

Mathematical Model to Design a Reliable Flow of Materials using Supermarkets.

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I would like to dedicate this thesis to my family who have supported me throughout my life.

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ABSTRACT

To Sustain production in a mixed model manufacturing environment, techniques such as lean manufacturing, Zone Based Manufacturing are implemented to increase the efficiency of the system. Along with improving the assembly line processes, it is necessary to design a reliable logistics of materials within the facility to support the production process and gain maximum productivity. The high product mix causes variation in the demand of materials and disruptions in material flow which has an effect in the overall productivity of a manufacturing facility. To reduce the disruptions, it is necessary to store the materials as close as possible to the assembly lines.

The current study elicits a framework to design a reliable material feeding system using supermarket warehouses which complements the zone base manufacturing technique to achieve a standardize flow of materials within the facility. A mathematical model with optimization approach is used to determine the key decisions such as location and number of supermarkets, safety inventory and the flow of materials within the facility. To validate the mathematical model, this study is carried out at manufacturing facility and comparison of the results of the current material flow and the output from the model are provided.

TABLE OF CONTENTS

Chapter One Introduction.....	1
Background	1
Problem Statement.....	5
Approach	6
Phase 1 - Classification of material feeding systems.....	7
Phase 2 -Identification of parameters for JIT Supermarket systems.....	8
Phase 3 - Formulation of Mathematical model.....	9
Phase 4 - Validation.....	9
Assumptions.....	10
Scope of Study	10
Organization of Study.....	11
Chapter Two Literature Review	12
Material Feeding Systems:.....	12
Line Stocking:	14
Kitting:.....	15
Just in Time:	15
Comparison between Feeding Policies: LS vs Kitting vs JIT	16
JIT Supermarkets:	22
Long Term Strategic Problem	24
Short Term Strategic Problem	26
Research Gap:	29
Chapter Three Methodology	31
Optimization	31
The Location of Supermarkets:.....	32
Number of Supermarkets:.....	33
The Level of Inventory:	33
The flow of Materials:.....	34
Defining Parameters, Variables, and Objective function.	36
Parameters	36
Decision Variables:	43
Objective Function:	45
A mathematical model with constraints	46
Indices:	47
Parameters:	47
Decision Variables:	47
Objective Function:	48
Constraints.....	49
Chapter Four Results and validation.....	52
Background of the Company	52
Flow of Materials - Current State	55
Defining Parameters and Variables.....	56
Demand:	56

Possible Number & Location of Supermarkets (Candidate Locations)	62
Calculating the Distances	64
Transportation Cost	68
Inventory Cost.....	68
Capacity of Supermarkets.....	69
Installation Cost	71
Results	72
Comparison of Current and Future state - Cost Analysis.....	81
Chapter Five Conclusions and future work	84
List of References	86
Vita.....	91

LIST OF TABLES

Table 1 – Summary of the literature review	13
Table 2- Summary of the literature review continued	14
Table 3 Comparison of different methods	22
Table 4- Template to collect the material data for different product mix.....	38
Table 5 Template to calculate demand/shift for each material	39
Table 6 Template for collecting the materials per station.....	40
Table 7 Material Disruptions	54
Table 8 - Product Mix.....	57
Table 9 - Demand of each material for different product mix	58
Table 10 - Daily production of product mix.....	59
Table 11 – Demand of each material for each period	61
Table 12 – Demand of materials per station	62
Table 13- X & Y Co-ordinates of stations and candidate supermarket locations	64
Table 14 Distance between stations and candidate supermarket locations.....	66
Table 15 Coordinates of main warehouse	66
Table 16 Distance between candidate supermarket location and main warehouse	67
Table 17 Cost of each material	69
Table 18 Capacity of each material in the supermarkets	70
Table 19 Maximum Capacity of supermarkets.....	71
Table 20 – Installation cost of supermarkets based on different capacities	72
Table 21 – Optimal supermarkets for each capacity value	72
Table 22 Scenario 1 Flow of materials from supermarkets to stations.....	74
Table 23 Scenario 1 – Material flow of each material from supermarkets to stations	74
Table 24 Scenario 1 Number of trips from supermarkets to stations	75
Table 25 Scenario 1 Number of trips from warehouse to supermarkets.	75
Table 26 Optimal solution for different scenarios	76
Table 27 Optimal solution	78
Table 28 Flow of materials.....	80
Table 29 Flow of each material from each supermarket	80
Table 30 Number of trips from supermarkets to stations	81
Table 31 Number of trips from warehouse to supermarkets	81
Table 32 Current state cost analysis.....	82
Table 33 Comparison of current state and future state	82

LIST OF FIGURES

Figure 1-1.1 Material feeding with centralized warehouse	2
Figure 1-2 Material feeding system with decentralized warehouses	3
Figure 1-3 Material feeding system where materials are directly supplied from the supplier to the stations.....	3
Figure 1-4 Approach	7
Figure 3-1 Layout of the problem	31
Figure 3-2 Flow diagram of mathematical model	46
Figure 4-1 Layout of the facility	53
Figure 4-2 Current state material flow	55
Figure 4-3 Normal Quantile Plot	60
Figure 4-4 Comparison Test	60
Figure 4-5 Possible location of supermarkets	63
Figure 4-6 Graphical representation of stations and candidate supermarket locations using coordinates.....	65
Figure 4-7 – Graphical representation of facility layout using coordinates	67
Scenario 1 Figure 4-8	73
Figure 4-9 Transportation cost for different scenarios.....	76
Figure 4-10 Inventory cost for different scenarios	77
Figure 4-11 Total cost for different scenarios.....	78
Figure 4-12 Optimal supermarket locations	79
Figure 4-13 Current state material flow	82

CHAPTER ONE

INTRODUCTION

Background

To remain competitive in today's industry, manufacturers tend to focus on improving their production process or assembly lines by implementing techniques such as lean manufacturing. The emphasis of lean manufacturing is to reduce the non-value-added activities by reducing wastes and by implementing the techniques of just in time (JIT) strategies [1]. Wastes can be categorized as overproduction, waiting, excess transportation, or unnecessary inventory [1]. Firms try to commit to the use of lean production by prioritizing the JIT and implementing total quality management programs [2]. In real life, the implementation of lean is a complex task [3]. It is complex because while designing a lean manufacturing system, it is assumed that there is a smooth demand for the product/material. There is a need to consider the flexibility of the demand, set up times for the process, and other necessary steps related to variation in the overall process [3].

Zone-Based Manufacturing (ZBM) like Lean focuses on reducing waste by balancing the workload of the employees by eliminating the non-value-added activities but also focuses on reducing stress and improving the quality of life of employees. ZBM technique is useful in determining the cycle times, line balancing, and scheduling the jobs done by an employee using precedence-based tasks to balance the work done by each employee [4]. ZBM concept is based on three pillars which are as follows

- 1) Zone Base Production
- 2) Material Flow
- 3) Employee fatigue and stress.

For ZBM, it is important to have materials staged near the stations or assembly lines such that the employees do not have to travel a large amount of distance to fetch them; also, waiting time for the process is reduced by keeping the materials close to the line [4]. This study focuses on the material flow aspect of ZBM.

Material feeding systems play an important role in affecting the productivity of the manufacturing industry. The primary function of these systems is to keep up with production to minimize the disruptions, which is achieved by designing the system, which eliminates wastes such as excess transportation, waiting, and unnecessary inventory.

The structure of moving the parts, i.e., the logistics behind the materials being delivered to the assembly line, is one of the important factors affecting the efficiency of the manufacturing companies. If the right materials are not delivered at the right time at the desired point of use, it results in an unreliable process, thus affecting the efficiency by increasing the Cycle Time (CT) and Throughput (TH) of a manufacturing company. In the manufacturing area, material/parts feeding systems include a wide range of processes such as storage of the parts to the delivery of those parts at the required point of use.

The feeding of parts from storage to the assembly line is controlled by parts feeding systems [5]. The following figure represents the working of part/material feeding systems.

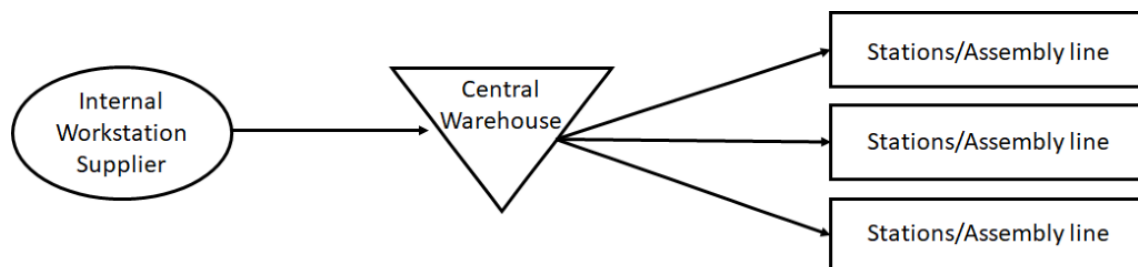


Figure 1-1.1 Material feeding with centralized warehouse

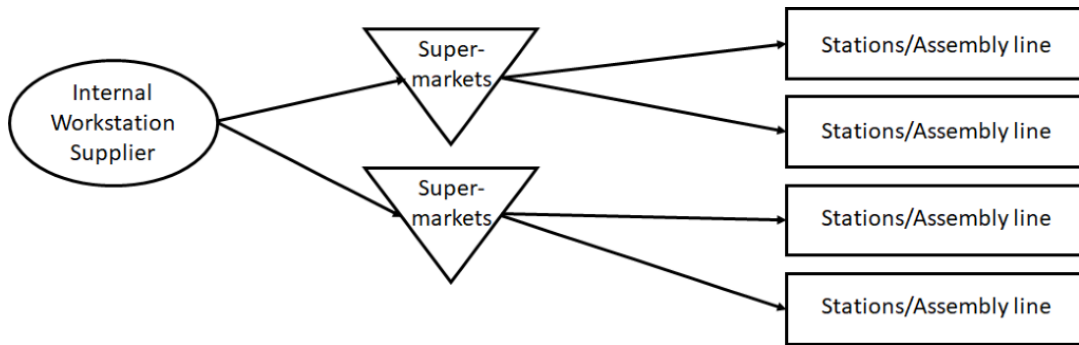


Figure 1-2 Material feeding system with decentralized warehouses

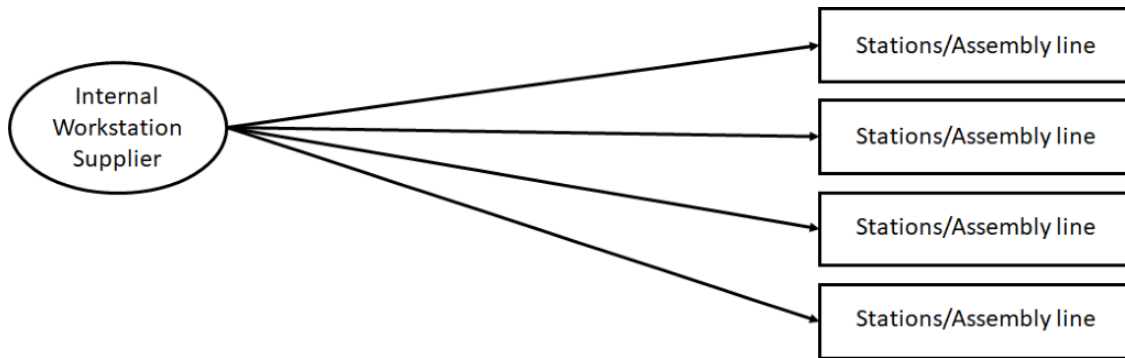


Figure 1-3 Material feeding system where materials are directly supplied from the supplier to the stations

Figure 1.1 represents a material/part feeding system where the parts are delivered from the internal workstation to one central warehouse which then feeds the stations or the assembly lines. Figure 1.2 represents the system where the parts are delivered from the decentralized storage places, called supermarkets, which are generally close to the stations or the assembly lines. Whereas, Figure 1.3 represents a system where parts are directly supplied from an external or an internal workstation supplier directly to the stations or the assembly lines. Centralized and direct supply systems are used when the manufacturer follows

batch production. The disadvantage of batch production is that large inventory of raw materials is stored near the line of which is governed by the number of parts produced in a batch. This results in excess inventory and occupying a large shop floor area. Whereas decentralized storage systems complement the single piece flow as only one product is worked at a time in each station and inventory that is necessary is used. Depending upon the nature of production, whether it is a batch production or single piece flow, the parts feature, the layout of the plant, the main decision while designing the system is to decide on the centralization/decentralization of the storage with the facility.

Nowadays, due to increase in mass customization and different customer needs, most of the automobile companies prefer to have a decentralized storage in the form of supermarkets to counter the demand variation and customization of the products. This system enables the process to develop timely deliveries in small amounts such that the unnecessary inventory stored at the point of use can be eliminated, as well as reducing the non-value added activities such as wait time, transportation time in the process, since the materials are stored close to the point of use, resulting in a reliable material flow and a reliable process.

Many of the applications of material feeding systems are applied in automobile industry due to the advancement and mass customization of the product and the needs of the customer. The focus of this research is on the manufactured housing industry which has been on a rise for the past few years. Two of every three houses in rural areas in the U.S. are manufactured homes. Since 1989, manufactured homes account for 21.5% of all new single-family homes sold [6]. The annual shipments of manufactured homes increased by 3.9 % in 2018 and is estimated to only rise in the future [7]. The houses vary in sizes, requirements and hence mass customization is offered for the customers to satisfy individual needs. Manufactured homes are also produced on assembly lines just like automobiles where all the raw materials or the parts from the sub-assemblies are brought together to the assembly line to make a finished product. Thus, it is crucial to have a reliable process, as well as a reliable material flow which helps in achieving the

desired efficiency and ensures higher reliability of the overall production. The challenge in the housing industry being the size of the product, hence, the materials required to build the houses are also big in size. To deliver the materials, there is a need for material delivery equipment that can carry these large materials with flexibility. The equipment needs to maneuver through tight spaces due to the layout of the assembly stations in the plant. Hence, forklifts are used to deliver the materials because it has the capability of delivering large materials in tight spaces. This study helps in designing the system for efficient and reliable material which takes into consideration different types of products manufactured such that the material travels less than required at the assembly line resulting in reduced waiting time thus increasing the efficiency of the process.

Problem Statement

One of the important decisions of designing and managing the production lines is the way components/parts and sub-assemblies are delivered to the assembly stations [8].

The following are a few shortcomings of the past research efforts which we must deal with.

- There are studies done comparing different material feeding systems but there is a lack of research on JIT supermarket material delivery systems in the manufacturing industry.
- There is a lack of implementation of the JIT supermarket systems in manufacturing industries other than automobile and semiconductor industries.
- There is a fixed way on how to deliver the parts to the line using tugger trains as the material delivery equipment which is represented in the past studies. This is not the case for other industries as different material delivery equipment is used.

- Part features, such as weight of the materials, is an essential component while considering the material handling equipment which is not covered in the past research.
- The study considers the designing the JIT supermarket system similar to a supply chain network where the materials move from warehouse or main storage to supermarket and then from supermarket at the right time and in the right quantity.

This mathematical model will result in a framework for an efficient supply of materials within the facility with transferable knowledge across different manufacturing and supply chain industries.

Approach

Figure 1-4 depicts the framework to design a supermarket material feeding assembly system in a manufacturing environment. This study aims to determine the optimal location of supermarkets within a house manufacturing facility also determining the flow of materials moving from supermarket to station with the use of optimization techniques such as integer programming. This study consists of 4 phases which are explained as follows.

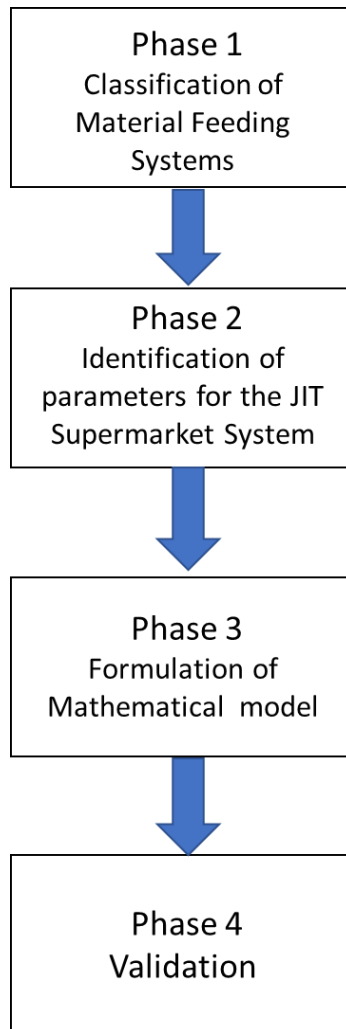


Figure 1-4 Approach

Phase 1 - Classification of material feeding systems

This phase relies on understanding the concepts of material feeding systems and also classifying different types of feeding policy and systems such as Kitting, Continuous Supply which can be categorized as Line Storage and JIT Supermarkets. Later in this phase the study focuses on a specific material feeding system which is the JIT supermarket system. Details such as conditions,

scenarios, and necessary logistics required are discussed, as well as the research gap is explained for this particular material feeding system. This process is discussed in detail in chapter 2.

Phase 2 -Identification of parameters for JIT Supermarket systems

After the comprehensive research about different material feeding systems and then narrowing the focus solely on JIT Supermarket systems, the next phase is to define the parameters which are crucial to design the JIT Supermarket system. The following are the initial parameters that are essential to design the supermarket system.

- **Demand** - Daily demand is calculated for different types of products which are being produced and also the demand for each material required for a specific product is calculated.
- **Location** - In order to design the Supermarkets, there is a need to determine the optimal locations which are selected out of the possible candidate locations that are initially known. The location of the candidate supermarket places is determined with the help of plant layout and expert opinions.
- **Distance** - The third essential parameter is the distance between the stations and the possible location of the supermarket, as well as the distance from the warehouse to the possible locations of the supermarket. This is a very crucial parameter because while designing the system, the main objective is to reduce the distance that material flow travels until the time it reaches the assembly stations.

Phase 3 - Formulation of Mathematical model

The next phase is to develop a mathematical model using the Mixed Integer Linear Programming (MILP) optimization technique to determine how many optimal supermarkets should be opened/established out of the candidate locations, the flow of materials from supermarkets to stations, the number of trips from supermarket to stations, as well as from warehouse to supermarket. The value for these variables is obtained by minimizing the overall cost function which is defined by using the following parameters:

- **Transportation cost** - The cost of moving the materials from the warehouse to the supermarket and from the supermarket to the point of use (stations).
- **Inventory Cost** - It is the cost of safety stock inventory which needs to be stored in the supermarket to satisfy the variation in demand.
- **Installation Cost** - It is the cost associated with opening/establishing the supermarket.
- **Capacity of the Supermarket** - This parameter states the quantity of materials a supermarket can hold once it is open.

The detailed explanation of this phase is given in chapter 3. Once, the mathematical model is formulated, a case study is done to test the model in the house manufacturing industry which is explained in detail in chapter 4.

Phase 4 - Validation.

After formulating the mathematical model, the new system is validated with the help of a case study in a house manufacturing industry. To see the behavior of the model, it is tested under different conditions by changing the capacity of the supermarkets that supply materials to the stations in the assembly line to provide

the best results. The best/optimal result is compared with the system that is currently being followed in the facility on the basis of cost analysis.

Assumptions

The following are some assumptions made while designing the JIT supermarket material feeding system.

- Demand for the product mix is stochastic and is considered to follow normal distribution.
- It is assumed that the replenishment of supermarkets can take place either before the shift starts or at the end of the shift.
- The materials are uniformly distributed by weights in the supermarkets.
- Each supermarket has the capability and capacity to hold each material.
- Material delivery equipment is always available.
- Material delivery equipment can carry all the materials in one trip based on its weight capacity.
- Expert opinion is representative of operating conditions and constraints for the facility.

Scope of Study

The research methodology provides the following scopes and limitations:

- This model can be applied to any manufacturing industry with a high number of parts required to produce a product.
- Along with the supermarket location, the decision of the flow of materials from supermarket to stations is also made using this model.
- All the variables such as flow of materials, inventory, and transportation necessary to design the material flow system are identified and tested with the help of a single mathematical model.

- This model is transferable to other facilities of the same manufacturing industry, as well as other manufacturing and supply chain industries which is discussed in chapter 5.

Organization of Study

This thesis is organized into five chapters. The first chapter introduces this research which is followed by a comprehensive literature search by reviewing theses and journal articles related to the study of different types of material or parts feeding systems and comparison between these systems review of the methods and tools used to approach the above systems in chapter 2. Chapter 3 discusses the methodology and provides the mathematical model required to design a Just in Time (JIT) supermarket system to supply parts or materials required to the assembly line. Chapter 4 provides the case study along with validation of the results. Chapter 5 is the final chapter that provides the conclusion of the research leading towards future work and research limitations.

CHAPTER TWO

LITERATURE REVIEW

In this chapter, various types of part or material logistics systems used in manufacturing industry for delivering the parts from the warehouse to the point of use are discussed [5]; for example, the assembly line, the decisions related to implementing the material feeding policy and transportation equipment necessary. Later the literature focuses on implementation of one particular type of feeding system, which is currently being used in most of the automobile industries called supermarket warehouse system. Also, various models/algorithms used to solve the problem are discussed.

Material Feeding Systems:

In manufacturing companies, material management is of the utmost importance to reduce the overall material holding and handling cost [9]. The logistics of material in a manufacturing environment is termed as the parts feeding system [5]. Part feeding systems comprise of three key components which are storage of parts, part feeding policy and transportation of parts [10]. The literature generally classifies the part feeding systems into three types,

- Line Stocking
- Kitting
- Just in time

Table 1 – Summary of the literature review

Paper	Study type	Objectives	Line Feeding System	Simulation	Empirical	Optimization	Heuristics
[9]	Literature Review	Survey on JIT Supermarket System	JIT Supermarkets				
[11]	Quantitative	Supermarket Location Problem	Supermarkets System			x	x
[12]	Quantitative	Supermarket Location Problem	Supermarkets System				x
[13]	Quantitative	Supermarket Location Problem	Supermarket System		x		
[14]	Quantitative	Scheduling the Logistics	Supermarket System			x	x
[15]	Quantitative	Supermarket Location Problem	Supermarket System			x	
[16]	Quantitative	Scheduling the Logistics	Supermarket System				x
[17]	Quantitative	Scheduling the Logistics	Supermarket System				x
[18]	Qualitative	Comparison of different Feeding Systems	LS Vs Kitting Vs Continuous Supply		x		
[19]	Qualitative	Selecting the Feeding Policy	LS Vs Kitting Vs Continuous Supply		x		
[20]	Qualitative	Comparison of different Feeding Systems	LS Vs Kitting Vs Continuous Supply		x		
[21]	Qualitative	Selecting Feeding Systems based of parts feature	LS Vs Kitting Vs Continuous Supply		x		
[22]	Qualitative	Comparison of Feeding Systems	Kitting vs LS		x		
[23]	Qualitative	Comparison of Feeding Systems	Kitting vs LS		x		

Table 2- Summary of the literature review continued

[8]	Quantitative	Comparison of Feeding Systems	Kitting vs LS			x	
[10]	Literature Review	Survey on the three material feeding policies	LS Vs Kitting Vs Continuous Supply				
[24]	Qualitative	Comparison of Feeding Systems	Kitting vs LS		x		
[25]	Quantitative	Designing of JIT Feeding System	JIT				x
[26]	Qualitative	Designing JIT supermarkets with Kits	Kitting & JIT	x			

Line Stocking:

Line stocking is the oldest feeding policy, in practice, in most of the manufacturing companies [24]. In line stocking policy, the materials are received from the main central storage to the stations which are stored near the line in large amounts which can be in the form of an entire pallet [10]. The containers, which are kept near the line, are replenished once they are emptied. The advantage of the line stocking policy is that there is a continuous supply of materials to the line, but on the contrary uses a lot of shop floor space which is generally very scarce in a facility [10]. Also, if there is high product variety then a lot of time can be wasted searching for a specific part [27]. Few papers have talked about batch supply which is similar to line stocking only difference being the parts are delivered in batches rather than a unit load [28].

Kitting:

Kitting can be defined as the activity of feeding required parts to the assembly lines in predetermined quantities that are put together in specific containers [27]. Kits prepared can be of two types; stationary kits can be specific to the station and can be replenished once depleted or traveling kit which goes along the assembly line, station to station with the end product [27]. Parts are fed from the main warehouse to a local area known as the kitting area where the parts are kitted as per the production sequence. Kits can be prepared having the same parts or having multiple parts inside a kit depending on the demand and part diversity required to assemble one final product, which can be made up of more than one container. A kit container is picked up from this kitting area with the help of material delivery equipment which is delivered to the assembly line and an empty container in which the parts need to be replenished is picked from the line back to the kitting area. Number of kits, number of workers required for kitting and the kitting area are the critical factors while designing this type of parts feeding system [27]. Based on the demand of parts and its variants for an assembly, and capacity of the container, the number of kits is determined. Also, depending upon the number of kits and the production schedule, the number of workers to prepare the kits are determined. Finally, the location of kitting area where the replenishments of kits takes place are considered while designing this type of system [27, 29-33].

Just in Time:

Just in time (JIT) is a Kanban based feeding policy which uses supermarkets as decentralized storage areas that act as an intermediate location between the warehouse and the assembly line [10]. In the supermarkets, the containers contain the required number of parts for the end product of the stations and a Kanban, including all the information related to the parts attached to each container. The Kanban is released as the parts are being depleted and the replenishment takes place [10]. Two key components while designing a JIT Kanban system are Kanban

number determination and supermarket design [10, 34]. Lots of studies regarding Kanban number determination can be obtained in the literature with Kanban number optimization being the most frequently solved problems [33-36]. The objective is to optimize the number of Kanbans which are the “maximization of average cumulative throughput rate and the minimization of average production lead time and the average work in progress” [37].

However, there are only a few studies done on determining the optimal location of supermarkets, replenishment of supermarkets, scheduling and routing of the transportation equipment used, which are an integral part of designing a JIT supermarket feeding system, which is the scope of this thesis and is explained later in section 2.4 [11-15].

Comparison between Feeding Policies: LS vs Kitting vs JIT

There has been a considerable amount of studies in the literature comparing all three parts of the feeding system. The decision problem that needs to be solved is the degree of centralization/decentralization of the inventory and the appropriate feeding policy to transport the materials from the main centralized warehouse to the assembly line, which is also known as the parts feeding problem [18]. The location of the parts and components, as well as the transportation mode used to deliver the components, must be considered while designing the parts feeding policy. Those two attributes have an impact on time, cost and performance in terms of Work in Process (WIP), space utilization, and personnel requirement [8, 18, 19, 38]. In [18, 19] the authors share an insight of different types of feeding policies and the environment that is feasible for those policies. The paper discusses pallet to workstation, trolley to workstation and kit to assembly line policies each using different transportation equipment [18]. The first policy i.e. pallet to workstation, as the name suggests, a unit load of each component is transported to the workstation with the help of a forklift from a centralized warehouse. In trolley to workstation feeding policy, parts from the warehouse are loaded in trolleys which moves the

components to the assigned workstations. Parts required for specific product/workstation are loaded in the trolley thus reducing the inventory near the line. The third feeding policy, discussed in the paper, is kit to assembly line in which kits of each end product is prepared and delivered to the assembly line which passes through the entire line until the finished product is obtained [18, 19, 27]. In [19], the authors identify the goals of their comparative study on material feeding policies as: “to provide consistent means to seize resources and compare the performance of alternative material supply policies for assembly lines and to suggest an empirical method to develop combined feeding policies according to a class-based components aggregation approach”. The studies clearly distinguish the feeding policies in three basic types viz. Kitting, Kanban (JIT) and line stocking are compared with each other to see which policy fits the best in what environment [18, 19, 38, 39]. A study has been performed by the author to compare the three-part feeding systems, i.e. line stocking, kitting and sequencing. Instead of a JIT system, sequencing is considered. “Sequencing is a particular form of stationary kit where the assortment of parts holds the needed variants associated to one and only one component” [20]. A decision using empirical cost base model is suggested to select the optimal part feeding policy for the assembly line [39].

A framework is introduced which presents phases to design an optimal feeding policy given as follows. 1) Data collection and analysis, 2) centralized/decentralized degree of choice, 3) assembly feeding choice and management. Based on the data collected in phase one, such as average demand rate, size of materials, average demand, and area near the assembly line, a decision is made to have one centralized warehouse or to have multiple loading areas near the assembly line. Based on the degree of centralization/decentralization, the appropriate feeding policy from the three mentioned above is selected based on evaluating each feeding policy with the factors which most influence the total time function. The factors influencing the decision to select the feeding policy is the lot size. If the dimensions of the lot size are modest then kit to assembly line is the feasible option, whereas for high lot size

dimension, pallet to workstation seems to be the best policy and for medium size dimension of the lot, trolley to workstation or pallet to workstation policy can be used [18]. Apart from the traditional material feeding systems, the authors propose an alternate feeding policy called the hybrid policy. The above framework is applied to a real industrial case study of two components for which main parameters such as the demand, capacity, safety stock is calculated to determine the degree of centralization/decentralization and then the feeding policy is selected based on it [19]. The feeding policies are compared with each other based on total time function by using techniques such as ANOVA, DOE, as well as simulating the scenarios to get the best results. All the models are being formulated assuming a warehouse, a single I/O point and a single-product assembly consisting M number of stations arranged serially [19]. Variables such as cost of kitting, cost of equipment, cost of WIP inventory and space utilization are calculated and the model with the least cost is preferred [8, 10, 19, 20]. A hybrid policy is suggested by classifying the components into Class A, Class B and Class C where Class A is the specific component to a single end product with low degree of commonality; Class B has intermediate degree of commonality; and Class C has the most common components [19]. An empirical study for the framework carried out using a case study of a manufacturer of vending machines for hot and cold beverages. It suggests that kitting policy has the best performance in terms of capital investment and WIP cost but the worst in terms of labor cost, whereas Kanban policy was an intermediate in every respect and the line stocking policy had the high capital and WIP costs but low labor cost. In order to highlight such a tradeoff, the possibilities of hybrid policies were explored by the authors which was a noticeable compromise. The hybrid policies such as Kitting/Kanban/Line stocking or Kitting/Kanban/Kanban for ClassA/ClassB/ClassC materials were found to be the best performers [19]. “The benefits and drawbacks of different assembly lines appears to depend on the characteristics of the production and the material supply environment they are used in” [20]. The above policy only considers a single product which does not capture the complexity of the real-world case which

comprises of mixed model assemblies. This paper compares different feeding policies, cost functions, such as preparation cost, transportation cost, storage cost, as well as Border Line Picking cost (BOL) are calculated by taking in consideration the different part variants. An empirical study supporting the above framework for multi scenario problems is accomplished in an automotive industry to determine under which condition a particular feeding system is the least costly one. By combining different values of variable parameters such as number of components, number of variants per component, Bill of Materials (BOM) coefficients, component class, usage profile, usage rate, delivery and preparation of batch size and 94,050 potential scenarios were created. All three part feeding systems were compared based on the above variable parameters and line stockings yield the best components having low diversity, low BOM, high unused rate and unbalanced variants of the usage rate, whereas Kitting is more convenient for small components with high part diversity and sequencing is benefited by big components having high diversity [20]. A quantitative study, suggesting which policy to select for the kind of assembly line environment, is proposed using a decision mode [39]. A mathematical model, based on the objective of minimizing the cost of Equipment cost, WIP holding cost, space occupation cost and marginal cost for all three feeding systems (Kitting, LS, JIT) using Mixed Integer Linear Programming (MILP), was solved to determine the optimal feeding policy to be used. A real company case was used in which the model suggests that JIT is preferred for small size components. JIT and LS are quite evenly distributed for intermediate and high weight class items. But for intermediate and high-volume classes, LS is preferred due to the constraints imposed because of JIT bin constraint. Kitting is not suitable for medium and large sized items. If container size and component dimensions allow both JIT and LS, then the policy is evenly distributed between the components. To summarize the results, JIT is the preferred policy as it strikes a compromise between Kitting and LS [39].

Comparison between Kitting and continuous supply (Line Stocking) has been studied by authors Robin Hanson and Anna Brolin using two case studies

performed in Swedish automotive companies [22]. The study focuses on man hour consumption, product quality, flexibility, inventory levels and space requirements. Using the four performance areas, the relative effects of kitting and line stocking are studied where the results in Case 1 suggests that kitting is useful for parts with many variants, whereas for the parts with low variants line stocking is preferred [22]. To investigate which part feeding system to use for which part type, the authors introduce a mathematical cost model for evaluating the assignments of parts between two material supply systems, i.e. by kitting or line stocking. An optimization technique is used to make decisions on the material feeding technique to be selected on the individual part on the basis of overall handling costs [23]. The numerical results from the study shows that, “kitting all parts is not a cost-effective way to mitigate the shortage of space at the line”, and thus encourages to have a hybrid feeding policy for a material delivery system which are cost effective [23]. Different feeding systems not only affect the in plant logistic flow, but also govern the amount of inline stock [8]. An assignment model for an individual part has been discussed by authors to determine the part feeding system to be used between kitting and line storage which incorporates the variable distances traveled by the operator since picking costs make the considerable part of the in-line part feeding cost [8]. One of the noticeable things suggested was that the decision to kit the part does not only depend on its own characteristics but the characteristics of the other parts as well and reducing the walking distance of the operator increases the attractiveness of kitting even for stations with large floor space[8]. A study is carried out focusing on designing feeding line policy based on parts feature and scenario condition [21]. “The effect of relevant part and measurable part feature such as unit volume, weight and cost are considered have on the parts feeding cost is explored by developing suitable economic models” [21]. Cost break even points are studied based on the basic attributes to decide on areas where each feeding policy is convenient over the other [21]. The framework developed by the authors consists of a cost function for the three most widely known part feeding policies which are Kitting, JIT, LS on a part by part basis including the parts

features and determining the policy for each individual material without using complex optimization approaches. To calculate the total cost function, a wide array of cost items such as labor consumption, floor space, occupation cost, capital investment and WIP holding costs are developed for each feeding policy which offers a more realistic cost assessment. It is suggested that kitting has an advantage when the unit cost is high, unit volume is high, labor cost is low, unit weight is low, limited available space at workstation, and mixed model production; whereas the JIT system has an advantage when unit cost is intermediate, unit volume is low, labor cost is high, unit weight is low, limited space at workstations, and mixed model production; and line stocking policy has an advantage when unit cost is low, unit volume is high, labor cost is high, ample space at workstation, and single model production [21]. Table 3 represents the summary of different studies which compares different parts feeding systems based on various features. As said earlier, there is less literature available for JIT supermarket compared to the other two-part feeding systems. So, this research focuses more on the implementation of the JIT part feeding system using supermarkets.

Table 3 Comparison of different methods

Papers	Policy	Quality	Man- Hour Consumpti on	Space Requireme nt	Handling Cost	Part Features	Capital Investment s	WIP Inventory
[32]	Kitting vs LS	x	x	x				
[23]	Kitting vs LS			x	x			
[8]	Kitting vs LS		x	x	x			
[21]	LS vs Kitting vs JIT		x	x	x	x	x	
[18]	LS vs Kitting vs JIT		x	x				x
[19]	LS vs Kitting vs JIT		x	x	x			x
[20]	LS vs Kitting vs JIT		x	x	x		x	x

JIT Supermarkets:

JIT supermarkets were developed in response to the need for the companies to mass customization as per the demand of individual customers. Recently there is a shift in the focus of the companies for process innovation from final assembly to its parts logistics [9, 40]. This is due to the undeniable trend to make a variety of products to satisfy customer demand [12]. Companies are facing several challenges because of diversified customer demand. Each individual customer has different needs and due to this, most of the companies, especially the automobile

companies, try to adapt a system of mass customization [9, 11]. The system used to tackle the above-mentioned issue is using mixed model assembly lines to produce multiple products in the same assembly lines with almost negligible setup times [12]. The demand of individual customers can be met with great accuracy, but the material logistics become very difficult [15]. In order to run the mixed model assembly lines smoothly and efficiently, movement of materials from the storage to the feeding areas is one of the most vital tasks. Materials must reach the assembly line when they are required such that there is no starvation on the feeding line. If a crucial part is missing, it can halt the assembly line leading many workers idle incurring loss in production, which can be very costly [14]. Also, excessive in line inventories contributes to high handling and holding costs [12]. Companies generally try to reduce the in-stock inventory as it does not generate any returns [13].

To overcome the above challenges, most of the manufacturing companies, especially the automotive industry, are trying to implement the JIT supermarket concept. Supermarkets are decentralized storage areas on the shop floor, which are placed near the assembly lines that act as intermediate storage for the parts required at the final assembly line. Supermarkets consist of racks of parts, for quick access, that needs to be delivered to the workstation rather than storage density and are resupplied to the supermarket from the main central warehouse [14]. This way small frequent deliveries over short distances can be made from supermarkets to stations such that there is no excess inventory on the line. Supermarkets are generally like food supermarkets in that the warehouse operator, as well as the customer, go through the warehouse taking all the parts that are necessary for a certain period of time. Supermarkets ensure a fast, flexible and reliable in-house logistics process [9]. Long term strategic and short-term problems can be solved with respect to the time frame for implementing the supermarket concept [9].

Long Term Strategic Problem

In the long term, the most critical problem to solve is the number of supermarkets that need to be opened, the optimal location for the supermarket, and the workstations that each supermarket will serve [9]. Optimization is the standard or preferred approach to the problem of opening or operating a supermarket. The objective function in the optimization problem needs to consider the fixed costs caused due to the addition of supermarkets weighing against the operational gains, such as transportation and inventory costs [13]. To solve the long-term strategic problem, the authors developed a mathematical model to get the optimum stocking policies while minimizing the global cost by reducing the transportation cost and the inventory cost. Transportation cost is proportional to the distance between the supermarket and station, i.e., it is the function of the transportation system used for feeding the materials. Whereas inventory is the function of component consumption and the chosen centralized location, and the cost is proportional to the safety stock and not the operative stock. Multiple assembly lines are considered with common parts serving those lines [13]. The estimation of inventory cost is done by calculating safety stock. The distance between stations and the potential supermarkets were interpreted using x and y coordinates in the rectangular distance formula. The transportation cost is a function of the distance and the cost required to move one bin from supermarket to workstation. A step by step approach is being represented in an applicative case. The studies indicate what component category is advisable to adopt as a decentralized solution with kits to supply the assembly line from supermarkets or is it worth to complete centralization or decentralization of warehouses. The model captures a typical aspect of assembly processes such as types of components and their commonality, load unit transportation, transportation equipment used, availability of space inside the shop floor, and the safety stock values. The materials management, in the case of an assembly environment, has shown to have a particular characteristic different than that of a generic supply chain problem [13].

Solving long term strategic problems is very critical for the implementation of the supermarket concept. Since creating more supermarkets will incur costs while having too few supermarkets will diminish its purpose. Hence it is necessary to have an optimal number of supermarkets in strategic locations [12]. Studies about the supermarket location problem using tow or tugger trains have been carried out. Tow or tugger trains with conjunction to supermarkets enable frequent small-lot deliveries so that inventory on the shop floor is reduced and long distances are avoided [13]. The idea behind using a tow-train schedule is that one tow-train should supply all stations making cyclic deliveries. If the tow-train reached its maximum capacity, another vehicle is scheduled to help make it a cyclic delivery [13]. Supermarkets serve consecutive stations, i.e., it will serve station 1, 2, 3 rather than serving 2, 1, 3. It is necessary to solve the problem for the location, placement, frequency of deliveries, scheduling, routing, loading, and unloading of the tow trains as all are interconnected, but it is difficult to solve all this in one single problem [12]. An algorithm is developed using a polynomial-time dynamic program to solve the strategic problem for the number of supermarkets and their optimal location, as well as the decision on the assignment of supermarkets feeding particular stations without taking into consideration the routing, scheduling and loads as they can be sensibly assigned if the information of the production sequence is available, which is generally a few days advance [12]. The fixed cost associated with the addition of supermarkets and maintaining them are considered. A computational study is performed with the outputs of dynamic programming for an assembly line with 40 sequences and 400 workpieces, which creates per station demand bin. The program is solved for a realistic size problem with less run time to determine the optimal number of supermarkets, as well as their location. The comprehensive simulation shows evidence of the solution being good. At the same time, the numerical studies suggest that supplying the workstations with a small number of supermarkets, for example, 3 to 4, shows a great reduction in inventory, as well as the transportation cost compared to materials being supplied to one centralized storage [12]. Shortcomings such as

placement of supermarkets if space is constrained, an extension in the algorithm to account for it, as well as the supply of common parts if the material is shared between the stations, as well as the multiple assembly lines are not considered. A similar problem using mixed integer programming is solved [11, 15]. The study focuses on supermarket location problem in a mixed model assembly line environment capturing real case situations such as lack of space and the capacity of the supermarket by minimizing the installation cost of the supermarket and the transportation cost. A more robust genetic algorithm was developed to capture a large size problem, resulting in accurate results in less processing time. Effect of number of supermarkets on the total safety stock was not considered for this problem [11]. A study captures the aforementioned problem by considering a mixed model assembly line with stochastic demand. A stochastic mathematical model is proposed using mixed integer programming for supermarket location problem in which the total cost of part feeding is calculated using the shipment, i.e. transportation, inventory and installation cost of supermarkets are optimized simultaneously. The inventory cost for the safety stock, required by the supermarkets to respond to the stations demand variation following a normal distribution, is considered in the above SLP model [15]. To see the effect of demand variation on the number of supermarkets, the models were compared, and the results suggest that the number of supermarkets are affected because of the demand variation and the increase and decrease in the optimal number of supermarkets are about 33% and 12% respectively. Also, there is a 100% increase in the total inventory costs whereas, the increase and decrease in total shipments is about 24% and 33% and for installation cost it is about 33% and 12% respectively [15].

Short Term Strategic Problem

Apart from the long-term decision problem of location and number of supermarkets, the next crucial decision is how to solve the routing problem [9]. An

integrated framework for a multiple mixed model assembly line for both long term (static analytical model) and short term (dynamic simulation) problems dealing with Kanban and a supermarket system dedicated to assembly lines, and the tow train fleet sizing and management is proposed [16]. The designed supermarket framework is based on the Kanban-based continuous supply where stock keeping Unit (SKU) is normally associated with a Kanban card to control to the production and replenishment flow. By keeping the main aim to provide the decision maker with a useful tool focused on supermarket feeding system design and management, the framework is divided into three main steps. 1) A robust model to design and co- relate the tow train fleet size and the Kanban number using Kanban number optimization. 2) Multi scenario dynamic analysis using simulation to determine the best delivery frequency and the vehicle capacity utilization. 3) System validation and performance analysis for long term and short term. The above framework is studied in an Italian automobile factory and the results were interpreted as follows: 1) for the long- term sizing problem, static formulation has been derived for the Kanban number and the tow train fleet, which has shown to have a correlation with other variables such as safety stock. 2) A dynamic multi scenario model is more effective because of the dynamic nature of the fleet loading problem. 3) Refilling interval has a high impact on the system performance hence optimizing it is vital. There are studies investigating part delivery of a mixed model assembly line with supermarkets as decentralized storages and tow train [16]. One such experimental study is done using heuristic based dynamic delivery strategy which dynamically schedules the routes, departure time, quantities and types of loaded parts each tour with minimum delivery cost. In addition, decisions such as number of tow trains and the route layout are suggested. The results from the above study are compared to periodic delivery strategy. The results obtained from the study shows that the performance of the experimental result is superior over the periodic delivery strategy in terms of line stopping ratio, the total traveling time and the average utilization of the tow trains. For future research, the authors suggest the use of forklifts with different capacities because of its flexible nature of

delivering the parts [17]. The authors develop a mathematical model with a heuristics approach for the design of parts feeding system when constructing the routes of in plant milk run and determining the service period with a JIT system [25].

The replenishment of the supermarket is another critical thing that needs to be considered while designing this particular part feeding system. To capture the first stage of the problem, which is the flow of materials from the warehouse to supermarkets, it is important to account for the capacity of the storage (supermarkets), number of times the storage needs to be replenished, deliveries required to complete the replenishment, as well as the transportation equipment used for it. There are fewer studies which focus on the scheduling of the replenishment of the supermarket. One such study focuses on the first stage which deals with feeding parts to the supermarket from the main warehouse [14]. A special lot of sizing and scheduling problems has been the focus considering a specific structure of the storage area to determine when to restock the supermarket, in what quantity, of which part given the limited amount of storage space. The problem also considers the capacity of vehicle such that the number of deliveries is optimal by keeping the inventory cost minimal. The problem is structured in a way that the supermarket receives the material in pallet size with the use of industrial trucks. The parts that are required at that period of time are being sequenced and put in a container (Kits) to be delivered to the station. A Mixed Integer Problem (MIP) is formulated to solve the above problem with the objective of having the optimal storage at the supermarket and to minimize the inventory cost. Along with MIP, computational studies were also done to solve four different scenarios using heuristics. The results suggest that the near-optimal solution for the schedules greatly outperforms the unplanned deliveries planned by using Kanban signals. Also, increasing the number of deliveries more than a certain point of feasible deliveries is pointless as the marginal benefits of supply quickly diminishes by little decrease in work in progress [14].

Research Gap:

1. From the above literature, it can be stated that the JIT supermarket feeding system is mainly studied in automotive and semiconductor industries. This study tries to capture the working of the same in a different type of manufacturing industry, i.e. house manufacturing industry as there is a difference in parts used, the structure and complications involved in the assembly line such as the layout of the plant.
2. As stated in the literature review, long term decisions involving the location of supermarket is solved considering just the decentralized location and the final assembly line. It fails to capture the location on supermarkets considering materials flowing from the main warehouse to supermarkets to final assembly line. This research tries to capture the effect of considering the supermarket location problem as a multi-stage supply chain problem.
3. Most of the time the equipment used to deliver the parts from supermarket to station are tow trains, Automated Guided Vehicles (AGV) because of its capacity as it is able to hold more materials than other feeding equipment but lacks flexibility in delivering the parts to a sophisticated layout. This study takes into consideration the flow of material with the help of a forklift. The capacity of a forklift is less compared to tow trains, but it has the ability to carry heavy large size items and to maneuver through tight spaces, which the assembly line in the house manufacturing facility represents.
4. Routing and scheduling of the material delivery equipment is also necessary to assure a smooth flow of parts from the warehouse to the supermarket and from the supermarket to the final assembly. Since the forklift cannot perform the milk runs like the tow trains, it is crucial to schedule and determine the number of trips associated with the forklift and which routes it needs to take within the facility such that there is no mix up while delivering the parts. This study covers the bases for this idea in terms of number of

trips, but the routing and scheduling problem for the same can be implemented in the future.

CHAPTER THREE

METHODOLOGY

A detailed approach to the implementation of the material feeding system using supermarket warehouses in a manufacturing facility is presented in this chapter. Critical components essential to design a reliable material feeding system is discussed. The components such as demand for the product manufactured, as well as the demand of the raw materials/components used for the products, capacity of warehouses, the flow of materials from the warehouses to stations, material handling equipment are analyzed and discussed. An optimization model to minimize the transportation cost and inventory cost using all the above-mentioned variables and parameters essential to design a material feeding system which is solved.

Optimization

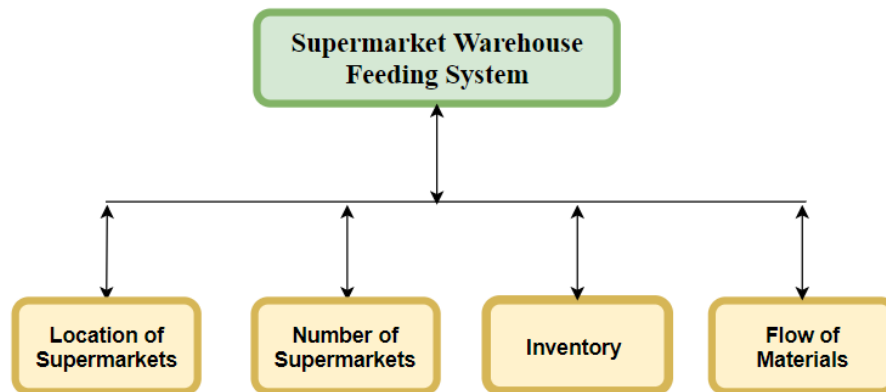


Figure 3-1 Layout of the problem

This thesis presents the design of material flow within the facility. To design a reliable system, long term decisions need to be solved such that an optimal solution is attained. The following are the long-term decisions,

- i. The location of supermarkets
- ii. Number of supermarkets
- iii. Level of inventory stored in supermarkets
- iv. Flow of materials

The Location of Supermarkets:

Consider a facility in which the management identified multiple candidate locations for supermarkets. The decision that the management needs to make includes the optimal number of supermarkets and the subset of locations at which they must be installed in a facility. The decision should be made such that the distance between the supermarkets and the point of use of the materials, i.e., the assembly/stations, should be minimal. This can be done by having the supermarkets installed as close to the stations as possible. Reducing the distance significantly impacts the time needed by the employees to fetch the materials. This result in reducing the non-value-added time resulting in the cycle time of the process to reduce and make the process efficient and reliable. This problem resembles the transportation and assignment problem in which mathematical models are formulated to address questions such as the number of facilities that should be sited and located, how the demand of the customer should be allotted or scheduled? Facilities are interpreted as various entities such as factories, hospitals, warehouses, schools, retail-outlets, and computer concentrators, but the analysis of a few of these has been mentioned in the literature [41-44]. Therefore, supermarkets can be considered as a facility, and a decision is to be made on the number of supermarkets needed and where they should be located such that the materials are staged near the assembly line and the demand of the customer is being satisfied. Customers, in this case, being the stations of the assembly line and

demand is the number of materials required to build the product on a particular station.

Number of Supermarkets:

Once the location of the supermarket is determined, the number of supermarkets is a crucial component of this material feeding policy. As the number of supermarkets increase, the overall operating cost of the system increases. If a decision is made to open all the possible locations of supermarkets, there is an increase in the overall operating cost of the system. On the contrary, if a smaller number of supermarkets are opened, it will result in the reduction of the overall operating cost but then there is a risk of the demand of the stations not being satisfied. This results in a less reliable material feeding system. Hence it is necessary to have the number of supermarkets opened such that the demand for the stations is met with the lowest overall operating cost.

The Level of Inventory:

After deciding on the location and an optimal number of supermarkets, the next decision that needs to be made is the amount of inventory stored in the supermarkets. Since the supermarkets need to be installed close to the stations or assembly line to reduce the travel time of the materials, it is imperative to have an optimal level of inventory stored at the supermarkets. Determining the level of inventory is essential because inventory takes a huge amount of space. If a large level of inventory is stored in the supermarkets or near the stations, more time is spent searching for the material, increasing the non-value-added time. An increase in non-value-added activities increases the cycle time of the process, as well as huge floor space is occupied, resulting in more costs and high ergonomic risks. To account for the variation, it is necessary to determine the safety stock stored in the supermarket. It has been stated that the inventory cost for a supermarket is calculated based on the safety stock and not the operating stock of inventory [13].

The inventory stored is calculated based on the capacity of the supermarket. The available storage capacity in the supermarket for each material in terms of quantity should be known to store the optimal level of inventory. The capacity of the supermarkets should be greater than the overall demand for that material required to manufacture the product. If a manufacturing facility is transitioning from a different material feeding system to the supermarket warehouse system, it is necessary to determine the capacity of the supermarket as well. The capacity of the supermarket can be represented by determining the maximum number of materials that can be stored in the supermarkets or depending on the available floor space for the supermarket location. In this case, the exact capacity of a supermarket was unknown and was approximated based on minimal operating cost from a range of typical capacity values. The best value is then selected out of the range such that the demand of the stations was met at the lowest cost as possible. The range is determined such that the selected value helps to have the necessary level of inventory without occupying huge spaces within the facility.

The flow of Materials:

Another important component of the supermarket feeding system is the decision on how the materials are moved, i.e. the transportation modes used to deliver materials from the warehouse to the selected supermarkets, and also the flow of each material from supermarkets to stations. Transportation is recognized as one of the important aspects of the physical distribution [41]. The flow of materials is crucial as the required materials should flow from the warehouse in the desired quantity and at the right stations that should satisfy the demand for that particular material without having a large lead time to fetch the materials. Supermarket warehouse feeding system has the materials stored near the stations, thus reducing the risks of large lead times while making sure that demand is always met. Material handling equipment used to deliver the materials is also a crucial decision to make while designing a supermarket feeding system. Based on the

nature of parts/materials used, the complexity of the layout of the plant and orientation of the assembly line/ stations it is necessary to select proper material handler equipment and based on that, it is imperative to determine the use of the material handler equipment. For example, in the case of automobile industries, to deliver parts tugger or tow-trains are used, and the parts are delivered in a milk-run fashion. To deliver the parts at the right place and right time, optimal scheduling and routing are required. In this case, the material handling equipment considered to solve the problem is a forklift. The limitations of this material handling equipment such as material carrying capacity to determine the number of trips is taken into consideration while designing the material feeding system using supermarkets. Hence, the decision to make in this case is the number of trips required for the forklifts to make so that the materials are delivered to the supermarkets, as well as the stations. Similar studies have been done to solve problems to determine total transportation cost and inventory cost dealing with different scenarios using different transportation methods [44].

All the decisions, as mentioned earlier, need to be solved for the long term in a single problem considering the effect each decision has on each other. Various decisions of selecting best supermarkets from the possible locations, having them located close to the assembly line, decide on the level of inventory stored, the flow of the materials needs to be solved in a single decision-making problem. Solving the problem as a single decision is necessary to obtain the best solution at a minimum cost. Therefore, it falls into the criteria of optimization where an objective function can be formulated by considering each of the above decisions as cost functions and minimizing it to achieve the optimal solution to the problem. In Operations Research, mathematical models are formulated to provide the optimal solutions required to make the decisions while designing a material feeding system using supermarket warehouses. Similar concepts, for example, the relationship between the inventory management, facility/warehouse locations, and determination of transportation policy alongside the distribution network design environment and the interaction between these areas in a supply chain, are

captured using Mixed Integer Linear Programming (MILP) Optimization. The design objective representing a minimization in the total distribution cost related to all the areas mentioned above (facility location, inventory parameters, transportation selection) such that the demand of the customer is satisfied by opened distribution centers by having the lowest inventory, transportation and location cost [41]. Another supply chain study uses optimization to solve a three-layer Location-Distribution-Inventory problem. The problem of locating the distribution centers that supply the commodity to the customers with stochastic demand is solved using Mixed Integer Programming (MIP) and heuristics approach to finding the optimal solution [45].

Defining Parameters, Variables, and Objective function.

To model the supermarket material feeding system using optimization, the problem must have four basic components. They are as follows and are described in the next section of this chapter.

1. Parameters
2. Decision Variables
3. Objective Function
4. Constraints

Parameters

Parameters are the data set of an optimization problem such that the decision is based on the parameters and the values that are determined for a specific problem. The parameters required for constructing a supermarket-based material feeding optimization problem are as follows.

Demand:

Demand is a crucial parameter that governs the optimization problem. In a network optimization problem, the demand must be met at all costs. A manufacturing facility can produce one or more than one type of product within its assembly line. Each product can have the same or different sets of requirements, such as process times, the number of raw materials/components, types of raw materials/components, different machining, and others. Hence it is necessary to have a list of the product mix that a manufacturing facility produces such that raw materials/components required for each product mix are supplied at the right time in the right quantity. Based on the daily schedule, the demand for the production of the product mix is generated, i.e., the products and their quantity produced per day to satisfy the customer orders. Once, the production of the product mix is determined for the day, the raw materials, or the components required for the respective product mix needs to be determined. In a manufacturing facility, the products are processed in an assembly line such that the work is done at various stations, and the product moves from one station to another before the finished product is obtained. Due to this, each station in an assembly line has its demand for raw materials/components that are needed to be satisfied. Hence, the demand should be generated such that the materials used at each station for each product mix are considered along with the quantity required to satisfy the demand for the considered amount of time (shift/days/weeks/month). A template is provided below, which helps in listing all the necessary details required to formulate the demand. The template represented in Table 4 can be used to determine all the raw materials/components needed to build each product from the product mix, as well as the quantity of the raw material required. The first two columns represent the number and the list components/materials used for each product mix represented by the rows.

Table 4- Template to collect the material data for different product mix

	Materials	Product Mix(Quantity)									
		Product 1	Product 2	Product 3	Product 4	Product 5	Product 6	.	.	.	m
1	A										
2	B										
3	C										
.	.										
.	.										
.	.										
.	.										
.	.										
.	.										
n	z										

Once all the product mix and the respective materials used for each product is determined, the next step is to determine the demand for each station at each period. To calculate the demand, the initial step will be to determine the production schedule or predict the production for a shift, day, or week. The demand for the product can either be deterministic, i.e., it is known or remains the same for all periods or stochastic, i.e., the demand can be unknown and random. If the demand, if deterministic, then scheduling the production is straightforward based on the same shift wise, daily, or weekly demand. But if the demand is stochastic, additional efforts to determine the schedule by forecasting or giving a weighted probability to the product based on the historical data of production is required. For this problem, the demand is assumed to be stochastic and is formulated using the weighted probability to a different product mix that is manufactured. The following template, represented in Table 5, is used to formulate the total demand of each material for each shift. The mean and the standard deviation are calculated to understand the variation of demand for each material.

Table 5 Template to calculate demand/shift for each material

Number	Materials	Demand/shift										Mean	Stddev
		1	2	3	4	5	6	7	8	9	10		
1	joist												
2	Insulation bat												
3	Wires												
4	OSB T& G (8x4)												
5	OSB T& G (other)												
6	Plumbing pipes												
7	Vinyl												
8	Insulation roll												
9	8 ft inside corner												
10	8 ft outside corner												
11	shower tubs												
12	water heater												
13	furnace												
14	Wire												
15	range wire												
16	Breaker box												
17	Ground wire												
18	Sheet rock												
19	Energy brace												
20	bathroom seats												
21	Insulation blocks												
22	light box metal												

After the production is predicted/known, the demand of each material is calculated for each shift for the considered period. Also, the mean and standard deviation of each period is calculated to capture the variation in the demand. Once the mean and the standard deviation are calculated, a matrix for the demand of each material at each station in the considered period is formulated. The following template represented in Table 6 is used to formulate the matrix. Using the template to formulate the matrix, the demand for each material at each station has been used as an input to the mathematical model. The first column represents the list of materials used to make the product, and the second column helps to determine the demand of a particular material at different stations in an assembly line for a different number of periods. For example, column S1 represents the demand of different materials at station 1.

Table 6 Template for collecting the materials per station

Materials	Stations								
	S1	S2	S3	S4	S5	S6	S7	S8	S9
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									

Possible Number and Location of Supermarkets (Candidate Locations)

Locations of supermarkets is another primary parameter that is crucial while designing the material feeding system. As the primary purpose of the supermarkets is to support the JIT principles, the location of the supermarkets is selected such that they are located as close as possible to assembly lines and sub-assemblies within the design constraints of the facilities. Design constraints of the facilities implement the way an assembly line is laid out within the facility, and space availability for supermarkets close to the assembly lines. The candidate location of the supermarkets is defined, taking into consideration the opinions of experienced personnel such as the facility design engineer, production manager, or facility manager.

Calculating the Distances

The next step is to see how far the candidate supermarkets are located from the stations of the assembly line, as well as the main warehouse where the materials are stored. Based on the distance, the optimal location of the supermarkets to be opened is obtained. The distance of supermarkets to stations is calculated using the distance formula, which is shown below. Initially, it is necessary to find the x and y coordinates of the candidate locations, as well as the stations and the warehouse. Once the x and y coordinates of all required places are known, the following rectangular distance formula is used to obtain the distances [15].

$$d(S_k, A_c) = |x_k - x_c| + |y_k - y_c|$$

Where,

$d(S_k, A_c)$ = Distance of candidate supermarket location from stations

(x_k, y_k) = Coordinates of candidate supermarket locations

(x_c, y_c) = Coordinates of stations of an assembly line

Similarly, the distance from the main warehouse to the candidate supermarket locations is represented as follows.

$$d(W_j, S_K) = |x_j - x_k| + |y_j - y_k|$$

$d(W_j, S_K)$ = Distance of candidate supermarket location from the main warehouse

(x_k, y_k) = Coordinates of candidate supermarket locations

(x_j, y_j) = Coordinates of the main warehouse

Transportation Cost

Transportation or the shipment cost is related to the distance traveled by the material delivery equipment to the stations (point of use) to satisfy the demand [15]. Since it is assumed that the material delivery equipment used for this problem

is a forklift, the transportation cost is derived such that it is the cost of delivering the materials to the stations in one trip.

Inventory Cost

Inventory cost is related to the cost of raw materials/components that can be stored in the supermarkets so that the demand of the stations to produce the product can be met [46]. Generally, since it is related to the cost of inventory on hold, it is also referred to as the inventory holding cost. The holding cost is considered to be aggregate of the total inventory cost required to produce a product, i.e., the total inventory cost has been calculated by adding the cost of each material required to manufacture a product.

$$\text{Inventory Cost} = \frac{\sum_i^I C_i \times \text{Mean}_i}{\text{Total Number of materials}}$$

Where, C_i = Cost of each raw material for $i = 1, \dots, I$

Mean_i = Mean of each material i for i in $1, \dots, I$

Capacity of Supermarkets

The capacity of the supermarket is a parameter where it is necessary to define how much materials can be stored in the supermarket. Capacities can be defined based on area available for each supermarket within the facility or if the maximum quantity of materials stored is known. There are two types of capacities of the supermarket for this problem, 1) capacity of each material that is stored in the supermarkets and 2) the overall capacity, i.e., the cumulative of all materials stored in the supermarkets. Each of them needs to be specified as this problem has a limit of total materials stored in the supermarkets.

Installation Cost

Installation cost is represented based on the number of shelves and racks required to store the materials, as well as the cost of employees required to maintain the supermarkets. As the capacity of the supermarket increases, the installation cost increases because of additional shelves, racks, and possibly additional personnel that is required for maintaining the supermarket with increased capacity.

Decision Variables:

The variables which can be controlled, and which influence the overall system, are known as the decision variables [47]. The following are the variables that need to be considered and controlled, which influence the designing of a material feeding system using supermarkets.

The number of trips:

The main objective while designing the material feeding policy is to have the supermarket placed as close as possible near the stations. Another thing to consider is the material movement from the supermarket must be such that it should have an optimal number of trips that a forklift must make to satisfy the demand for the period that is being considered. Also, the number of trips for the materials moving from the main warehouse to the supermarkets needs to be considered. The number of trips both from the warehouse to supermarkets and supermarkets to the stations/assembly line incurs costs. Hence, the decision to have an optimal number of trips is necessary when designing material feeding systems with supermarkets.

Level of Inventory at the end of each period:

Supermarket warehouses are designed such that the level of inventory that is required to satisfy the demand is stored in them. Inventory incurs costs. Hence, it is necessary to have an amount of inventory (safety stock) stored in the supermarkets, which takes into consideration the variation of the demand in case the assembly line produces a high variation of product mix, as well as the need to consider any shortages if possible. The optimal level of inventory is calculated based on the maximum capacity of the supermarket. This decision variable helps to determine the quantity of the material that needs to be transported at the start of each period based on the inventory level of the previous period.

The flow of materials:

The flow of materials is a critical decision variable that represents how the materials flow in the system such that the demand is met. The decisions such as which supermarkets to serve which stations in what quantity is determined with the help of this decision variable. Also, it is necessary to know the flow of materials from the main warehouse to the supermarkets, i.e., which material is stored in which supermarket and in what quantity.

Number of Supermarkets:

Determining the number of supermarkets that need to be established to make sure the system is reliable is an important long-term decision. To have a large number of supermarkets incurs a large amount of costs as installing the supermarkets, as well as maintaining them takes effort and is expensive. On the other hand, having one or a few supermarkets is not advisable as it may not be able to fulfill the demand. Hence, it can influence the productivity of the manufacturing facility.

Hence, it is imperative to have an optimal number of supermarkets installed such that it satisfies the required demand, as well as incurs less cost.

Objective Function:

The problem of finding the optimal number of supermarkets is represented mathematically in terms of the objective function in the optimization model. The objective function is to minimize the transportation cost, inventory cost, and installation cost associated with the flow of materials to determine the optimal number of supermarkets and the optimal level of inventory.

The mathematical model comprised of all the parameters, decision variables, and objective function, along with a few constraints, is represented below.

A mathematical model with constraints

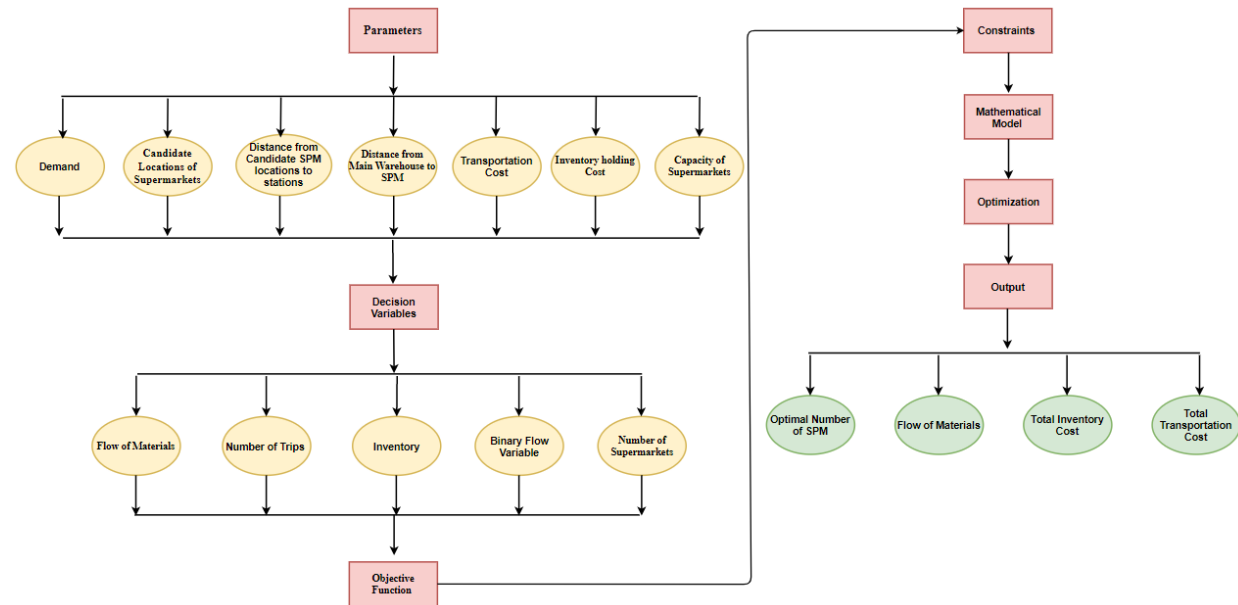


Figure 3-2 Flow diagram of mathematical model

Indices:

- i = materials
- j = warehouse
- k = supermarkets
- c = stations
- t = periods

Parameters:

$Dist_{jk}$ = Distance the material needs to travel from the main warehouse to the possible supermarket locations.

$Dist_{kc}$ = Distance the material needs to travel from possible supermarket location to the online station.

C_T = Transportation cost of moving the material from supermarket to station.

IC = Installation cost of a supermarket.

W_i = Weight of material i .

C_{inv} = Inventory holding cost for materials i .

$CapacitySuperM$ = Maximum capacity of supermarket $[k]$ for each material $[i]$.

$MaxCap$ = Total capacity $[s]$ of supermarket $[k]$.

F = Material carrying capacity of the forklift.

Std_{ic} = Standard deviation of each material $[i]$ used at station $[c]$.

LT = Lead time to fetch the materials from the warehouse to the supermarket.

Z = Confidence interval representing the standard deviation.

Decision Variables:

X_{ijkt} = Total materials i supplied from warehouse j to supermarket k .

Y_{ikct} = Total materials i supplied from supermarket k to station c .

R_{jkt} = Number of trips required to supply materials from warehouse j to supermarket k.

Q_{kct} = Number of trips required to supply materials from supermarket k to station c.

INV_{ikt} = Amount of materials i stored in supermarket k at the end of period t.

$OpenS_k$ = 1 if supermarket k opened,
0 otherwise.

V_{ikct} = 1 if materials are supplied from supermarket k to stations c in period t,
0 otherwise.

Objective Function:

Minimize,

$$\begin{aligned} & \sum_j \sum_k \sum_t R_{jkt} \times C_t \times Dist_{jk} + \sum_k \sum_c \sum_t Q_{kct} \times C_t \times Dist_{kc} \\ & + \sum_i \sum_k \sum_c \sum_t C_i \times Std_{ic} \times Z \times \sqrt{LT} \times V_{ikct} + \sum_k OpenS_k \times IC \end{aligned}$$

- $\sum_j \sum_k \sum_t R_{jkt} \times C_t \times Dist_{jk}$ represents the transportation cost for moving materials from warehouse j to supermarket k in period t.
- $\sum_k \sum_c \sum_t Q_{kct} \times C_t \times Dist_{kc}$ represents the transportation cost for moving materials from supermarket k to station c in period t.
- $\sum_i \sum_k \sum_c \sum_t C_i \times Std_{ic} \times Z \times \sqrt{LT} \times V_{ikct}$ represents the holding cost of the safety stock that needs to be stored in each supermarket to counter the variation in the demand.
- $\sum_k OpenS_k \times IC$ represents the installation cost of a supermarket.

Subjected To,

Constraints

$$\sum_k Y_{ikct} = Demand_{ic} + Std_{ic} \quad \forall i, \forall c, \forall t$$

$$Y_{ikct} = M * V_{ikct} \quad \forall i, \forall c, \forall t$$

$$\sum_k V_{ikct} \leq 1 \quad \forall i, \forall c, \forall t$$

$$\sum_j X_{ijkt} = \sum_c CapacitySuperM_{ik} \times V_{ikct} - INV_{ikt-1} \quad \forall i, \forall k, \forall t$$

$$\sum_i \sum_j X_{ijkt} = MaxCap \quad \forall k, \forall t$$

$$Y_{ikct} \leq CapacitySuperM_{ik} * OpenS_k - INV_{ikt}$$

$$\sum_i X_{ijkt} \times w_i \leq F \times R_{jkt} \quad \forall j, \forall k, \forall t$$

$$\sum_i Y_{ikct} \times w_i \leq F \times Q_{kct} \quad \forall j, \forall k, \forall t$$

$$\sum_i \sum_k X_{ijkt} \leq CapacityWarehouse \quad \forall j, \forall t$$

$$\sum_i \sum_j \sum_t X_{ijkt} \leq M \times \sum_s OpenS_k \text{ where } M \text{ is a big number } \forall k$$

$$\sum_i \sum_c \sum_t Y_{ikct} \leq M \times \sum_s OpenS_k \text{ where } M \text{ is a big number } \forall k$$

$$\sum_j X_{ijkt} - \sum_c Y_{ikct} + INV_{ikt-1} = INV_{ikt}$$

$$X_{ijkt}, Y_{ikct}, Q_{jkt}, R_{kct}, INV_{ikt} = integers$$

$$OpenS_k, V_{ikct} = Binary$$

- Constraint (1) states that the demand for the materials at each station from the supermarkets should always be met for each period t.
- Constraint (2) and constraint (3) state the material (i) should satisfy the demand of stations (c) for the same material(i) from one supermarket only.

- Constraint (4) states that the supply of materials from the main warehouse j to the supermarkets k should not exceed the maximum capacity of the supermarket for each material and should supply the materials considering the inventory of each material i from the previous period.
- Constraint (5) states that the materials supplied from the main warehouse should not exceed the total capacity of all materials stored in supermarkets.
- Constraint (6) states that the capacity of all supermarkets that are opened should be the same.
- Constraint (7) states that the materials flowing from the supermarkets to the stations should not exceed the capacity of supermarkets for each material.
- Constraint (8) and constraint (9) state that transporting the materials either from the main warehouse to supermarkets or from supermarkets to the warehouse should not exceed the material carrying capacity of the material handling equipment, in this case, a forklift.
- Constraint (10) states that all the materials required to fulfill the demand should be available in the main warehouse, and the flow of materials from the main warehouse to supermarkets should not exceed its capacity.
- Constraint (11) and (12) state that the material should be delivered and transported only to and from the supermarkets which are opened and not from the other candidate locations.
- Constraint (13) is a flow constraint stating whatever is coming into the supermarket must go out, and the remaining materials should be stored as the end period inventory, which can be used to satisfy the next period's demand.
- Constraint (14) lists the integer variables, i.e., variables having integer values that are used while formulating the mathematical model.

- Constraint (15) lists the binary variables used while formulating the mathematical model.

CHAPTER FOUR

RESULTS AND VALIDATION

This chapter provides a detailed interpretation and validation of the mathematical model derived in chapter 3. To validate the mathematical representation, a case study is provided in which the material flow of the facility is designed using supermarket warehouses. This chapter is divided into three sections namely background of the company, determining the components of optimization and sensitivity analysis. First section explains about the company in which this study was carried out, the second section is similar to chapter 3 where we define the values to the parameters and solve the mathematical model to get the desired long-term decisions such that an optimal solution is obtained. The third section represents the results showing different scenarios (sensitivity analysis) to see if the model is robust for different sets of values for the parameters.

Background of the Company

The case study is based on a company that produces manufactured and modular homes and is one of the largest builders of these houses in its industry in the United States. The company was established in 1956 and since they have managed to grow by establishing different plants all across the united states and by acquiring other small businesses in the same field. To this date the company owns 40 manufacturing facilities, 361 retailers, 19 supply centers and 16,748 employees. The study is carried out in one of these 40 facilities. Layout of the facility is represented in Figure 4-1. The facility consists of 12 stations in total out of which the first nine stations make up the main assembly and the remaining three stations consist of painting and final finishing of the product. The study is focused on the

floors. In the future, the production of the facility is expected to increase. Time and motion studies were performed to determine the value added and non-value-added operations performed at each station. The non- value-added operations were then broken down to find the time lost due to disruptions in the material for each station. Following Table 7 represents the average time lost due to material disruption for 9 stations for to build one floor.

Table 7 Material Disruptions

Stations	Value Added Time / floor (mins)	Non-Value-Added Time / floor (mins)	Total Cycle Time / floor(mins)	Avg Material Disruptions / floor (mins)
1	19	40	59	15
2	9	23	32	8
3	23	13	36	3
4	26	32	58	10
5	26	32	58	12
6	70	37	107	15
7	53	31	84	12
8	64	24	88	7
9	64	24	88	7

A potential method to increase production is the use of Zone-Based Manufacturing (ZBM) [4]. Based on a pilot study on four workstations, ZBM was shown to reduce cycle times (CT) and increase the throughput to on average 10 floors a day. An increase in throughput, as exemplified by methods such as ZBM, accentuates the importance of the work presented in this thesis to make materials required for the product available at the right place at right time in the right quantity. The study considers the production of 10 floors a day with a demand of product mix being stochastic. The JIT supermarket material feeding system enables the facility to supply the materials required for the production at that time in a timely manner ensuring the availability of materials during the production. Hence, a reliable

per the demand of each material, they are supplied to the stations either from the temporary storage or directly from the main warehouse. Also, the quantity of materials stored is not fixed as an entire day's worth of materials are stored near the lines or in the temporary location which occupies unnecessary space within the facility. Due to this, there is increase in the transportation of the materials as the material handler needs to find the materials and then transport them to the respective station depending on the material demand resulting in disruptions as shown in Table 7 Material Disruptions in the assembly line which causes increase in cycle time of each station and thus affecting the throughput. Hence, to complement the productivity, it is necessary to have a reliable system that helps standardize the flow of materials. Cost based comparison of the current state and the future state is provided later in chapter 4.

Defining Parameters and Variables

To implement the mathematical model to the mentioned case, it is necessary to determine the values for the parameter that was discussed in chapter 3. The following are the values of the parameters.

Demand:

The first step is to get the daily demand of production. In order to get the demand, it is necessary to have the information regarding the different product mix that is manufactured in the facility. Also, the materials used for those product mixes, as well as the quantity of each material used to manufacture a product, should be known. This analysis is done using Table 4 mentioned in chapter 3.

To formulate the demand, it was observed that the facility manufactures eight different types of houses which are represented in Table 8. The product mix is categorized based on different sizes of houses that the facility manufactures.

Table 8 - Product Mix

Sr No	Product Mix
1	48x28ft
2	50x28ft
3	56x28ft
4	60x28ft
5	66x32ft
6	68x32ft
7	70x32ft
8	72x32ft

To build a house initially, a total of 91 materials were listed. These materials were listed based on observations made while analyzing the assembly line and considering the opinions of experts such as the production manager and station supervisors. Out of those 91 materials, some of the materials were filtered based on the part features, i.e., if the size of the materials is very small, for example switches, plugs. As small materials such as switches and plugs can be stored near the line and does not occupy huge space, they are not considered. Also, materials stated as the main materials are considered based on the expert opinions of the production manager and station manager in charge within the facility. Hence by filtering the material data, a total of 61 essential materials are considered in this problem. The lack of availability of these materials at the right place and at the right time can have effects on the cycle time by increasing delays and starvation along the assembly line. Table 9 represents the materials and the quantity required for each product mix. All the materials are listed in the column and the quantity of the corresponding material for each product mix is stated. For example, the 1st material

in the list is the joist and for a 56x28ft house the quantity of joists required to manufacture is 98.

Table 9 - Demand of each material for different product mix

Sr no	Materials	48x28ft	50x28ft	56x28ft	60x28ft	66x32ft	68x32ft	70x32ft	72x32ft
1	joist	82	90	98	102	106	110	114	116
2	Insulation bat	140	164	180	188	200	204	212	216
3	Wires	6	6	6	6	6	6	6	6
4	OSB T& G (8x4)	36	42	42	48	72	72	72	72
5	OSB T& G (other)	12	14	14	16	0	0	0	0
6	Plumbing pipes	11	12	14	15	16	18	20	20
7	Vinyl	2	2	2	2	2	2	2	2
8	Insulation roll	4	4	4	4	6	6	6	6
9	8 ft inside corner	32	39	45	45	48	56	59	61
10	8 ft outside corner	21	18	15	17	20	25	21	21
11	shower tubs	2	2	2	2	2	2	3	3
12	water heater	1	1	1	1	1	1	1	1
13	furnace	1	1	1	1	1	1	1	1
14	Wire	2	2	2	2	2	2	2	2
15	range wire	1	1	1	1	1	1	1	1
16	Breaker box	1	1	1	1	1	1	1	1
17	Ground wire	1	1	1	1	1	1	1	1
18	Sheet rock	28	32	35	37	37	40	40	42
19	Energy brace	14	16	18	20	22	22	25	25
20	bathroom seats	2	2	2	2	2	2	3	3
21	Insulation blocks	32	32	32	32	32	32	32	32

Once the data for the materials and quantities used for different product mix is known, the next step is to determine the demand of each material for the considered period of time based on the production schedule. For this problem, it is assumed that each working day in the facility comprises of two shifts and the supermarkets should satisfy the demand of each material for each station, i.e., one shift. As discussed, the capacity of the facility is to produce five houses a day and a house is comprised of two floors. Hence the demand in terms of number of floors to be produced is 10 floors per day. It is implied that in a shift the capacity of the facility is to produce five floors which represents two and a half houses. To design a schedule, it is assumed that the probability of each house manufactured is equal. Based on this assumption, a random schedule is generated such that the

probability of a house being manufactured on any given day is equal. This implies that the facility has the ability to manufacture any product of their product mix at any given time of the day. Such a random schedule is generated for a period of six months in which it is assumed that the facility operates for 20 days a month consisting of 40 shifts. Table 10 represents an example of the production schedule for each day. The Column “Houses” represent the production of 5 houses per day and the product mix produced is represented by the number which can be correlated with Table 8. For example, the first house produced on day 1 is number “3” which is a “56 x 28ft” house represented in Table 8.

Table 10 - Daily production of product mix

Days	Houses				
	1	2	3	4	5
1	3	8	1	4	8
2	3	6	6	1	8
3	8	1	6	4	8
4	8	2	4	6	8
5	8	2	5	4	5
6	2	5	4	3	1
7	6	3	4	6	4
8	4	4	4	8	3
9	5	4	1	3	7
10	6	2	2	5	5

Table 11 represents the total demand for each material in each period. For example, the demand for joists in shift 3 is 263 which is represented in the 3rd column under demand/sift row and is calculated based on the product mix produced on day 2 represented in Table 10 - Daily production of product mix Since the demand is generated using random discrete variables and a normal quantile

plot is plotted as shown in Figure 4-3 which represents an example of data for the joist. As the data points lie on the 45-degree line, we can approximate that the demand follows the normal distribution [51]. Similar analysis was carried out for other materials to determine the normal approximation. Once the data was assumed to follow the normal, comparison test was conducted between binomial, Poisson and normal distribution to see determine the best fit distribution for the data. Figure 4-4 represents the comparison test and we can determine that normal distribution is the better fit for the demand data. To capture the variation the mean and the standard deviation of each material is calculated and is considered to be the input for the demand parameter of the model.

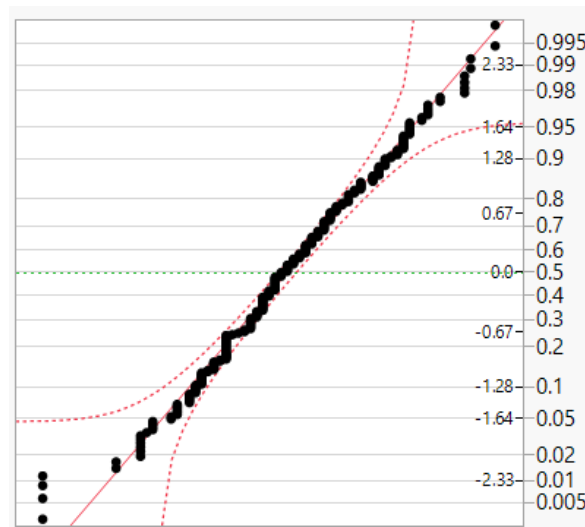


Figure 4-3 Normal Quantile Plot

Compare Distributions							
Show	Distribution		AICc ^	AICc Weight	.2 .4 .6 .8	BIC	-2*LogLikelihood
☒	Normal	—	2872.8416	1		2880.6026	2868.8083
☒	Poisson	—	2908.6066	0		2912.4927	2906.5956
☒	Binomial	—	3925.7211	0		3929.6073	3923.7101

Figure 4-4 Comparison Test

Table 11 – Demand of each material for each period

Materials	Demand/shift									
	1	2	3	4	5	6	7	8	9	10
joist	257	258	263	267	260	239	261	260	251	251
Insulation bat	470	472	482	494	484	436	482	480	460	466
Wires	15	15	15	15	15	15	15	15	15	15
OSB T& G (8x4)	135	147	150	153	153	120	141	129	135	150
OSB T& G (other)	21	13	14	15	15	28	23	31	21	14
Plumbing pipes	40	41	42	43	40	34	40	40	38	37
Vinyl	5	5	5	5	5	5	5	5	5	5
Insulation roll	12	13	13	13	13	11	12	11	12	13
8 ft inside corner	122	125	128	131	120	104	124	121	115	115
8 ft outside corner	48	54	53	51	48	46	50	44	47	51
shower tubs	6	6	6	6	6	5	5	6	6	5
water heater	3	3	3	3	3	3	3	3	3	3
furnace	3	3	3	3	3	3	3	3	3	3
Wire	5	5	5	5	5	5	5	5	5	5
range wire	3	3	3	3	3	3	3	3	3	3
Breaker box	3	3	3	3	3	3	3	3	3	3
Ground wire	3	3	3	3	3	3	3	3	3	3
Sheet rock	92	93	95	97	93	85	95	94	89	89
Energy brace	51	51	53	54	53	45	51	52	50	49
bathroom seats	6	6	6	6	6	5	5	6	6	5
Insulation blocks	80	80	80	80	80	80	80	80	80	80
light box metal	13	12	13	13	12	10	10	12	12	10
Tower vents	5	5	5	5	5	5	5	5	5	5
bands	57	58	60	61	55	46	56	55	52	51
washer box + VTR	3	3	3	3	3	3	3	3	3	3
Water lines	36	33	36	36	33	30	30	33	33	30

It is also necessary to know the material that is required at a particular station in an assembly line. Hence, the above demand needs to be broken down in a way such that the demand of each material per station is represented. Table 12 represents the subset of the demand required for each station. For example, the demand for material 1, which is joists in period 1 is 257 and is used only in the station which is represented in header names as S1 which means station1. Since joists are only used at station1, the demand for it at other stations is input as zero. Similarly, the demand for all 61 materials is formulated for all 9 stations.

Table 12 – Demand of materials per station

Materials	Stations								
	S1	S2	S3	S4	S5	S6	S7	S8	S9
1	254	0	0	0	0	0	0	0	0
2	465	0	0	0	0	0	0	0	0
3	15	0	0	0	0	0	0	0	0
4	0	140	0	0	0	0	0	0	0
5	0	19	0	0	0	0	0	0	0
6	0	0	39	0	0	0	0	0	0
7	0	0	5	0	0	0	0	0	0
8	0	0	0	13	0	0	0	0	0
9	0	0	0	0	0	118	0	0	0
10	0	0	0	0	0	50	0	0	0
11	0	0	0	0	6	0	0	0	0
12	0	0	0	0	3	0	0	0	0
13	0	0	0	0	3	0	0	0	0
14	0	0	0	0	5	0	0	0	0
15	0	0	0	0	3	0	0	0	0
16	0	0	0	0	0	3	0	0	0
17	0	0	0	0	0	3	0	0	0
18	0	0	0	0	90	0	0	0	0
19	0	0	0	0	50	0	0	0	0
20	0	0	0	0	0	6	0	0	0
21	0	0	0	0	0	80	0	0	0
22	0	0	0	0	0	0	12	0	0
23	0	0	0	0	0	0	5	0	0
24	0	0	0	0	0	0	54	0	0
25	0	0	0	0	0	0	3	0	0

Possible Number & Location of Supermarkets (Candidate Locations)

The possible number and location of supermarkets which are also represented as candidate locations are defined based on the layout of the facility. Since the manufacturer is going through a transition phase where they are planning to expand the facility, the candidate locations were decided based on the future layout of the company. The future layout considers the expansion of the facility due to the setup of the assembly line changes. The candidate locations were selected such that they are as close as possible to the stations and have adequate space to store the required materials. Based on these two criteria and also taking into consideration the expert's opinion such as the Plant Design Engineer, Station

Supervisor, Production Manager and the General Manager, five candidate locations were selected to be the supermarket locations. Figure 4-5 represents the layout of the facility. The five candidate supermarket locations are represented in the five green boxes as shown.

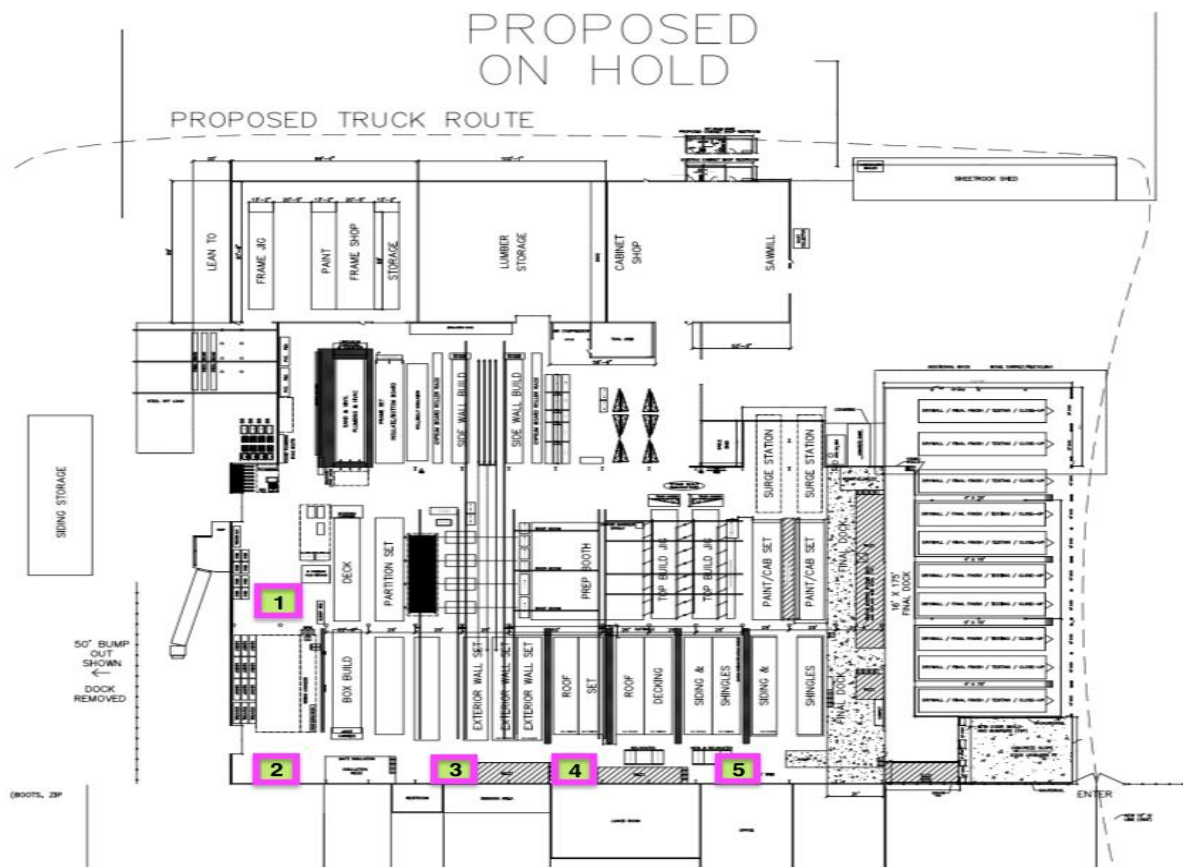


Figure 4-5 Possible location of supermarkets

Calculating the Distances

Once the candidate locations for the supermarket is determined, the next step is to calculate the distance between the candidate locations and the stations of an assembly line and also from the main warehouse to the supermarkets.

Distance from Supermarkets to Stations

As stated in chapter 3, the distance is calculated using rectangular distances [11, 13, 15]. To calculate the distance, the first task is to determine the x & y coordinates of the stations, as well as the supermarket locations as represented in Table 13. An assembly line in this facility consists of 9 stations. To determine the co-ordinates, the midpoint of each station and the candidate locations are considered. As the last two stations, i.e., Stations 8 & 9 share the same materials, the midpoint between these two stations is considered in determining the co-ordinates.

Table 13- X & Y Co-ordinates of stations and candidate supermarket locations

Location	X Co-ordinate	Y- Co-ordinate
Station 1	19.00	20.88
Station 2	19.00	45.62
Station 3	19.00	79.94
Station 4	25.91	79.94
Station 5	25.93	45.10
Station 6	37.14	20.88
Station 7	56.69	20.88
Station 8	67.41	20.88
Station 9	85.14	20.88
Location 1	8.34	37.10
Location 2	7.82	3.04
Location 3	43.12	2.36
Location 4	71.98	2.03
Location 5	94.67	1.88

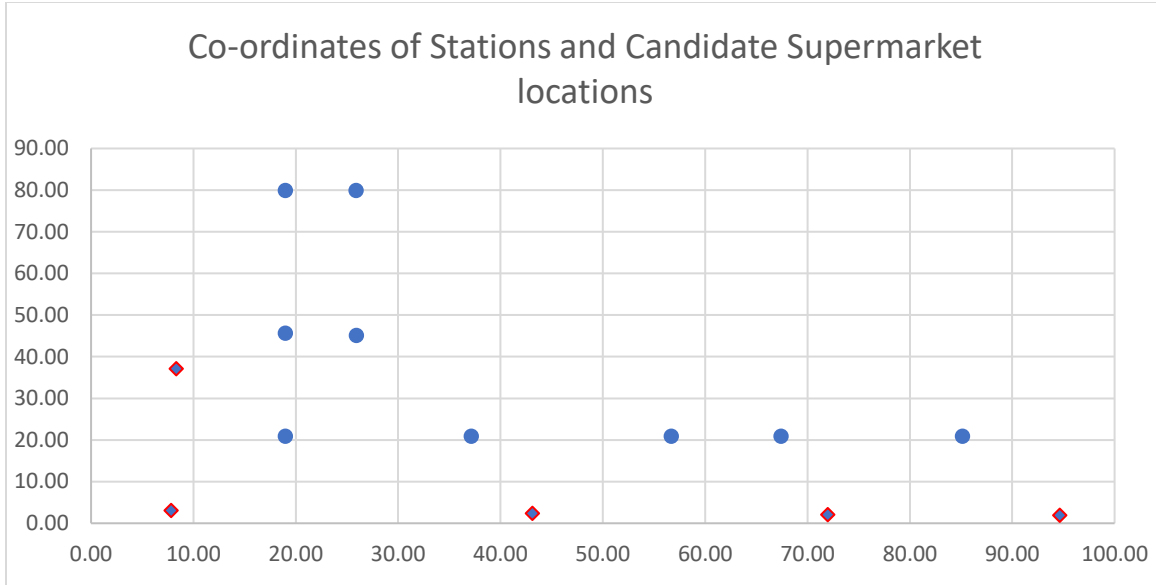


Figure 4-6 Graphical representation of stations and candidate supermarket locations using coordinates

Applying the distance formula, we get the value as,

$$d(S_k, A_c) = |x_k - x_c| + |y_k - y_c|$$

$$d(S_1, A_1) = |18.80 - 5.61| + |22.21 - 37.09|$$

Similarly, the distance between all the candidate supermarket locations and assembly line stations is calculated. Following matrix in Table 14 represents the distances in meters from the candidate locations to the different stations. The column represents the stations and rows as stations. For example, the distance for candidate supermarket location 2 to station 2 is 54 meters.

Table 14 Distance between stations and candidate supermarket locations

	Location 1	Location 2	Location 3	Location 4	Location 5
Station 1	27	29	43	72	95
Station 2	19	54	67	97	119
Station 3	53	88	102	131	154
Station 4	60	95	95	124	147
Station 5	26	60	60	89	112
Station 6	45	47	25	54	77
Station 7	65	67	32	34	57
Station 8	75	77	43	23	46
Station 9	93	95	61	32	29

Distance from Warehouse to Supermarkets.

It is also necessary to calculate the distance from the main warehouse to supermarkets. The distance is calculated similarly using the same distance formula. The coordinates of the warehouse are represented in the Table 15.

Table 15 Coordinates of main warehouse

	Warehouse(m)
x	44.74
y	113.46

The position of the warehouse is represented by the black data point on the top of Figure 4-7. The flow of the materials is from the main warehouse to the red color points which are the candidate supermarket locations. The materials then flow to the stations which are represented in blue points as per the demand.

▲ - Warehouse

● - Stations of an assembly line

◆ - Supermarket locations

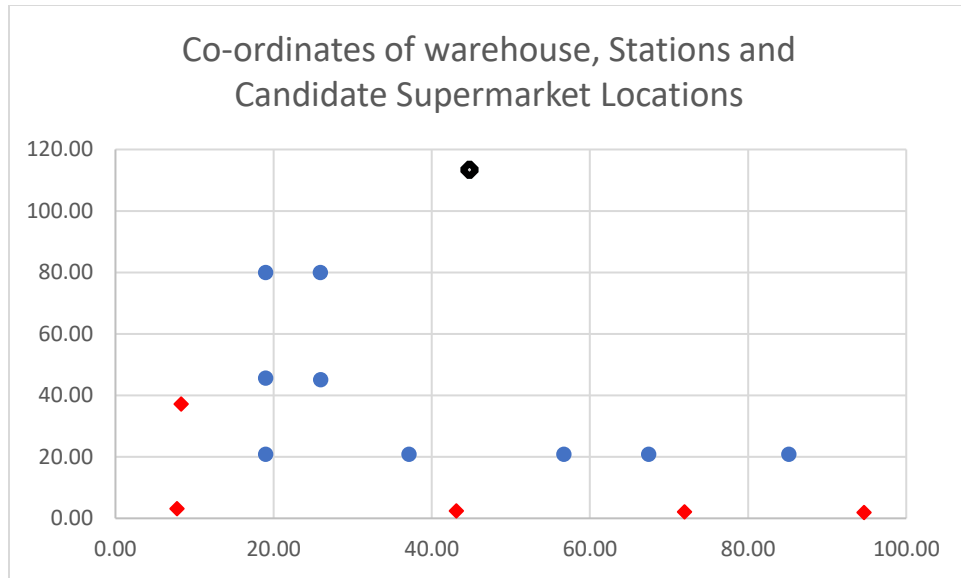


Figure 4-7 – Graphical representation of facility layout using coordinates

Using the same rectangular distance formula, the distance from the main warehouse to each of the five candidate locations of the supermarkets is calculated and is represented in the following Table 16.

Table 16 Distance between candidate supermarket location and main warehouse

	Warehouse(m)
Location 1	113
Location 2	147
Location 3	120
Location 4	122
Location 5	156

Transportation Cost

As stated earlier, the material handling equipment used to transport the materials is a forklift. Hence, the transportation cost is calculated based on the distance a forklift travels in a shift. The operating cost of a forklift in the facility is stated as \$40/hr. This cost is including the cost of a forklift driver, the cost of fuel and the cost of maintenance of the forklift. The above-mentioned cost is a standard for use of a forklift in the facility. Since, the cost is represented in terms of dollars/hour, it needs to be converted in terms of the distance travelled by forklift. The allowable speed of a forklift is supposed to be 8 mph [52]. But since there are employees moving in the facility, it is assumed that the speed of a forklift is 3 mph [52]. To translate dollars/hour to dollars/meters the calculations are done as follows.

To travel a mile,

$$\text{transportation cost} = \frac{40}{3} = \$13.33/ \text{ Mile}$$

To translate in dollars/meter,

$$\text{transportation cost} = \frac{13.33}{1609.34} = \$0.008/\text{meter}$$

Since 1 mile corresponds to 1609.34 meters.

Therefore, to travel a distance of 1 meter, the cost of the forklift is represented as \$0.008.

Inventory Cost

Inventory cost represents the cost of inventory on hand at the supermarket also known as the inventory holding cost. To inventory holding cost is calculated by summing the total inventory cost. It is assumed that the holding cost of inventory is equivalent to the aggregate of the total inventory cost of the materials. This is done using the inventory equation mentioned in section 3.2.1.5. Table 17 shows and example of the materials used and their respective costs.

Table 17 Cost of each material

Sr No	Materials	Cost (\$)
1	joist	0.5788
2	Insulation bat	0.1196
3	Wires	65.93833
4	OSB T& G (8x4)	9.017
5	OSB T& G (other)	9.017
6	Plumbing pipes	0.8314
7	Vinyl	358.4944
8	Insulation roll	68.89
9	8 ft inside corner	0.274
10	8 ft outside corner	0.275

$$Inventory\ Cost = \frac{\sum_i^I C_i * MeanDemand}{Total\ Number\ of\ Materials}$$

$$Inventory\ Cost = \frac{8857.5}{1065} \cong 8.35$$

Therefore, the inventory holding cost is assumed to be \$8.35 for each material for all supermarkets.

Capacity of Supermarkets

Since the demand for each station must be satisfied for each of the shifts, the capacity of the supermarket to hold each material should always be greater than the demand. It is assumed that all the supermarkets have the ability to store each material. Therefore, the capacity of the materials is represented by considering the maximum demand out of 40 periods and adding the standard deviation of each material to the maximum demand. Standard deviation is added to the maximum capacity to make sure there is no shortage of materials in the supermarkets corresponding to the change in demand. Also, Table 18 represents the capacity of each supermarket for each material.

Table 18 Capacity of each material in the supermarkets

Materials	Supermarket 1	Supermarket 2	Supermarket 3	Supermarket 4	Supermarket 5
joist	299	299	299	299	299
Insulation bat	559	559	559	559	559
Wires	15	15	15	15	15
OSB T& G (8x4)	195	195	195	195	195
OSB T& G (other)	35	35	35	35	35
Plumbing pipes	54	54	54	54	54
Vinyl	5	5	5	5	5
Insulation roll	16	16	16	16	16
8 ft inside corner	160	160	160	160	160
8 ft outside corner	60	60	60	60	60
shower tubs	8	8	8	8	8
water heater	3	3	3	3	3
furnace	3	3	3	3	3
Wire	5	5	5	5	5
range wire	3	3	3	3	3
Breaker box	3	3	3	3	3
Ground wire	3	3	3	3	3
Sheet rock	106	106	106	106	106
Energy brace	67	67	67	67	67
bathroom seats	8	8	8	8	8

The level of inventory stored in the supermarket is defined by the total capacity, i.e., the sum of all material stored in the supermarket. Therefore, it is necessary to decide the total capacity of the supermarket. The decision for total supermarket capacity is defined by selecting the value from a range of different capacities. As mentioned earlier, a house is made by combining two floors. Therefore, the values of the range are defined by summing the total materials required by one floor of the largest size of product mix and so on till the sum of total materials required by 5 floors of the largest size of product mix, i.e., a 72X32 ft. Floor. The limit is set to 5 floors because of the facility constraints of space and the opinions of the experts are taken into consideration. The value for the first range based on the above-mentioned calculation is 700. The value 700 is obtained by summing up all the quantities of the materials required to make 1 floor. Hence, the supermarket is assumed to have a capacity that it can store the total number of materials similar

to the number of materials required to produce 1 floor. Similarly, for the last value of MaxCap it is assumed that the supermarket has an ability to store all the demand for all materials at each station. The range for the maximum capacities is represented in Table 19.

Table 19 Maximum Capacity of supermarkets

MaxCap	1	2	3	4	5
	700	1220	1830	2440	3500

Installation Cost

Installation cost is calculated based on the Maximum Capacity range (MaxCap) of the supermarkets. Installation cost is the fixed cost of setting up and operating the supermarkets. It is assumed that at least one employee is needed to operate a supermarket for the first two range values and at least two employees for the last two values of range mentioned in Table 19. The cost on assigning one employee per supermarket is considered to be \$20/hour which is standard in the facility. Since a shift comprises of four hours, the cost of an employee for each period (shift) is \$80. It is assumed that to install a supermarket, industrial racks are required due to the part feature of the materials. Part features such as weight of the material is used to determine the number of racks required for the different values of the maximum capacity range mentioned in Table 19. A standard industrial rack with the maximum weight capacity of 9750 lbs. is considered to be installed in the supermarkets. The cost of the rack mentioned above is \$1800 which is divided over the number of period (shifts) considered for this problem, i.e., 40. Therefore, the cost of installing one rack for one period is \$45. Table 20 represents the cost of installing the supermarkets with different capacities.

Table 20 – Installation cost of supermarkets based on different capacities

MaxCap	Total Weight of Materials	Racks Required	Cost/Period (\$)
700	17599	2	170
1220	35198	4	260
1830	52797	6	430
2440	70396	8	520
3500	105594	11	575

Results

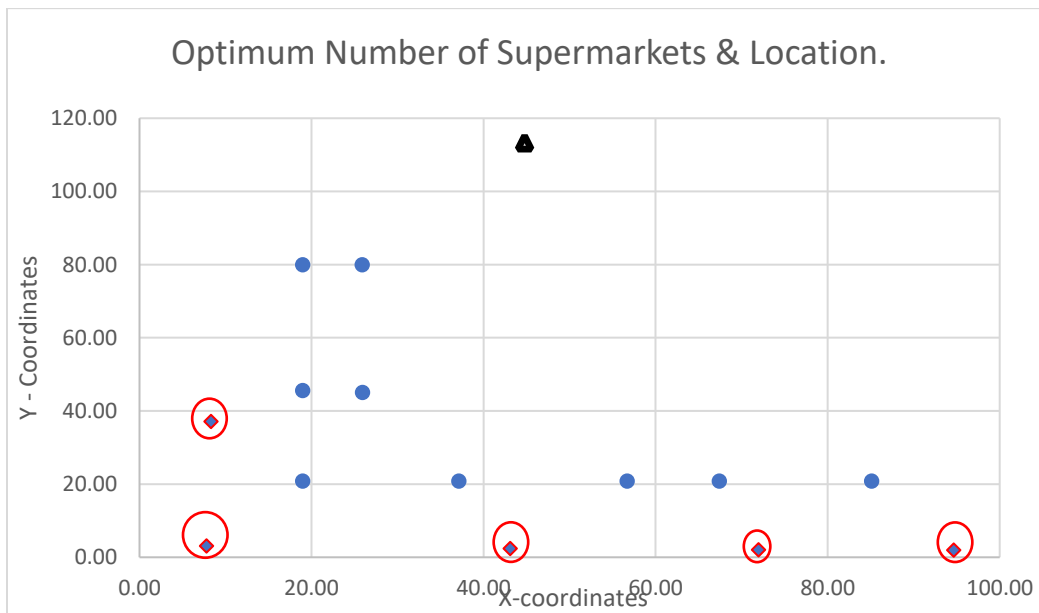
Once all the parameters necessary are defined, these parameters are used in the mathematical model to find the optimal solution for the decision variables stated in Section 3. The computational results are obtained by running the model in an optimization solver. The optimization model is solved using an optimization solver known as Gurobi. The following are the results obtained.

To determine the location and optimal number of supermarkets, the model is solved for sensitivity analysis for different scenarios. The different scenarios are defined considering the different capacities represented in Table 19 to observe the behavior of the model for different values of the capacities. The Table 21 represents the number and locations of the supermarkets that are opened for different scenarios.

Table 21 – Optimal supermarkets for each capacity value

Scenarios	MaxCap	Optimal Supermarkets
1	700	5
2	1220	3
3	1830	2
4	2440	2
5	3150	1

Table 21 represents the number of optimal supermarkets opened for different scenarios (sensitivity analysis). The location of the supermarkets is represented in the following graphs. Scenario 1 Figure 4-8 represents the number of supermarkets opened for scenario 1. In this case, the optimal solution is to open all the candidate location of supermarkets. Since the capacity of each supermarket is less than the demand, the model represents that it is best to have all the candidate places opened and serve the stations to satisfy the demand.



Scenario 1 Figure 4-8

Table 22 represents the flow of materials from the supermarkets to the stations. “x” represents that the station receives the material from a particular supermarket. For example, Supermarket 1 serves stations 1,2,3,5 and Supermarket 2 serves Stations 1 and 4.

Table 22 Scenario 1 Flow of materials from supermarkets to stations

Supermarket	Stations								
	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9
1	x	x	x	-	x	-	-	-	-
2	x			x	-	-	-	-	-
3	-	-	-	-	x	x	x	x	x
4	-	-	-	-	-	-	x	x	x
5	-	-	-	-	-	-	-	x	x

Table 23 Scenario 1 – Material flow of each material from supermarkets to stations

Scenario 1		
Supermarket	Materials	Station
1	1	1
	3	1
	4	2
	5	2
	6	3
	7	3
	12	5
	13	5
	15	5
	19	5
2	2	1
	8	4

Table 23 represents the different flow of materials from a supermarket to stations. Different materials flowing from supermarkets to the desired station is represented. For example, materials 1,3 flow from supermarket 1 to station 1 and material

12,13,15,19 flow from supermarket 1 to station 5. Similarly, supermarket 2 supplies materials 2,8 to stations 1 and 4 respectively.

Table 24 Scenario 1 Number of trips from supermarkets to stations

Supermarket	Stations								
	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9
1	5	1	3	1	1	-	-	-	-
2	1	-	-	1	-	-	-	-	-
3	-	-	-	-	2	1	1	2	1
4	-	-	-	-	-	-	1	3	2
5	-	-	-	-	-	-	-	-	1

Table 25 Scenario 1 Number of trips from warehouse to supermarkets.

Period	Warehouse	Supermarkets				
		1	2	3	4	5
1	1	4	1	4	4	1
2		8	1	5	5	1

Table 24 represents the number of trips forklifts take to satisfy the demand of the stations in one shift. For example, a forklift takes 5 trips from supermarket 1 to station 1 to satisfy all the demand for 1 shift. Similarly,

Table 25 represents the number of trips for an entire day which comprises of 2 periods (shifts).

Table 26 Optimal solution for different scenarios

Scenario	Supermarkets Opened	Transportation Cost (\$)	Inventory Cost (\$)	Total Cost (\$)
1	1,2,3,4,5	96.128	7029.488	7125.616
2	1,3,4	90.976	6349.485	6440.461
3	1,3	91.264	7049.465	7140.729
4	1,3	91.264	7409.465	7500.729
5	1	101.152	6469.468	6570.62

Similarly, the results are calculated for the remaining scenarios. As represented in for different capacities, there are a different number of total supermarkets are opened. As supermarkets for each scenario are different, the flow, as well as the number of trips vary. Table 26 represents the results for sensitivity analysis and provide the comparison of different costs such as transportation cost, inventory cost and the total cost of implementing the material feeding policy using supermarkets. As shown in Table 26 and Figure 4-9 the transportation cost is the maximum when only one supermarket in established. While considering the flow of material as a multi-stage supply-chain, the cost is also high if all the candidate locations are opened.

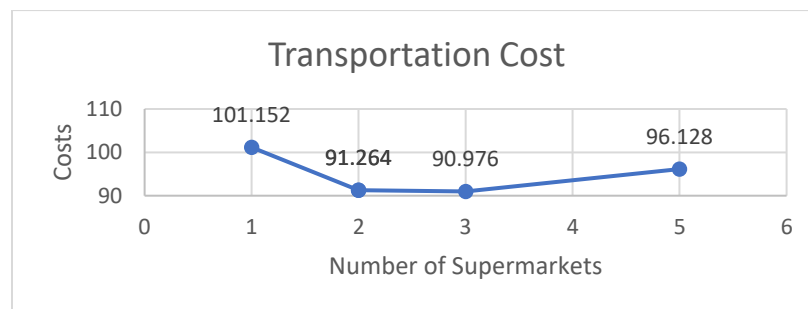


Figure 4-9 Transportation cost for different scenarios

Figure 4-10 represents the inventory cost for different scenarios. As discussed earlier, inventory cost is calculated based on safety stock which is used to satisfy the demand in case of any variation and not on the operating stock of materials. Also, the inventory cost is a function of installation of supermarket, i.e., as the number of supermarkets is increased, inventory cost also increases. This behavior can be observed in Table 26. The inventory cost is highest when all five candidate locations are selected as optimal supermarket location whereas the inventory cost is comparatively less when only one supermarket is opened.

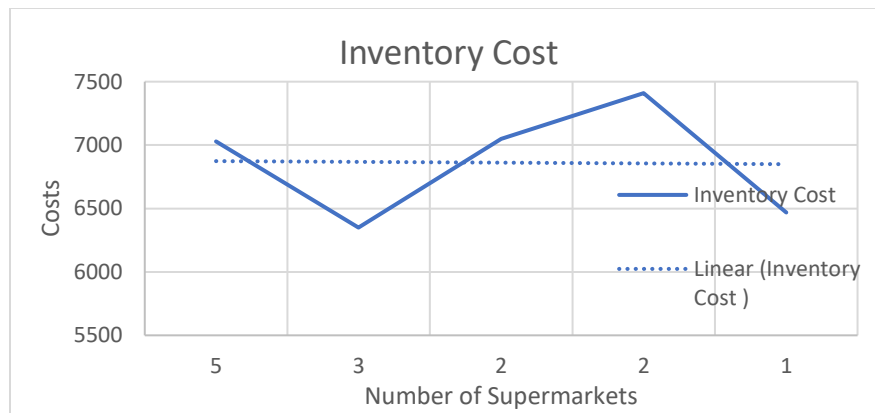


Figure 4-10 Inventory cost for different scenarios

Similarly, the total cost of operating the maximum number, i.e., in this case 5 supermarkets is the highest. The optimal solution should be the one such that the total cost of transporting the materials, as well as storing the inventory in the supermarket should be minimum. From Table 27 it is observed that the minimum total cost from the sensitivity analysis is when there are 3 supermarkets installed. This provides a better flow of material in which the transportation cost is slightly less compared to when only one or all five of the supermarkets are installed. Hence, the optimal solution for this case will be to install 3 supermarkets and the location is represented in Figure 4-12.

Table 27 Optimal solution

Scenario	Supermarkets Opened	Transportation Cost (\$)	Inventory Cost (\$)	Total Cost (\$)
1	1,2,3,4,5	96.128	7029.488	7125.616
2	1,3,4	90.976	6349.485	6440.461
3	1,3	91.264	7049.465	7140.729
4	1,3	91.264	7409.465	7500.729
5	1	101.152	6469.468	6570.62

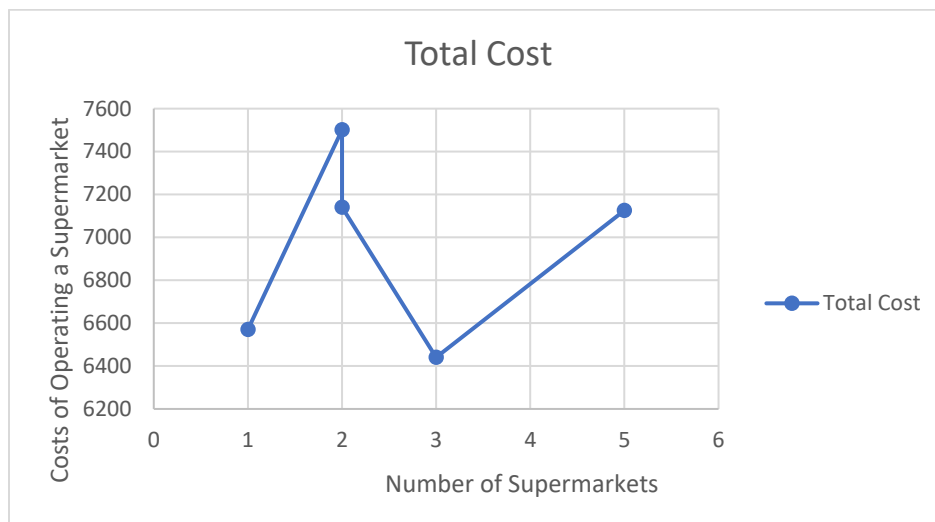


Figure 4-11 Total cost for different scenarios

Location and Number of the supermarket for the Best (Optimal) Solution.

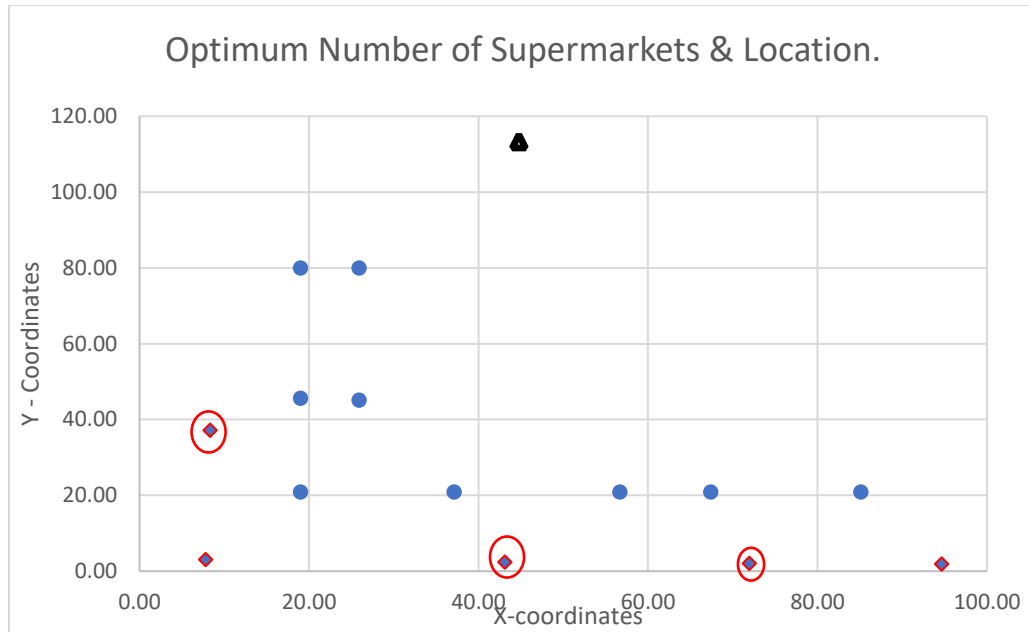


Figure 4-12 Optimal supermarket locations

Flow of Materials

Table 28 represents the flow of materials from supermarkets to station. The optimal solution suggests that it is cost effective to deliver materials from supermarket 1 to station 1,2,3,4 and 5. Whereas, supermarket 3 is responsible for supplying materials to station 6, 7 and 8 and supermarket 4 is responsible to supply materials to station 8 and 9. Table 29 indicates the detailed representation as to which material is served from supermarkets to the assembly line station.

Table 28 Flow of materials

Supermarket	Stations								
	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9
1	x	x	x	x	x	-	-	-	-
2	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	x	x	x	-
4	-	-	-	-	-	-	-	x	x
5	-	-	-	-	-	-	-	-	-

Table 29 Flow of each material from each supermarket

Supermarket	Materials	Station
1	1	1
	2	1
	3	1
	4	2
	5	2
	6	3
	7	3
	8	4
	13	5
	14	5
3	11	5
	12	5
	15	5
	18	5
	19	5
	9	6
	10	6
	16	6
	17	6
	20	6
	21	6
	22	7
	23	7
	24	7
	25	7
	26	7
	27	7
	28	8
	29	8
	30	8
	31	8
	34	8
	35	8
4	38	8
	32	8
	33	8
	36	8
	37	8
	39	8
	40	9
	41	9
	42	9
	43	9
	44	9
	45	9
	46	9
	47	9
	48	9
	49	9
	50	9
	51	9
	52	9
	53	9
	54	9
	55	9
	56	9
	57	9
	58	9
	59	9
	60	9
	61	9

Number of Trips:

Table 30 represents the optimal number of trips required by forklifts to satisfy the demand of the stations on the assembly line to the supermarkets. Whereas Table 31 represents the optimal number of trips required to supply the materials from the main central warehouse to the supermarkets that are opened.

Table 30 Number of trips from supermarkets to stations

Supermarket	Stations								
	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9
1	5	3	1	1	1	-	-	-	-
2	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	2	1	4	-
4	-	-	-	-	-	-	-	1	4
5	-	-	-	-	-	-	-	-	-

Table 31 Number of trips from warehouse to supermarkets

Period	Warehouse	Supermarkets				
		1	2	3	4	5
1	1	5	0	6	0	4
2		9	0	7	0	3

Comparison of Current and Future state - Cost Analysis.

To validate the performance of the new material system design, the proposed design is compared to the system that is currently followed in the facility. In the current state, there is inconsistency in the way materials are stored. Some materials are stored near the line, whereas other materials are stored away from the line in locations which are not fixed. Also, a day's worth of materials is stored for a shift that is replenished again at the end of day which results in the materials occupying a lot of space near the assembly line. Figure 4-13 represents the material system and the flow of materials currently followed in the facility. It is understood that the materials are stored at different locations which are not fixed. Table 32 represents the transportation and inventory cost per day using the current state of material flow in the facility.

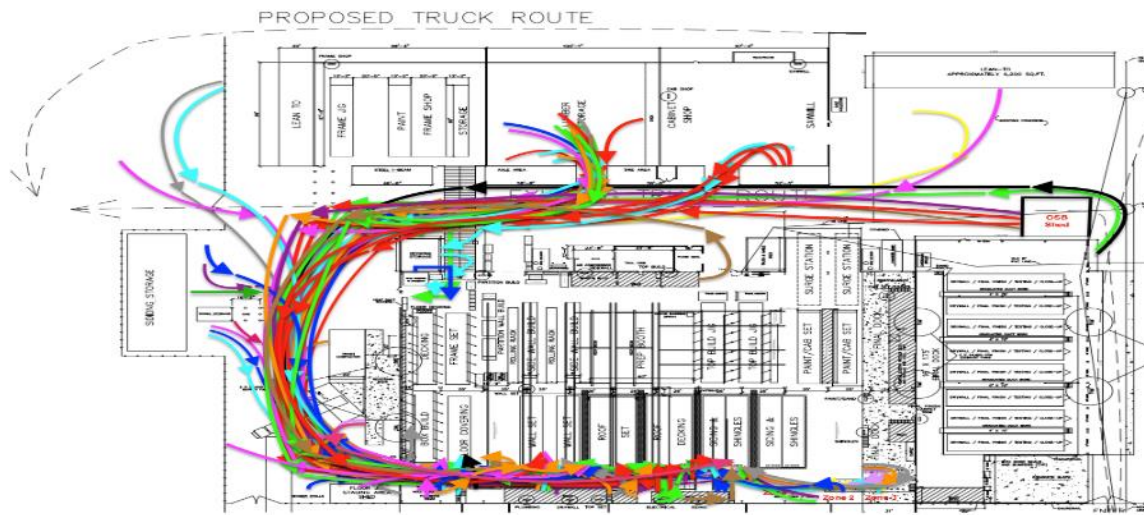


Figure 4-13 Current state material flow

Table 32 Current state cost analysis

Current State	Transportation Cost/day (\$)	Inventory Cost/day(\$)
	117.22	22211

Table 33 Comparison of current state and future state

	Transportation Cost/day (\$)	Inventory Cost/day (\$)
Current State	117.22	22211
Future state	90.976	6349.485
Difference (%)	22.38867088	71.412881

Table 33 represents the comparison of the transportation and inventory cost per day for the current state and the future state, i.e., using a JIT supermarket material feeding system. By Implementing the JIT supermarket system there is a significant reduction in the transportation and inventory cost. Since the supermarkets are

installed close to the assembly line standardizing the flow of materials the daily transportation cost is reduced by 22.39% thus reducing the disruptions. Also, the inventory cost is reduced by 71.41% as the excess inventory is eliminated.

CHAPTER FIVE

CONCLUSIONS AND FUTURE WORK

There has been an increase in the trend towards the use of a supermarket material feeding system in the manufacturing industry. The JIT supermarket systems ensure a standardized and a reliable material flow such that the needed materials are always stored in the supermarket in the right quantity. These prevent the unnecessary usage of space inside the facility which is already scarce. Hence, determining the optimal number of supermarkets and the location of the supermarkets are also a key decision for a manufacturer. The Supermarket Location problem (SLP) is being applied largely in the automobile industry and has failed to capture the complexity involved in the other manufacturing industries like the house manufacturing industry which is considered in this study. Also, the literature fails to capture the decision on the flow of materials from the main warehouse to the supermarkets and the flow from supermarkets to stations which is considered in the study along with different material handling equipment which is a forklift. The transportation cost is minimized by optimizing the number of trips taken by forklift to deliver the materials. Also, the nature of the demand is considered to be stochastic in which the SLP problem is solved by optimizing the transportation, as well as the inventory cost.

A real case, as well as some tests, are solved to find the optimal number of supermarkets and their location as along with the flow of materials. The optimized solution is then compared to the current state, i.e., the way materials are currently being moved in the facility. The computational results verify that the proposed mathematical model provides the minimum transportation cost, as well as the inventory cost, then the current flow of materials that the facility follows. The proposed mathematical model also considers the variation in the demand of the product mix and thus providing a standard and a reliable flow of materials over the current state such that the demand is always met.

While formulating the model, the assumption is that the demand follows a normal distribution. For future research, a different distribution can be used to see the effect of variation in the stations demand. Also, it is assumed that the forklift can carry all types of materials in one trip until it satisfies its weight capacity. The future research can optimize the trips and the placement of materials to fit different sizes of parts considering the volume constraint of the forklift. There is also a scope of optimizing and scheduling the replenishment of a supermarket so that there can be a continuous flow of materials to the supermarket from main warehouse which can be studied in the future.

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