and effects of the demand volatility. There are service level calculations presented in chapter 4 suggest that the service levels are highly volatile when the demand is volatile. And there is a little effort given to mitigate the severity in this area. Therefore, this research introduces the application of aggregation to reduce the volatility in service levels with the demand aggregation.

The concept of aggregation is fairly old. The impact brought by aggregation are due to the course of general principle of grouping. And that is the reason aggregation is used in many scheduling tasks, as well as in production planning. The same way aggregation is helpful in the supply chain design when there is a higher variability involved in customer demand. In other words, the stores nearby each other are treated as a single customer zone. Earlier in chapter 4, the service level values are calculated for both the scenarios, when stores supplied by single warehouse as a single customer zone. The analysis of the part is discussed in the following paragraphs.

The graphical representation of optimized versus aggregated service levels in time period 1 for all 8 stores is given in following line graphs, for scenario 1 and 2, respectively. As discussed before the scenario 1 is low volatile and therefore the fluctuation in the service levels is low. In that case, the use of aggregation does not reflect a significant impact on the results. As can be seen from the figure 5.5, minimal difference between optimized versus aggregated service levels.

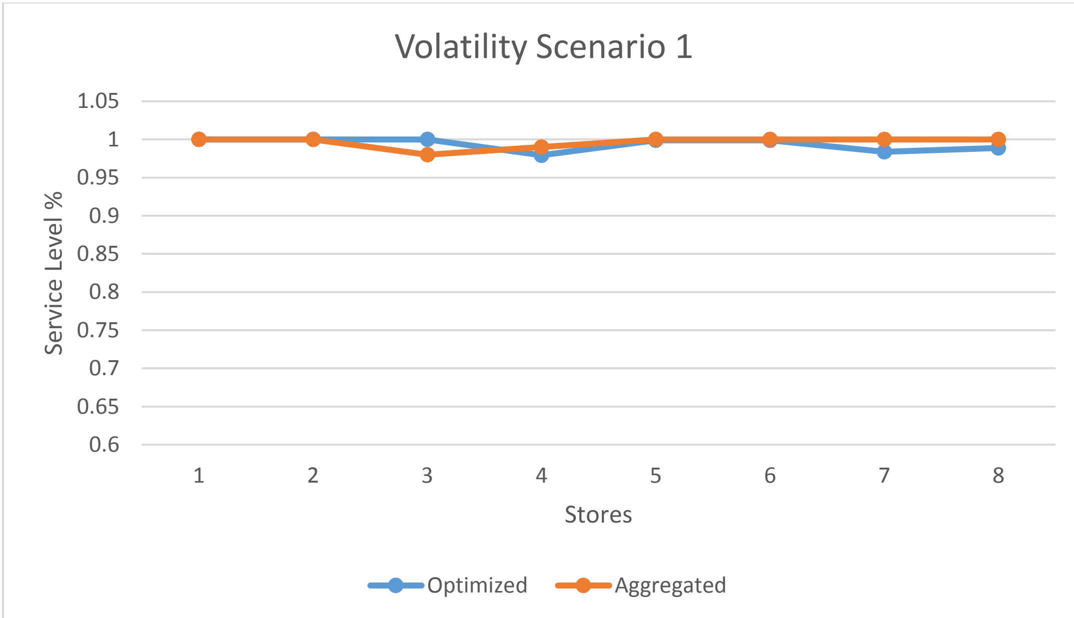

Figure 5.5: Optimized vs aggregated service levels- scenario 1

Scenario 2 is highly volatile with the customer demand fluctuating at the stores. In this case, the use of aggregated service levels is visible. The optimized vs aggregated service levels are given for scenario 2 in figure 5.6. As can be seen form the figure 5.6, the aggregated service levels are fluctuating less than the actual service levels.

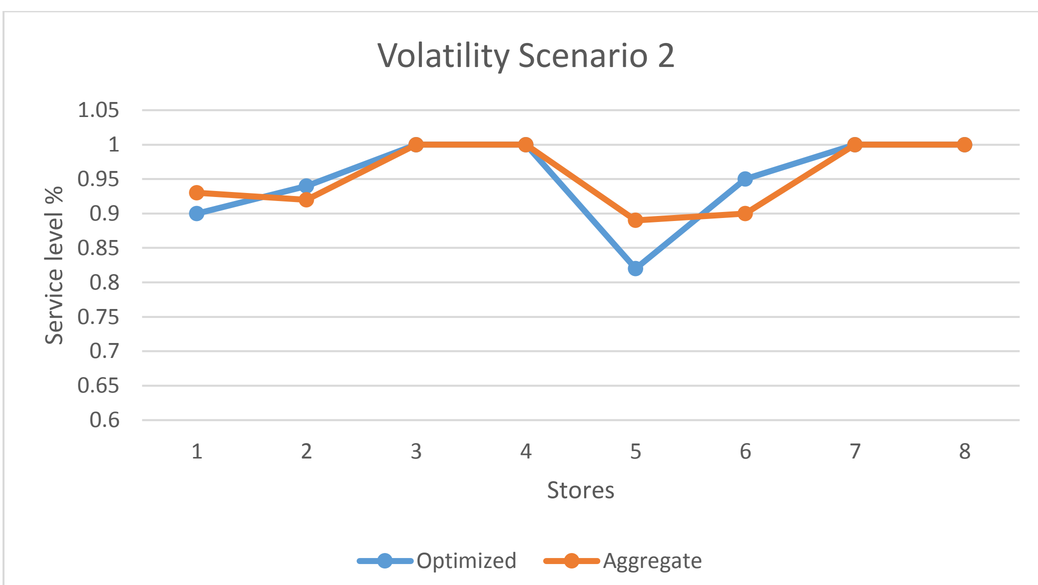

Figure 5.6: Optimized vs aggregated service levels- scenario 2

5.5 Conclusion

Above all the discussion and analysis points are also conclusion points to comprehensively understand the outcome of this research. As explained above, the objective function 1 reduces the supply chain cost. Objective function 2 maximizes the service levels of the stores in the supply chain network. And objective function 3 is the attempt to represent the importance of reducing overage and stock-outs better, which enhances the cost minimization. The importance of not to have the higher overage and stock-outs is a wide spread intellect, but while translating the phenomenon into an objective function further supported the claim. More so, the optimization of all three objective functions in GAMS proven to be vital to have multi-objective model. Which fundamentally proves that DTC and JITD concepts are need to be enabled for the modern supply chain design problems. Furthermore, data aggregation is helpful to reduce the volatility of service levels, even if the customer demand is volatile.

5.6 Future Study and Limitation

There are three parts where the research can continue. The first will be to develop the location modeling to strategically counter the cost and service levels with the help of DTC and JITD. The second future work area is to improvisation of this location model into a model which can generate impromptu locations for better cost and service levels trade-offs. And the third is to concentrate on the trade-offs of cost and aggregation. A model which can provide the information on when the aggregation should be used and at what proportion to achieve the desired volatility and cost. However, the limitation of the research is to be with the pace of the cutting edge technology. The developments are rapid and the research have tried all the possible attempts to strategically involve the known progressions.

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