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NORMALIZING AND PROCUREMENT OPTIMIZATION WITH SUPERMARKET AND ASSET MONITORING

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ABSTRACT

KISHORE RAVICHANDRAN: Normalizing and Procurement optimization with Supermarket and Asset monitoring
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Automobile part suppliers have struggled hard in the past to meet the requirements of the manufacturing companies. The Original Equipment Manufacturers (OEM) are constantly facing demand changes from the customer end. The connected world has raised the expectation of customers to provide cost efficient yet quality automobiles. Part suppliers are stressed to deliver the products in Just-In-Time (JIT) sequence to reduce the bulk stock in the warehouses. The thesis revolves around the review of JIT models in the automobile assembly process. It specially focuses on the importance of supermarket and their uses in providing the parts through tow train scheduling and routing. The models which are already existing are revised by changing certain criteria and combining all the models published into one system to make it easy for the readers to understand. The purpose of the model normalization is to have visibility on quantity of parts needed in supermarket. This is achieved by the normalized routing and scheduling models which exactly tells when, where and the number of parts transported to the desired work floor at specific time just before assembling. This gives the number of parts being used from the supermarket. From this the number of parts needed on the supermarket and subsequently to the warehouse are calculated.

The second half of the thesis focuses on procurement optimization after the revised demand of inventory in the warehouse. Procurement optimization paves way for choosing the right supplier according to the volatility in demand. The second half of the thesis discusses about the advantages of super market installation on supplier selection by doing procurement optimization using Mixed Integer Linear Programing. To end the research work on the automobile assembly process, the current problems faced by the industry and especially by the suppliers are discussed. A new way to mitigate the supplier loss is discussed with the introduction of Internet of Things (IoT) based solutions by tracking the assets. Asset monitoring devices have been gaining attention worldwide to safely transport the goods without damage. Transparency and visibility is provided in the form of bidirectional gateway process by the wireless asset monitoring devices. Not only the suppliers but also the OEMs are benefitted as it supports the JIT process and faster assembly of the automobiles with less number of damages.

PREFACE

The thesis aims to provide a better understanding of supermarket in the automobile assembly station and the changes in the procurement optimization for parts supply. It has been an immense pleasure to work on one such ways of benefitting the employees through the technology diffusion process on the automotive production assembly process. In the future, the innovative products can be easily managed to make the people buy by showing the advantages over the old technology with the new methodologies.

For giving me this opportunity to work on automobile assembly optimization, I would like to show my deep gratitude to Dr. Nina Helander and Dr. Simon Emde for guiding me throughout the whole project and helping me on solving issues during the project work. I would like to thank Mr. Prabhakar Chaudhary for giving me permission to visit one of the renowned automobile assembly station in Delhi to know about the current automobile production and assembly problems.

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Kishore Ravichandran

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LIST OF ABBREVIATIONS

3PL	Third Party Logistics
ERP	Enterprise Resource Planning
FTL	Full Truck Load
IoT	Internet of Things
JIT	Just-In-Time
JIS	Just-In-Sequence
LTL	Less than Truck Load
MILP	Mixed Integer Linear Programming
OEM	Original Equipment Manufacturer
OBD	On Board Diagnostics

1. INTRODUCTION

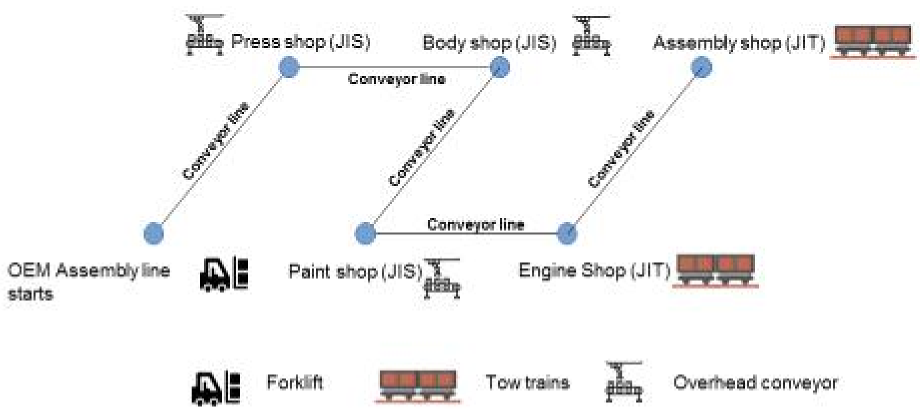
In the Automobile industry, over the years customer expectations from auto makers are increasing day by day. From the technology point of view, Automobiles are facing tremendous changes with Artificial Intelligence taking over leading to more installation of different combinations of parts such as sensors and technology related equipment to name a few. The customers are becoming aware of the safety and performance standards making the world a competitive work place. This means that the companies are under pressure to satisfy the needs of different types of customers given a common production and assembly plants. Companies are fighting over the customers trust to position themselves in a niche market. (Brandwatch, 2017)

The changing customer needs and technology evolution in the Automobile industry has made a tremendous impact on the whole supply chain processes. The companies are strengthening their core business processes by outsourcing the trivial processes. Increased part variety and mixed model assemblies led to complexity in the manufacturing and part sourcing. (Hu *et al.*, 2008). With the increasing part variety in the automobiles, the companies are starting to schedule their production assembly in such a way that the customer demands are satisfied in shorter time intervals (Thomopolous, 1967). The demand varies for different types of models therefore the automobiles are manufactured in a customized production sequence. The OEMs are moving towards build to order meaning the auto manufacturers build the automobile based upon the customer demand. (Parry and Graves, 2008). Hence the parts to the production stations should be delivered according to the production sequence in order to save time and maintain the flow. The companies are moving towards a sustainable business model by integrating the suppliers and souring the parts as and when needed (Holweg & Pil, 2004). The parts cannot be also stocked near the production line as it increases the inventory holding cost. Hence the concept of Supermarket is introduced to have efficient production by having reduced additional inventory in the assembly station. A Supermarket is a temporary storage place in the form of racks. The parts are taken from the warehouse to supermarket to store it temporarily in the assembly floor instead of directly placing them on the working station (Seidl & Dvorak, 2012). Two to three assembly floors will have one supermarket depending upon the size and quality of the parts assembled. At the same time, the parts cannot be stocked out which will lead to stopover of production affecting the production sequence. Generally, the production sequence of the current day is given 4 to 5 days prior to the production. This makes it easier for the companies to schedule the parts according to the production sequence. This is where JIT from the Toyota production plays a vital role. The parts are received from the part supplier JIT and allowed to enter the production plant without much of inventory holding. To do this, the supermarket concept is widely used in the automobile production plants to transport the parts locally from the supermarket to the respective production stations (Battini *et al.,2010).*

Parts which are sorted in the production sequence in the supermarket should be transported to the production station just before the start of the production. (Dong *et al.,* 2016)This saves more time, avoids damage of the products lying the inventory incurring damage costs and shortage of inventory. Apart from saving time it increases the unwanted labor movement inside the assembly plant which in-turn increases the labor efficiency (Samalley, 2009).

To transport the parts as and when needed, the transport mechanism inside the plant should be properly assigned according to the production sequence of each station. However, a lot of scheduling and routing has to be made for the mixed model assembly line (Golz *et al.,*2015). Among different types of transport methods, the automobile companies are preferring tugger wagons with the forklift as it can carry high amount of parts when compared to forklift. Tuggers has its own disadvantages leading to many constraints in the transportation of parts although the main objective is satisfied. Tugger wagons are connected with a tow trains for an efficient and safe transportation of parts. The tow trains cannot transport more than 6 wagons as the assembly station are designed with U or S shaped assembly floors. Since it involves sharp turns, the tow trains will not be able to transport more than 6 wagons at a time. The tow trains are either operated manually or automated to travel based on the schedule and route. There are also automated wagons which uses sensor to pick up the empty wagons lying on the working station while retrieving back (Emde *et al*, 2015). A brief overview of automobile assembly process with different material handling systems is shown in the following figure 1.

Figure 1. Automobile assembly process with different material handling systems



The automobile assembly station has four different assembly shops where various parts are assembled. The assembly line starts from press shop to body shop to paint shop to engine and final assembly shop. Different material handling equipments such as forklifts, tugger wagons and conveyors are used during the process. Conveyors are used in press shop and body shop while the tugger wagons are used in engine shop and final assembly process where lot of tiny parts will be required. To reduce the inventory, a supermarket is installed which can hold the parts temporarily in the assembly station. Due to the supermarket installation, the inventory needed will reduce and eventually the parts needed for warehouse also reduces. This leads to more competition and the player who provides customer specific deliveries wins the bid. Procurement optimization and inventory planning are periodically done matching the customer expectations. The study answers the following research questions in accordance with the current practices and the problems faced by the automobile industry.

- How does the effective utilization of Tow trains help in minimizing the inventory (safety and cycle stock) through proper scheduling and routing?
- What is the alternative to free up the space in the assembly station leading to efficient production and damage free products?
- What are the effects of installation of super market and how does it affect the vendors?
- How real-time monitoring of assets helps in sustaining the manufacturer pressure and deliver the customer expectations?

The thesis work mainly focuses on normalizing the scheduling models of tugger wagons in order to efficiently transport the parts from super market to the respective stations without any lag. Procurement optimization after the supermarket installation and the impact of real-time asset monitoring solutions is also discussed in the following chapters. Apart from this, the recent trends in the automotive industry and the problems solved by these technologies are also discussed.

2. LITERATURE REVIEW

2.1 Automobile Assembly Operations

Automobile supply chain has a subset of many other different supply chains as it contains a variety of products to be assembled at during manufacturing and in final assembly. Generally, a supply chain involves three different flows namely physical, information and financial flows. Physical flow means the actual transport of materials from suppliers as raw materials through OEMs and then to the customer from distributors and retailers. To attain the smooth flow of products from upstream to downstream without unnecessary delays, information flow is crucial in transporting the goods. Although in most cases with the advent of technology, information flow happens between computer to computer under strict data restrictions without any human intervention. Once the information and physical flows are optimum, the financial flow across different stages of the supply chain will start from the customer till the suppliers.

According to Meyr (2004), the production planning in the automobile industry has four different stages starting with metal pressing, welding, paint and then to final assembly. The final assembly consists of stations with a conveyor belt to move the automobile from one station to another. Each station has its allocated space to store the parts needed for the current production sequence. In certain cases, these stages might not be run by the same plant as OEMs focus only on the core business to improve accuracy and efficiency in bringing quality products to the customers. In most OEMs, the first three stages are completed by outsourcing and the parts are ready for assembling in the waiting area. In some cases, the distance might be too long for which a different carrier has to be hired possibly having long distance transport makes sense.

Due to competitive and flexible supply chains, the customer expectations are increasing exorbitantly as they demand customized products. It means that the manufacturing strategy should be changed from Make to stock towards Make to order as the customers specifies the make according to their wish. However, the manufacturing strategy cannot be completely changed to Make to order as retailers require inventory of automobiles to stock. Hence, a mass customization should be put into practice to satisfy all the customer along the orders given by retailers. A balanced and sequenced mixed model should be implemented to satisfy the customers by reducing the waiting time (Alghazi, 2015).To make this efficient, a production sequence is created to deliver the finished goods on time. This whole assembly line containing different variants getting produced in the same plant is called ‘Mixed model’ assembly line. Therefore, the production planning area is customized in such a way that the any model can be manufactured and assembled with small adjustments according to the production sequence. (Meyr, 2004)

Most of the auto manufacturers are already practicing mass customization approach by integrating JIT method for manufacturing and part retrieval in the final assembly. As the name says it, JIT is a process of delivering products as and when needed to save space and time in the production plant. In the ASEAN context, JIT lies as the significant factor in maintaining a high production efficiency (Kurosu & koyoma, 2013).

2.2 Part Logistics

The thesis mainly deals with one of the subdivisions of automobile supply chain i.e final assembly. In the final assembly, all the parts needed for automobile assembly are retrieved and then used according to the need. There are certain limitations in providing the parts to the assembly. The limitations and the solutions are mentioned along with the part logistics processes.

Part logistics mainly covers three types of logistics namely external, internal and reverse logistics covering two types of supply chain forward and reverse supply chain. The main overview of the part logistics deals with the transport of part from the external supplier or company owned part manufacturing facility to the OEM and then finally to the corresponding station in the assembly plant. In the external logistics process, a call order is submitted to the supplier by Manufacturing Execution system which is a part of ERP. Parts can be ordered by following periodic review policy or continuous review policy. Due to space and demand constraints, a trade off should be made with the suppliers to provide the parts JIT. As a result, only required parts for the particular time horizon are delivered by the suppliers. The OEM must have long term relationship and trust over the suppliers as it requires on-time delivery of parts (Fan, 2016). The required demand is also derived following time series analysis of demand forecasting. As the demand depends on level, trend and seasonal factors calculations are made and sent to the suppliers for them to be ready anytime providing parts JIT. As the inventory level is maintained very low, a cycle service level of 95-100% is expected from the suppliers and quality inspection is done before the external logistics itself. If there are any damaged parts even after the quality inspection, the trucking company and/or the supplier will pay a penalty for stocking out i.e. having defected parts. According to Emde (2015), if there is potential stock out, depending on the consequences alternative solution has to be put into practice immediately such as delaying a car, providing express delivery or stopping the line until the part is received. Based on the initiation, the suppliers will pay the penalty. Since most of the parts required can be produced near the OEM, truck delivery is the efficient means of transportation of automobile parts and an immediate alternative can be processed depending on the problem situation.

Internal logistics are the crucial part of delivering the parts to the respective stations. This starts with receiving the parts from the trucks as a full load, categorizing the parts and then transporting them to the stations according to the production sequence. To smoothen the flow of parts and to save time, a decentralized limited storage capacity center called supermarket was introduced. Instead of transporting the parts from the warehouse to the stations, the parts are delivered to the supermarket and then according to the production sequence, the parts are delivered to the stations in the form of bins. Once the parts are consumed by the stations, the empty bins are taken back to the warehouse and this process is called reverse logistics or backward supply chain.

2.2.1 External Logistics

External logistics have two processes before the parts are received in the production facility. The process starts up with initial call order or ordering the products from the ERP system of OEM. The call order can be classified into 2 types namely push and pull call order. Push call orders are determined from the production sequence which generally suits for high valued products i.e. transmission, engines in the case of automobiles. It follows JIT and JIS production methods. For smaller parts such as mirrors, head lamps pull based call order is followed once the bins or supermarket is emptied. Pull based call order either follows the Kanban policy or inventory policies such as periodic review policy and continuous review policy.

Once the call order is processed, the supplier transports the parts to the OEM at the right time. The parts are transported in three ways according to the tradeoffs made with the OEM. When an OEM requires an immediate delivery of the parts, a point to point system is executed. In a point to point system, the parts which are loaded in the supplier's plant are delivered directly to the OEM facility irrespective of the load such as Full truck load or partially loaded. The trade-offs in this system is between the speed of delivery and the costs. Typically, it incurs a higher cost than the other modes as faster delivery is made. Another way of delivering the parts is by processing milk run orders in which parts are collected from different suppliers in the route starting with an empty load and delivering the parts in the OEM (Fan, 2016). The trade off in this type of transportation is increased lead time with cost efficiency. This is most suited for small sized LOT parts. The last type of transportation is using a cross docking facility. In cross docking facilities, loads of similar parts are delivered in a place where these parts are segregated and moved to different trucks. Henceforth, the outlet end of the crossdocking facility will have truck loads with different parts and then they are delivered to the OEM according to the production sequence. The crossdocking facilities are called internodes where shipments are unloaded, sorted and moved to the outlet for another truck delivery (Emde, 2015). The main decision problem in External logistics is order frequency and cost minimization leading to changes in lead time. Apart from the main decision problem above, routing of the trucks is an important milestone in delivering the parts on time without any damages. Chuah and Yingling (2005) proposed a JIT based routing problem in which the all the suppliers in the cycle are merged in a single tour on regular intervals. The services are decided by the OEM and the logistic service providers depending on their logistic specialization.

2.2.2 Internal Logistics

Once the truck load reaches the OEM facility, the process of in-house logistics begins with the receipt of parts. The parts are received in two alternative pathways such as JIS and JIT or LOT. In Just in Sequence pathways, there is only one problem of scheduling the trucks to reach the dock at the right time so that the parts can be directed towards the conveyor in the production sequence. The freight carrier will pay a huge penalty if the JIS pathway is followed and the parts are not reached on time as it directly influences the production assembly work leading to Work-In-Progress. In JIS pathway, the truck drivers are informed with the dock number beforehand as the production sequence is created few days before the production. On the other hand, if the JIT/LOT pathway is used, the trucks are not assigned with any dock number earlier instead once the truck control center is informed about the presence of the truck a dock will be assigned until it becomes available (Klug, 2010). Contrastingly, the trucking company can choose the time windows from the OEM's IT systems and a preferred time window is allocated. This is however approximate as original time windows are given prior to the unloading of the parts. If the trucks need to visit more than one dock when it contains multiple type of parts, the decision problems cumulatively increase.

Receiving the parts is a time critical activity but the main problem lies in accessing the parts from the storage after the receipt of parts. The parts can be stored in a centralized storage or decentralized storage. In centralized storage, all the parts are sorted and placed like a warehouse where forklifts and pallets are used to load and unload the parts in the racks. On one hand, practicing JIT helps in having more free space in the stations while on the other hand the parts need to be sorted and moved to the stations according to the production sequence which is time consuming. This process has become obsolete in few automobile manufacturing companies. Instead companies are adapting towards decentralized storage i.e. supermarket where parts are placed directly near the stations in the plant. This leads to a decision problem of the number of stations to be allocated to one super market, number of supermarket to be placed in the plant along with the layout and the quantity of each part stored in the supermarket. (Battini *et al.*,2013).

The stored parts should be sequenced according to the production sequence to transport them into the bins and then to the required stations. There are two logistic pathways for sequencing the parts subject to the type of storage implemented as they are interdependent. Parts to pickers paradigm is followed where the parts are taken back from the storage i.e. ASRS and then moved into the bins. Generally, the small and low valued LOT parts are preferred for this type of pathway whereas high valued large JIT parts follow picker to parts. In picker to parts the parts are moved from the ASRS and due to heavy weight, they are generally placed in the ground storage for easy access. After retrieval, the parts are sorted according to the sequence and sent to respective stations. Sequencing has become a larger problem in recent time as the ergonomic stress is high and the industry is going through an aging workforce. (Faccio *et al.,* 2013)

Delivery of the parts to the stations is an important task in the assembly facility as all the parts should be in the station to follow the production sequence. The part delivery in an automobile assembly plant can be done in three different ways such as using conveyors, forklifts and tugger wagons. Conveyor can be used for JIS parts as it is directly connected to the dock. Forklifts and tugger wagons are the possible ways for transporting small sized JIT parts from the decentralized storage space. Forklifts are time consuming as they can lift only a limited capacity of parts. When a forklift is considered for transporting the parts, the transportation sequence and the number of jobs assigned to a forklift should be determined.

A tow train can carry and transport large number of parts without any restriction as in forklift which leads to less number of turns and higher transport accuracy. However, there are few limitations of tow trains. These include not able to access the sharp turns with large number of wagons. Hence the number of wagons are restricted to a limited capacity. The main objective of using tow trains (Battini et al,2013) are assigning a number of stations to each tugger, a delivery schedule for each tugger has to be assigned in order to maximize the capacity utilization. At present, the companies are preferring cyclic schedule for the tow train as the delivery time to each station takes only about 60-90 seconds which is considered nothing. To minimize the number of tuggers and unnecessary use of man power, routing and scheduling plan has to be created together as they are totally dependent on the each other. These plans should be made according to the number of tuggers and not having too many parts in the stations as it decreases the space in the stations. To satisfy these conditions, along with the routing and scheduling plan, loading plan for each tugger are created by JIT part delivery to the stations.

Once the parts are placed near the stations in the form of bins, for ergonomic advantages the parts are stored in gravity flow racks for small sized parts and ground storage for the large sized parts. In the case of gravity flow racks the parts are inputted at the back by a worker whenever the parts are depleted by the frontline worker. This helps in better handling of smaller parts (Bozer and McGinnis, 1992). But it increases the ergonomic stress leading to more handling of the bins. In addition to this, the stations contain a lot of immovable machinery items and large sized parts in the stations making the space scarce and bringing difficulty for the workers to do a flexible work. By placing the parts in the station is an important decision which is highly dependent on the number of parts received in the station from the tow trains.

2.2.3 Reverse Logistics

Whenever the parts are utilized by the stations, the bins containing those parts become empty and they cover a lot of space in the station area leading to scare space capacity in the station. This calls for the retrieval of the bins in the station area on a periodic interval of time. There are two processes involved in the returning process of the empty bins. The first process being the retrieval of the bins from the station to the decentralized storage and the other process is returning the empty bins to the respective suppliers.

In in the internal reverse logistics, the parts can be retrieved by following two pathways. One of the pathways is incorporating the return of the bins in the forward chain while supplying the bins. However, this cannot be done when a conveyor is used for supplying the parts as they are unidirectional. But the other two material handling systems such as forklifts and tow trains can be used in the forward chain. If these machines follow the same route and schedule an additional stop over time will occur due to an extra process but the trade-off being saving the additional transportation cost for returning the bins. The other pathway is to introduce a separate material handling system for the retrieval of the bins from the stations. This means that a new routing and scheduling has to be created to reduce the transportation cost of the process. This process will incur additional costs but smooth flow of the operations will be maintained in the assembly line. (Ravi, 2014)

In the external process of the reverse logistics, the empty bins and pallets are transported back to the suppliers. Some of the part handlers can be folded leading to higher storage of the bins and pallets. The trucks needed for this process are very less and hence the problem of saving the cost are taken into account. To mitigate this problem, the trucks can be routed and scheduled to follow a milk run pathway by consolidation of the bins carrying the same or similar parts in multiple production sites. These trucks do not directly reach the supplier location instead they unload the parts in the nearby cross company deposit system. From there, the bins will be transported to the respective suppliers once the truck has full truck load. In the digital world, networking among the competitors and the stake holders are possible which solves the problem of saving the costs. The other pathway is to directly transport the empty bins and pallets of specialized parts to the suppler location irrespective of the costs involved in the transportation.

3. RESEARCH METHODOLOGY

The following are some of the research methods used in-order to validate the effectiveness of the information (the balance),

As the industry is quite fragmented, all the information and the data collected should be validated with proper resources from the industry people. Hence, phone surveys and market validation with the respective professionals were done. The primary research involves two different types such as close ended and open ended. An exploratory research in the form of open ended questions are performed at the beginning stages. Once the target customers are identified then the closed end questions will be put forward. It specifically targets certain companies/ individuals to know more about the problems. The questions will be of phone survey types with individuals as the exploratory research involves the focus groups. One disadvantage with the primary research is that it is very expensive and it consumes a lot of time to validate the research. Hence a limited number of primary research was done to validate on the critical problems. (Coughlan and Coghlan, 2002)

Secondary research is a quantitative research methodology which includes collecting information from various online sources such as internet, magazine, blogs, publications and the government statistics on the field. The challenging part in the secondary research is to analyze the information according to the need rather than using the whole data. It is one of the pitfalls in doing the research as the data are not bound to certain industry or business.

The report published by different companies in the field on all the topics are analyzed through to get an inference. Case studies validate the date by allowing exploration and comprehending of uncertain issues (Zainal, 2007). The government also issues statistical reports time to time for the public analysis. Case studies from different automobile companies were analyzed.

Modelling is one of the critical things which was used extensively throughout the thesis. Different models published by the authors on the automobile assembly plant were analyzed to come to a conclusion for systematic approach on the Mixed Integer linear programming models. Mathematical modelling and the associated Mixed Integer Linear Programming are the research methodologies backing the thesis. (Edler *et al*, 2002)

3.1 Mathematical Modelling

According to McCarl and Spreen (2010), mathematical programming deals with set of procedures leading to analysis of optimization problems. Generally, in an optimization problem, the objective is to minimize or maximize the related costs and profit. It depends on the objective of the problem. A mathematical optimization model consists of an objective function which contains the decision variables. These decision variables are the unknown values of the problems which optimizes the problem to the best possible scenario. Apart from the objective function, there are also set of constraints which determines the boundaries for the problem. Some of the example constraints include linking constraints which creates a relationship between the constraints and the objective function. maximum capacity constraints, non-negativity constraints which varies depending upon the problem. A general model is listed below,

Decision variables: X,Y

Objective function : Min (or) Max F(x)= 2*X + 3*Y

Constraints: X + Y <= 10 (Maximum total capacity)

X > 2 (Minimum capacity of X)

X,Y > 0 (Non-negativity constraints)

There are different types of mathematical programming such as Linear programming, Integer programming, and Mixed Integer Linear programming. If the variables in the model are linear in nature then they are called linear programming whereas the variables which contain only integers are called integer programming. Most of the cases there are not any pure integer and pure linear values hence Mixed Integer Linear Programming (MILP) is widely used in solving many problems. MILP models contains a mix of integer and non-integer values. The underlying models discussed in this thesis are all of MILP in nature and hence these problems are discussed in detail in the following paragraphs.

Before discussing about MILP problems, there are different types of variables and rules followed by constraints irrespective of the type of mathematical programing. There are different types of variables used in mathematical programming and they are listed below,

1) Production variables
2) Sales variables
3) Slack variables
4) Purchase variables
5) Transformation variables
6) Surplus variables
7) Step variables
8) Artificial variables
9) Deviation variables
10) Accounting variables

Table 1 shows the types of variables used in the modeling problems,

Table 1. *Types of constraints (Adapted from Mccarl,2010)*

TYPE OF CONSTRAINT	DEFINITION
Resource Limitations	Sum of variables should be less than a constant Eg: Resource allocation problem
Minimum requirements	Sum of variables should be greater than a constant Eg: Transportation problem
Supply and demand balance	Supply of the variables should be greater than or equal to demand of variables Eg: Scheduling problem
Ratio control	Ratio of one variable to the other Eg: Feeding parts problem
Bounds	Variables are given with boundary conditions
Deviation constraints	Variables with multiple objectives leading to deviation from the target level Eg : Non linear transformations
Convexity constraints	Constraints with sum of the variables requiring to be less or equal to one

The constraints listed in the above table are related to the part feeding systems in Automobile production assembly and used for the optimization of the different costs involved. Each constraint plays a significant role in reducing the cost and improving the efficiency if applied on the right areas. Adding more constraints to the model leads to infeasible solutions. Hence, not all the constraints are used in all the models.

3.2 Mixed Integer Linear Programming (MILP)

A mixed integer linear problem is where some of the variables consists of fractional values and the rest of the values have integer values. As in all the optimization methods, the first step in Mixed Integer Linear programming is to determine the decision variables. For the ease of understanding the problem of juice manufacturing in different plants are taken as an example.

Step 1: Determining the decision variables

X_{ij} = Number of Juice units i made in plant j

$$X_{ij} \geq 0$$

Once all the decision variables are determined, the problem should be defined on whether to go for maximization or minimization. It is the step of defining the objective function.

Step 2: Defining the objective function

$$\text{Minimize } Z = \sum_i \sum_j C_{ij} \,.\, X_{ij}$$

Where X_{ij} = Number of Juice units i made in plant j

C_{ij} = Cost per unit of product i made at j

The last and the final step in building a model in MILP model is to formulate the respective constraints related to the problem statement according to the needs. In this case, there will be two constraints such as demand and supply constraints.

Step 3: Formulating the constraints

$$\sum_i X_{ij} \leq C_j \quad ,\forall\, j \ \text{(Capacity constraint)}$$

$$\sum_j X_{ij} \leq D_i \quad ,\forall\, I \ \text{(Demand constraint)}$$

Where C_j = Capacity in units at plant j

D_i = Demand for product i in units

Once all the steps are done, the model can be solved using simple Excel solver. For complex problems which contains lot of constraints and multiple objectives in the same model optimization solvers such as Gurobi and CPLEX are used. There are different types of methods in solving MILP models. They include branch and bound method, cutting plane methods and heuristic method. (Gurobi, 2017)

Applications of Mixed Integer Linear programming include transportation and transshipment problems, knapsack problem, capital budgeting problem, fixed charge problem. In this study, the methods are used in building a model for routing and scheduling of tow trains in the automobile production assembly. The tow trains are used to transport the automobile parts from the supermarket to the assembly stations

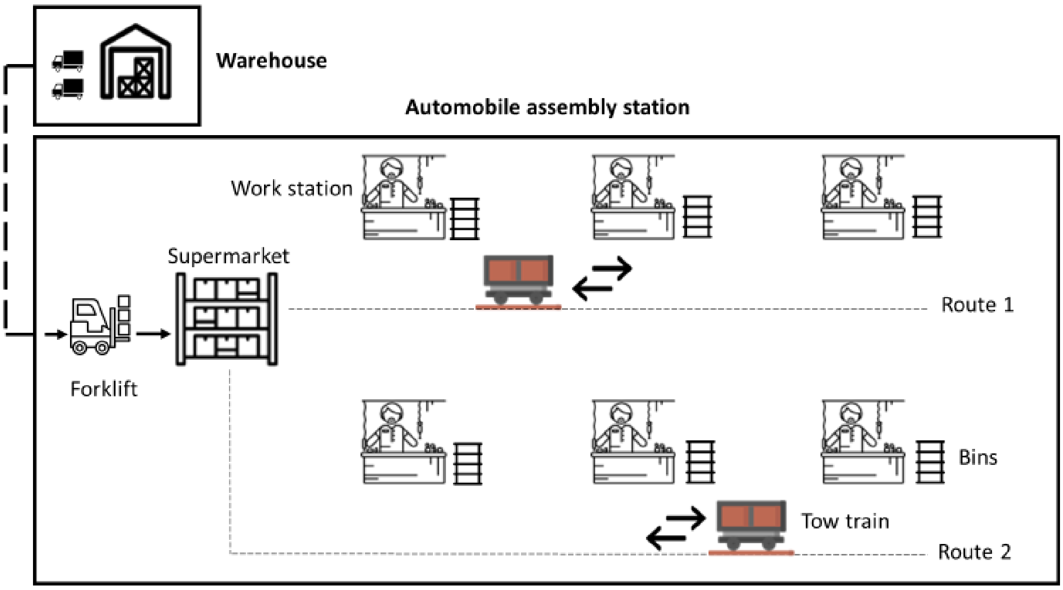
These are all the research methodologies used on the report. Section 4 deals with the systematic normalizing of the different models on scheduling routing of tow trains in the automobile production assembly plant. Section 5 deals with procurement optimization of the suppliers before and after the scheduling and routing of the tow trains as it directly impacts the inventory stored and then the suppliers. The chapter also focuses on the problems faced by the automobile industry in procuring parts as there is a lot of damage involved in the transportation of the parts.

4. SYSTEMATIC REVIEW OF TOW TRAIN ROUTING AND SCHEDULING MODELS

4.1 Production Assembly Setup

The whole problem is setup in an automobile production assembly plant of premium and budget car manufacturers. The plant has a warehouse and a separate assembly plant for assembling the parts and do the final assembly including the painting and re works. The warehouse has lot of dock stations to receive the parts from the suppliers in and around different part suppliers. The assembly plant has a supermarket where the parts from the warehouse are taken on a "Just-in-Time" and "Just-in-sequence" basis. Once the parts reach the super market, the parts are then transported to the assembly stations with the help of tow trains. The third chapter deals with review of routing and scheduling of the tow trains to each assembly station dealing with different varieties of cars. The following figure depicts the setup used in the automobile assembly stations incorporated with a supermarket.

Figure 2. *Automobile Assembly layout*



4.2 Model 1- Routing of JITCVRP

The following MILP model serves as the base model for all the models explained below. The model follows a JIT capacity routing problem adapted from Vaidhyanathan, 1998. The demand and the route interaction makes it a unique model from which a lot of models were extended. The objective of the model is to reduce the trip time of all vehicles including the travel time and the loading time leading to a better route for the stations considering the demand from each station. Apart from the objective function, the model has a limited number of constraints. The constraints include flow balance for all nodes, flow balance constraints for supermarket, trip continuity constraints and trip capacity constraints. Some of the assumptions while developing the model are usage rate is always equal to the production rate, the parts are always carried in bins or containers, the number of containers should always be an integer, all stations will be visited prohibiting the overlapping of the routes, one station can be visited by only one vehicle, demand rate is considered for calculating the number of bins, super market is always full, only one part is made for computational convenience and multiple vehicles can be allowed.(Vaidhyanathan, 1998)

The mathematical notations for the model are as follows,

Sets: N = Set of nodes

A = Set of arcs connecting the nodes

i,j = Node indices, i,j ∈ N

i=j=1

k = vehicle index

n = no. of nodes

k = no. of vehicles

$t_{i,j}$ = Travel time from i to j

d_j = Demand at node j

τ_k = Trip capacity of a vehicle k

l_j = Loading/unloading time per trip at j

$$x_{ijk} = \begin{cases} 1, & \text{vehicle k assigned to node i, j} \\ 0, & \text{otherwise} \end{cases}$$

Minimize: $Z = \sum_{k=1}^{K} \sum_{i=1}^{n} \sum_{j=1}^{n} t_{i,j} \cdot x_{ijk} + l_j \cdot x_{ijk}$ (1)

Constraints:

$$\sum_{j=1}^{n} \sum_{k=1}^{k} x_{ijk} = 1, \forall\ i = 2,3,..,n \quad (2)$$

$$\sum_{i=1}^{n} \sum_{k=1}^{k} x_{ijk} = 1, \forall\ j = 2,3,..,n \quad (3)$$

$$\sum_{j=2}^{n} x_{ijk} = 1, \forall\ k \quad (4)$$

$$\sum_{i=2}^{n} x_{ijk} = 1, \forall\ k \quad (5)$$

$$\sum_{j=1}^{n} (x_{ijk} - x_{jik}) = 0, \forall\ k,i \quad (6)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{k} (t_{i,j} + l_{j}) \cdot x_{ijk} \quad \sum_{i=1}^{n} \sum_{j=1}^{k} (d_{j} \cdot x_{ijk}) \leq \tau_k \quad (7)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{k} x_{ijk} \leq \tau_k + 1\ \forall\ k \quad (8)$$

The objective function involves two parts while the first part focuses on reducing the travel time and the second part on the loading time. Since loading/unloading is not going to make adverse impact on the model, it is neglected. Constraint 2 and 3 are the flow constraints for nodes following the conservation of flow with 1 node served by one vehicle. Constraints 4 and 5 are the flow balance constraints for supermarkets with K vehicles and at least one customer node. Constraint 6 is the trip continuity constraint with the vehicle coming in being equal to vehicle going out. Constraint 7 follows that trip capacity cannot exceed the trip time and demand rate. Finally, constraint 8 says that number of total nodes including supermarket should be less than or equal to trip capacity of the vehicle.

4.3 Model 2- Routing Of Single Route With Fixed Time Period

While the basic milk run model by Vaidhyanathan was covering the non-linear programming considering the trip time of the vehicles, this model focuses on single route with fixed time period. As like other milk run delivery models, the aim is to minimize the cost incurred with best possible route and higher efficiency following JIT practices. Three considerations are followed when designing single route models as all the routes cannot be designed. The three considerations are that the routes are not allowed to pass by the cells more than twice, related cells should have same number of pass by a vehicle and finally the routes should follow the physical conditions of the station layout. Some of the assumptions considered while designing the routes are that the vehicles are identical, breakdown of vehicles are impossible to occur, the associated cost and the vehicle speed remains the same throughout the process. The costs to be minimized are WIP, transportation cost and the fixed cost of the vehicles. The model assumptions include only part is taken from the supermarket to the stations, no overlapping of vehicles, one station is served by only one vehicle and the cost of vehicle is considered with fixed time. (Kilic & Durmusoglu, 2012)

The notations used for the model are listed below,

a,b	=	stock areas
r	=	route
t	=	time period
l_{ir}	=	loading time of stock point i in route r
vc	=	total cycle time(trip time + loading/unloading time)
C_r	=	Transportation cost of one cycle of route r
Y_{ar}	=	Binary variable determining the route of stock area ‘a’
V.cost	=	One vehicle cost
t_{fixed}	=	Determined time period
d_i	=	demand rate
ν_i	=	Volume of stock point I

Minimize: $Z = \sum_r route_r \times V.cost + \sum_r route_r \times C_r \times 24.60 / t_{fixed}$ (1)

Constraints:

$\sum_r X_{ir} = 1, \forall\, i = 2,3,..,n$ (2)

$X_{ir} = X_{jr}, \ \forall (i,j) \in B, \forall\, r$ (3)

$\sum_{i \in N} X = 0, \ \forall\, r$ (4)

$\sum_r Y_{ar} = 1, \ \forall\, a, a \in A$ (5)

$Y_{ar} = Y_{br}, \forall (a,b) \in C, \forall\, r$ (6)

$M. X_{ir} \geq D_{ir}, \ \forall\, i,r$ (7)

$M. X_{ir} \leq l_{ir}, \forall\, i,r$ (8)

$l_{ir} = D_{ir} . l_i \ \forall i,r$ (9)

$D_{ir} = t_{fixed} . D_i . X_{ir}$ (10)

$M. \ Y_{ar} \geq \sum_i X_{ir} . I \in N_a, \forall\, r,a$ (11)

$Veh.cycle_r = \sum_i l_{ir} + route_r, \forall\, r$ (12)

$Veh.cycle_r \leq t_{fixed}, \forall\, r$ (13)

$\sum_r route_r \leq max.vehicle$ (14)

$M. route_r \geq \sum_i X_{ir}, \forall\, r$ (15)

$M. route_r \geq D_{ir}, \ \forall\, i,r$ (16)

$M. route_r \geq l_{ir}, \forall\, i,r$ (17)

$\sum_{SS=1}^{S} \sum_i D_{ir} . v_i . Seq_{s,I} . Sign_i \leq Cap \ \forall\, r, s_r$ (18)

$X_{ir}, Y_{ar}, route_r \in (0,1) \ \forall\, r,a, s_r, i$ (19)

The objective function minimizes the number of vehicles and reduces the transportation cost and capital cost of one vehicle. The constraint 2 make sure that only one stock point is assigned to one node. The constraint 3 makes sure that related stock points are assigned to the same route. A stock point i is not assigned to the route r if it is not on the way of route according to the constraint 4. Each stock area is assigned to one route as per constraint 5. Constraint 6 makes sure that the related stock areas are assigned to the same route. The demand at stock point i=0 if it is not assigned in the same route according to constraint 7. The loading time of i will be equal to 0 if it is not assigned in the same route when constraint 8 is followed. According to constraint 9, the total loading and unloading time is always determined. Constraint 10 makes sure that the total demand in stock point i at the route r is always determined. All stock points are assigned to the same route according to constraint 11. Cycle time of vehicle (route) is determined and fixed from constraint 12 and 13. According to constraint 14, total number of vehicles in the route is restricted to upper limit (capacity). Constraint 15 make sure that stock point is not assigned to the unselected route. Demand and loading/unloading time is equal to 0 at unselected route according to the constraints 16 and 17. Capacity is controlled at each assignment of the material according to the constraint 18. Constraint 19 define the binary variables needed for the Optimization.

4.4 Model 3- Routing Of Multiple Routes With Multiple Vehicles

The model is based on determining multiple routes considering multiple vehicles to optimize the costs such as fixed and variable costs. Since the modeling is the same as one vehicle optimization, it is sufficient to only determine the decision variables for the model. The objective function and the constraints remain the same for the model with a small addition of number of vehicles into the decision variables. (Kilic & Durmusoglu, 2012)

The changes in the decision variables are,

X_{ikr} = Binary variable deciding whether the stock points i assigned to the K vehicle on the route r

D_{ikr} = one cycle demand for stock point i at vehicle k with route r

L_{ikr} = one cycle loading / unloading for stock point i at vehicle k with route r

Y_{akr} = Binary variable deciding whether the stock area assigned or not at vehicle k with route r

$Veh.route_{kr}$ = Binary variable deciding whether route r assigned to vehicle k

$Veh.route\ cycle_{kr}$ = total cycle time covered by route r with vehicle k

Veh_k = Binary variable deciding whether vehicle v is assigned or not

Except the changes in the decision variables, the model follows the exact constraints and objective as the routing of single route with fixed time period. Hence the model is omitted to ensure non-redundancy.

4.5 Model 4- Scheduling With Equal Cycle Time With Same Time Interval

The model is based on the scheduling of tow train models under the condition of equal cyclic time and same time interval (Kilic & Durmusoglu, 2013). Several assumptions are created for this model in order to create a feasible solution among the pool of solutions. The notations used for this model are listed below,

S_{ir} = Quantity of safety stock.

Z_{tr} = B.V time period

P = Ratio of the safety stock.

W_i = Monetary value of i.

tt_t = Number of time intervals in 't'

V_a = Volume of stock area 'a'

K_{max} = Maximum number of vehicles

f = Daily opportunity cost ratio.

The objective function of the model is to minimize the Work in progress and Demand as well as reduce the fixed cost and the vehicle cost of the total travel. The objective function along with the constraints are listed below.

Minimize: $Z = \sum_r \sum_i D_{ir} . W_i . f/2 + \sum_r \sum_i S_{ir} . W_i.f + \sum_r \sum_t C_r . Z_{tr} .(TWT/ C. tt_t. T_1) + \sum_r v\text{cost} .r$

Constraints:

$\sum_r X_{ir} = 1, \forall\ i = 2,3,..,n$ (2)

$\sum_r Y_{ar} = 1, \forall\ a, a \in A$ (3)

$\sum_{i \in N} X_{ir} = 0, \forall\ r$ (4)

$X_{ir} = X_{jr}, \forall (i,j) \in B, \forall\ r$ (5)

$M. X_{ir} \geq D_{ir}, \forall\ i,r$ (6)

$M. X_{ir} \leq l_{ir}, \forall\ i,r$ (7)

$M. X_{ir} \geq S_{ir}, \forall\ i,r$ (8)

$l_{ir} = D_{ir} . l_i\ \forall i,r$ (9)

$D_{ir} + M. (1 - X_{ir}) \geq Veh.cycle_r . d_i, \forall\ i,r$ (10)

$S_{ir} = D_{ir}. P, \forall\ i,r$ (11)

$\sum_r \sum_i (D_{ir} + S_{ir}). V_i \leq V_a, i \in N_a, v_a$ (12)

$M. Y_{ar} \geq \sum_i X_{ir}, \forall\ r, N_a, a$ (13)

$Y_{ar} = Y_{br}, \forall\ (a,b) \in c, \forall\ r$ (14)

$TI. tt_t - M (1 - Z_{tr}) \leq Veh.cycle_r, \forall\ r,t$ (15)

$TI. tt_t - M (1 - Z_{tr}) \leq Veh.cycle_r, \forall\ r,t$ (15)

$TI. tt_t + M (1 - Z_{tr}) \geq Veh.cycle_r, \forall\ r,t$ (16)

$\sum_t Z_{tr} \leq 1, , \forall\ r$ (17)

$\sum_t route_r = \sum_r \sum_t Z_{tr}$ (18)

$M. route_r \geq Z_{tr}, \forall\ r,t$ (19)

$M. route_r \geq \sum_i X_{ir}, \forall\ r$ (20)

$$\text{r. route}_r = \sum_i Z_{tr} \qquad (21)$$

$$\sum_r \text{route}_r = \text{veh. Number} \qquad (22)$$

$$\text{M. route}_r \geq \text{veh. Idle}_r \ \forall\ r \qquad (23)$$

$$\text{veh. Idle}_r \leq \text{Max. veh.idle}_r \qquad (24)$$

$$\text{M. route}_r \geq D_{ir,}\ \forall\ i,r \qquad (25)$$

$$\text{M. route}_r \geq S_{ir,}\ \forall\ i,r \qquad (26)$$

$$\text{M. route}_r \geq l_{ir,}\ \forall\ i,r \qquad (27)$$

$$\text{Veh.cycle}_r = \sum_i l_{ir} + \text{route}_r \,.\, \text{VT}_r + \text{veh.idle}_r\,,\ \forall\ r \qquad (28)$$

$$\sum_r Z_{tr} \leq \text{M.VV}_t \quad ,\forall\ t \qquad (29)$$

$$\sum_r \text{route}_r - \sum_r Z_{tr} \leq \text{M. (1- VV}_t)\ ,\ \forall\ t \qquad (30)$$

$$\sum_{SS=1}^{S} \sum_i D_{ir}\ .\ v_i\ .\ \text{Seq}_{s,I}\ .\ \text{Sign}_i \leq \text{Cap}\ \forall\ r,\ s_r \qquad (31)$$

$$X_{ir}\ ,\ Z_{tr}\ ,\ Y_{ar}\ ,\ \text{route}_r,\ \text{VV}_t\ \epsilon\ \{0,1\},\forall\ i,r,c,t \qquad (32)$$

The objective function of the model is divided into two parts. The first part is to have a reduced work in progress and safety stock. The second part of the objective function is to have minimum cost such as fixed cost of the vehicle and the vehicle transportation cost. Some of the constraints are same as the model explained above with an addition of few constraints for equal cycle time and interval. Constraint 2 makes sure that a route has at least one tow train and constraint 3 specifies that one stock point has at least a route. Constraint 4 makes sure that each stock area is assigned to one single route. Dependent stock points assigned to same route is specified by constraint 5. Constraint 6 makes sure that demand is zero if not assigned to the same route. Constraints 7 makes sure that safety stock is zero if not assigned to the same. Total loading/unloading cost is zero if not assigned to the same route is described under constraint 8. Total loading/unloading time is determined according to constraint 9. Demand is given by demand rate times the cycle time according to constraint 10. According to constraint 11, safety stock is given by ration P of demand at related stock point. Combination of demand volume and safety stock cannot be more than volume of the stock area is given by constraint 12. Constraint 13 makes sure that all the stock points are assigned to only one route. Constraints 14 and 15 makes sure that time period of chosen route is determined. Each route has utmost 1 period is determined by constraint 16. Constraint 17 restricts that number of chosen routes and time period are equal to one. Constraint 18 makes sure that time period is not assigned to the unselected route. Any stock cannot be randomly assigned to the unselected route. Constraint 19 makes sure that maximum a single time period is assigned to the selected route. Constraint 20 restricts the maximum number of vehicles. Idle time will be none for unselected route according to constraint 21. Constraint 22 restricts each vehicle's idle time to limited. No demand is assigned to the unselected route according to constraint 25. Constraint 26 makes sure that no safety stock is assigned to unselected route. No loading and unloading time assigned to the unselected route is restricted by constraint 27. Constraint 28 illustrates one tour cycle of the route consisting of idle time, loading/unloading time and fixed tour time. Total number of selected routes is zero or equal to routes assigned to related time period is determined by constraint 29 and 30. At each assignment of stock point I, capacity is controlled according to constraint 31. Constraint 32 are the decision variables.

4.6 Model 5- Scheduling And Optimal Loading Of Deliveries

The model is based on the optimal loading and scheduling of tow trains from the supermarket to the stations. It is similar to the models discussed in the previous cases with the combination of all the models. This model was adapted from Fathi et al,2014. The notations used for this model are listed below,

α = Importance coefficient for number of tours
β = Importance coefficient for inventory level
C_{it} = Inventory level of reference
RP_{it}= Replenishment rate of reference
τ_k= Capacity of tow train (volume)
τ_n= Capacity of correspondence station
Y_t= No. of tours

Objective function

Minimize: $Z = \alpha \,.\, \sum_{t=1}^{M} Y_t + \beta \,.\, \sum_{i}^{N} \sum_{t=1}^{M} C_{it}$ (1)

Constraints:

$\sum_{t=1}^{M} d_{it} \,.\, RP_{it} + C_{i0} \geq \sum_{t=1}^{M} d_{it}$, $\forall$ i=1,..,n (2)

$d_{it} \,.\, RP_{it} + C_{it-1} - d_{it} = C_{it} \quad \forall$ i,t=1,..,n (3)

$\sum_{i=1}^{n} d_{it} \,.\, RP_{it} \leq \tau_k \quad \forall$ i,t=1,..,n (4)

$d_{it} \,.\, RP_{it} + C_{it-1} \leq \tau_n$ (5)

$RP_{it} \leq RP_{max} \,.\, Y_t$, $\forall$ i,t=1,..,n (6)

$RP_{it} \in \{0, RP_{max}\}$ (7)

$a_{it} \geq 0$ (8)

$C_{it} \geq 0$ (9)

$Y_t \in \{0,1\}$ $\forall$ t=1,..,n (10)

The objective function of the model is classified into two parts. The first part deals with the reduction in the number of tours and the second part deals with the minimization of the inventory level and the cost associated with it. Constraint 2 restricts that total quantity is equal to the total demand. Constraint 3 makes sure that no stock out occurs in any tour.

Total number of bins does not exceed the capacity of tow trains is determined by constraint 4. Constraint 5 makes sure that the number of bins and the additional available inventory should be less than or equal to the capacity of the station. Any bin can be delivered if the tour does not exist is constrained by constraint 6. Constraints 6, 7, 8 and 9 determines the domain of variables.

4.7 Choi And Lee Dynamic Part Feeding

The thesis deals about dynamic part feeding system where the amount of part required by the stations are determined dynamically than in a static nature. A mixed integer model is created with the corresponding constraints for the dynamic part feeding system. The situation when the model is created includes mixed model assembly line with single warehouse and a limited carrying capacity of the tow trains. The problem associated with the setup can be divided into two categories: the amount of parts, identifying them and assigning a route for the tow trains with the respective parts. A hypothetical model is assumed in reference to the previously discussed models with dynamic part feeding. Since only a heuristic approach is possible, the model is not created.

4.8 Consolidation Of The Models And Inference

All the models listed in the third chapter are consolidated into a table. Table 2 shows the differences in the models in a brief way for the readers to understand without any complications.

Table 2. *Consolidation Table*

Model/Parameters	JITCVRP	Single route and fixed time period	Multiple route	Equal cycle time	Optimal loading	Dynamic part feeding
Objective	Travel time reduction	Reduces cost	Reduces cost	Reduces cost and inventory reduction	Reduction in No. of tours and inventory	Identify parts and assigning feeding orders
Flow balance constraint	✓	✓	✓	✓	✓	✓

Trip continuity	✓					
Non-overlapping		✓	✓	✓	✓	✓
One station one vehicle		✓	✓	✓		
One vehicle			✓			
Model/Parameters	JITCVRP	Single route and fixed time period	Multiple route	Equal cyclic time with safety stock	Loading and unloading	Dynamic part feeding
Multiple route			✓			✓
Mixed model assembly			✓	✓		✓
Bin capacity					✓	

Inventory and average part feeding length constraint						✓

From the above table it is inferred that, every model has its own parameters solving problems in a different way. The summary of the chapter is that, all the models are normalized by modifying slight changes to the notations and redoing certain constraints in a different manner to be understandable. Each model is followed by an added constraint of the following model providing lead for the readers. With the implementation of these models as a result of supermarket installation and optimizing through Mixed Integer Linear Programming, the part quantity in the inventory will have to be altered. If the warehouse inventory reduces, the suppliers have to react to the change because of the JIT basis mode of part delivery to the station. In the next chapter, the procurement optimization for supply of parts is extensively discussed with different level of constraints from OEM and suppliers.

The models normalized will act as a catalyst in determining the quantity of parts needed on the assembly station. Once the number of parts are determined per time period, the amount of parts to be ordered from the suppliers becomes easy. Going forward the additional inventory stocked which incurs the inventory holding cost is reduced. But the supply of parts has to be re-organized in order to have minimum inventory. Procurement optimization has to be revisited on matching the demand. Supplier selection is one of the crucial things to have proper timely delivery of the parts considering the JIT and supermarket based demand. A single supplier would not serve the purpose instead a co-opetition between the suppliers is required. The second half of the thesis will cover the supplier selection and the constraints involved in each lane to back the first half.

5. PROCUREMENT PLANNING AFTER OPTMIZATION

5.1 Procurement Optimization

When a company tries to buy products, the procurement department is in charge of getting the best deal according to the requirements. As we discuss about procurement optimization the best thing in closed proximity would be the lowest cost. It means that when the company is trying to get the best deal which is the lowest cost, the optimization should be done considering even the small disturbance to the flow. But nowadays the companies do not just have one objective of getting the deal of lowest cost but also other factors such as services and social goals. So, choosing a right supplier for parts depends upon the services provided, flexibility and the efficiency under uncertain conditions (Beskese & Sakra, 2010). There will be different type of procurement bids done when selecting the suppliers. The different types include simple bids and combinatorial bids. The simple bids are when three or less parties involved and the routes are primarily divided to all the parties involved. The one providing the best quote would get the auction. But when it comes to combinatorial bids, there are different constraints involved starting with supplier, capacity constraints and services such as minimum volume, volume discounts and minimum dollar discounts. The suppliers would fight for the best combination of routes to the customer with the least price. (BCG, 2004)

With the implementation of part logistics optimization for automobile production assembly, the whole of the supplier auction process and the procurement optimization has to be reanalyzed to make the changes. This change after the routing and schedule will have adverse changes in the demand and inventory management thus leading to lack of information flow and increase in the chances of variability causing bullwhip effect. When there is big gap between the number ordered by the customer and the amount of delivery done by the supplier, the whole system incurs a huge sum which will eventually hit the customer price for the product. This will lead to loss of market position held by the company.

The rest of the chapter moves on with the action of constraints on the procurement optimization model before the part logistic optimization and the changes experienced after the part logistic optimization. Different types of constraints will be discussed in detail with each case focusing on a single service or social goal in combination with the cost. The whole optimization is done based on Mixed Integer linear programming. The optimization for both before and after part logistic optimization is done using Excel solver.

5.2 Optimization Before Part Logistic Implementation

The supplier selection is one of the important process in reducing the customer price of the product. As it all begins with the supplier providing the right amount of parts in the right time at the right place, the production flow can be smooth enough to produce the parts on time and make it possible for the distribution planning team to deliver the products on or before the delivery time. It is not just important in B2C sector, but it is also a serious issue with respect to Business to Business domain (Golini & Kachschmidt, 2010). The reason being that in the B2B world, a customer is a supplier for another business and vice versa. So, if a supplier of raw materials fails to keep up with the down-stream value chain, then the whole process gets out of hands leading to customer dissatisfaction. The three flows such as physical, financial and the information flows should be properly maintained to avoid uncertain conditions (Sweeney, 2006)

Before the part logistics optimization is even done, the automobile production assembly was not efficient enough to reduce the in-house transport and inventory costs. The procurement process is done based on the requirements from the warehouse. The case discussed below is an assumption to prove the difference in the cost involved before and after optimization. There are three different production assemblies with attached warehouses to move the parts from warehouse to the super market and to the assembly stations. The transport of parts from one warehouse to the other two warehouses are done by two different types of carriers. The flow also includes the reverse flow of pallets and the damaged parts. Each warehouse is considered a supplier of parts. The three warehouses are assumed to have flows from each other and the part supply to the warehouses are not considered for this explanation but integrating them would smoothen the flow even more. The cost of transportation from one warehouse to other and all other ways are shown in the table 3 below.

Table 3. *Transportation cost for each load*

	Transportation cost			Capacity		
Lanes	I	I also	II	I	I also	II
A→B	520	500	525	5	100	8
B→C	470	460	475	5	100	4
C→A	500	480	525	5	100	3
C→B	525	510	500	5	100	100

The table shows the type of lanes starting with A and transporting the parts to B which costs 520$ for I carrier and 525$ for II carrier. There is another column I also which describes the discounted cost of transportation of I carrier when there is more than the normal capacity. The second table describes the capacity of each carrier on each lane. When the carrier I exceeds 5 loads, then it can pay only 500$ for the next 100 loads.

5.2.1 Procurement Optimization Without Special Constraints

Before optimization, the suppliers are selected based on the straight forward solution without any irregular constraints. For the simple explanation of this case, only two suppliers are selected. The cost on each lane and the respective capacity are explained in table 4 below.

Table 4. *Straight forward data*

Lanes	Capacity		Cost	
	I	II	I	II
A→B	10	10	500	525
B→C	10	10	500	475
C→A	10	10	500	525
C→B	10	10	475	500

The objective is to find the number of loads carried by each supplier on each lane. A normal mixed integer linear programming is carried out. The objective function is to minimize the cost. The constraints included are listed below,

- Non-negativity constraints
- Integer constraints
- Each lane can be carried with only 10 loads

The mixed integer linear programming is solved in excel with the solver tool. After the optimization is done with the listed constraints, the cost of transporting the goods equals to 19500. The load allocation is listed below in the table 5,

Table 5. *Results*

Lanes	I	II	Sum
A→B	10	0	10
B→C	0	10	10
C→A	10	0	10
C→B	10	0	10
Sum	30	10	

From the table it is observed that, the loads are greater than zero, does not contain any non-integer values and each lane all together combining the two suppliers does not exceed 10. Before adding the constraints, there were lot of losses in the form of excess loads leading to a cost of 40,000 which is double the amount of optimized cost. Once a number of constraints starts getting involved, the cost will surge provided the level of service is met. The optimization explained is simple yet a complex situation involving two suppliers with minimum constraints applied before the OEM optimization. Once the OEM optimization is done, the OEM will expect a little inventory from the suppliers but a quick one making transition from FTL to LTL and many logistic changes.

5.2.2 Procurement Optimization with Volume Discount Constraint

There are different special constraints associated with automobile part supply. Since most of the procured parts have a longer shelf life, the parts are procured in bulk which increases the buyer power. Apart from the shelf life of the products, the design of the parts does not change over time frequently which again leads to a higher buyer power. This in turn helps the buyers to make lot of negotiations with the suppliers. All these negotiations at the end are shaped in the form of constraints in the Mixed Integer Linear programming for cost optimization. The type of constraints depends upon the requirement of parts in quantity by the automobile production assembly. It solely depends upon the number of cars being assembled in the assembly station and the number of stations.

The type of constraint being looked upon is volume discount which means that whenever a buyer orders more than the specified quantity of parts, each part beyond the saturation limit will be given with a minimal discount. This has a disadvantage in the form of stoking up of inventory. Since the auto parts are not easily damaged excluding the uncertain conditions, it is wise to buy the parts in bulk. In doing so, the supplier will also be benefited as he gets to transport with Full Truck Load (FTL).

Table 6. *Capacity constraints*

Lanes	Capacity		
	I	I also	II
A→B	5	100	8
B→C	5	100	4
C→A	5	100	3
C→B	5	100	100

As you can see from the table 6, until the capacity of 5 loads the supplier will charge a certain amount of price to the OEM. After the 5^{th} load, until 100 loads the supplier will charge only a less amount giving a discount to the customer for buying more as it reduces the transportation as well as the operations cost. The constraint used to follow the rules are explained below,

For carrier on a lane: [Break – Expensive flow] x Cheap flow = 0

To explain this, let us assume from A to B lane supplier I gives a discount of 10$ after 5 loads. The capacity transported by supplier are 10 loads and the new capacity is 10. By using the formula,

$$(5-10)*10 = 0 \to -50=0$$

This forces the constraint to use the upper limit first and then go to the “I also” capacity and calculating the price according to the loads. After using this formula in the solver, the objective function results in an effective cost optimization of 39050 USD. In the following table 7, the number of loads carried by each supplier on each lane is listed.

Table 7. *Final loads after optimization*

Lanes	I	I ALSO	II	Sum	Need
A→B	5	15	0	20	20
B→C	5	15	0	20	20
C→A	5	15	0	20	20
C→B	0	0	20	20	20
Sum	15	45	20		
Objective Value		39050			

Surprisingly this leads to decrease in the cost of the objective function because a constraint is put on to hold the smooth flow of the equation disturbing the normal process.

5.2.3 Procurement Optimization with Level of Service Constraint

This constraint deals with the level of service provided by the supplier. When a supplier transports the parts with 100% level of service, it means that there will be no defects and damage in the parts. This is highly impossible for any supplier in the world as natural and uncertain conditions leads to damage of the products. Hence the reason, none of the suppliers commit to provide 100% level of service and to normalize and control the defects the system attribute constraint was developed. The level of service constraint contains a base percentage where the other percentages will be validated. For each percentage deviation from the base percentage there will be a cost associated with it. Let us consider that the base percentage is 94 and cost could be 10$ for each percentage deviation. For example, if lane A to B provides 92% at a cost of 500$ then the cost of each load would amount to 520$ which is an increase of 20$. The value is then used to calculate the objective function. For the given problem, the following percentages are used.

Table 8. *Level of service percentage table*

Level of Service Percentage			
Lanes	I	I Also	II
A→B	97	95	98
B→C	92	88	88
C→A	90	95	90
C→B	90	85	91

From the above table 8, it is inferred that, each supplier provides different level of service to each lane. The base percentage for normalization is 92% and each percentage level of service will cost 10$.

Using the calculation, the modified prices are found in the below table 9 along the original cost.

Table 9. *Original transportation cost vs. LOS cost*

Lanes	I	I also	II
A→B	520	500	525
B→C	470	460	475
C→A	500	480	525
C→B	525	510	500

Lanes	I	I also	II
A→B	470	470	465
B→C	470	500	525
C→A	520	450	545
C→B	545	440	510

Once the level of service cost is calculated then the problem becomes easier as it is the same with the above constraint. It is calculated in such a way that if the percentage level is low compared to the Level of service provided by the supplier then the cost would increase and it is vice versa if the percentage level is high. The problem now includes both the volume discount constraint as well as level of service constraint. The constraints used for finding the objective function is listed below,

- Non-negativity constraints
- Integer constraints
- Each lane can be carried with only 20 loads
- Volume discount constraint
- Level of service constraint

After solving the problem by mentioning the objective function and variables, the number of loads are determined below from the solver.

Table 10. *Final result of loads*

Lanes	I	I ALSO	II	Sum	Need
A→B	5	8	7	20	20
B→C	5	15	0	20	20
C→A	5	15	0	20	20
C→B	5	15	0	20	20
Sum	20	53	7		
Objective value		37890			
Real objective value		**39500**			

The above table 10 lists the number of loads carried on each lane by the suppliers. The objective function value is \$ 37890. It is higher than the estimated amount because of the level of service provided by each supplier. There is a decrement in the objective function value because for each and every case the constraints are being added which results in the cost decrement. There are certain cases where the Level of service is not appropriate as the supplier might use less quality materials and poor transportation leading to more damage and eventually poor level of service. In this case, the real objective function value is

39500 which is obtained by having a sum product of original transportation cost and the number of loads. The modified cost of transportation is used for finding out the number of loads on each lane by the suppliers.

5.2.4 Procurement Optimization with Supplier Constraint

Most of the suppliers try to maximize the capacity utilization whenever a truck load is confirmed with the OEMs. Since most of the procured parts in the auto industry are run by the milk run operations, the supplier will try to utilize the lanes and load maximum number of parts until it reaches the threshold. Supplier bidding is also dependent on the maximum space utilized as these trucks will charge less when compared with the Less than Truck Load (LTL) trucks.

The supplier constraint is created on basis of the number of loads carried on all the lanes by a single supplier. If the OEM realizes that the supplier is flexible in transporting the parts, then that supplier with less cost and high flexibility will get the bid. The supplier constraint makes sure that the load carried by each supplier on all the lanes is less than the capacity of the supplier put together on all the lanes. In this way, the OEM can decide whether to select the supplier or not as there will be lot of suppliers waiting to take the chance. The following table 11 lists the supplier constraints.

Table 11. *Supplier constraints*

Capacity			
Lanes	I	I also	II
A→B	5	100	8
B→C	5	100	4
C→A	5	100	3
C→B	5	100	100
SUM	20	400	115

From the above table it is inferred that, the sum of all the loads by each supplier on all the lanes makes the supplier constraint. Adding this constraint to the solver model along with the other two constraints such as volume discounts and level of service, the objective function would give a lesser value when compared to the other two models. The following model results in the table 12 as below,

Table 12. *Results table*

Lanes	I	I ALSO	II	Sum	Need
A→B	0	0	20	20	20
B→C	5	15	0	20	20
C→A	5	15	0	20	20
C→B	5	15	0	20	20
Sum	15	45	20		
Objective value		**37825**			

From the above table it is inferred that the objective function value is $ 37825. The model follows the supplier constraint which results in even lower cost of objective value. Now the model is being constrained to follow only the total sum of loads by each supplier and not on individual lanes. In this case, the supplier constraint on each lane is ignored.

5.2.5 Procurement Optimization with Minimum Dollar Constraint

There are cases where the OEM or the supplier will set a minimum dollar volume constraint agreement between the two parties. When a supplier is transporting goods across different lanes with expensive goods, the supplier would set a minimum dollar volume so that the profit is attained on top of the cost incurred. Either volume discounts or minimum dollar volume is a way to mitigate the costs involved and attain profit. With the increasing amount of auto part suppliers, the OEM takes advantage of surplus number and try to have minimum transportation cost as possible. The minimum dollar constraint is very simple as it is similar to the capacity or demand constraint. The supplier will quote a minimum value of goods to be transported comprising of the loads from all the lanes. The loads should be optimized in such a way that sum product of the loads and the cost should greater than or equal to the cost quoted by the supplier. The loads along with the minimum value is listed in the table 13below.

Table 13. *Minimum dollar value*

	Capacity		
Lanes	I	I also	II
A→B	5	100	8
B→C	5	100	4
C→A	5	100	3
C→B	5	100	100
Sum	20	400	115
Min dollar	6000	18000	8000

The minimum dollar amount is the value quoted by the supplier during the bidding process. The following table lists the number of loads transported after the optimization with the all the constraints discussed so far along with the minimum dollar value constraint.

Table 14. *Results table*

Lanes	I	I ALSO	II	Sum	Need
A→B	0	0	20	20	20
B→C	5	15	0	20	20
C→A	5	15	0	20	20
C→B	5	15	0	20	20
Sum	15	45	20		
Min dollar	7675	20850	9300		
Objective value	**37825**				

As you can see from table 14, the actual cost of transportation is lesser than or equal to the quoted value by the customers. This again decreases the cost in the optimization table to $ 37825 as a constraint was added to the solver. The more there are constraints, the cost of optimization will become lower.

5.3 Procurement Optimization After Part Logistic Implementation

The Mixed Integer Linear Programming for procurement optimization of supplier selection with different constraints were discussed in the previous chapter. The previous chapter also involved procurement optimization before part logistic implementation. Once the supermarket is installed and the tow-trains run under predetermined schedule and routes, the parts needed in the warehouse will be minimum because of the JIT part arrival to the stations. Once the parts move out of the warehouse, unlike in the past the parts do not sit on as inventory in the station. Instead the parts are temporarily stored in supermarket for a limited period and then they are taken from the supermarket to the respective stations.

Due to the reduction of parts in transit, the inventory management should be adjusted to encounter the high supply of goods. On the other hand, the suppliers keep on stocking with the usual amount of parts which again adds the inventory level leading to the higher probability of loss due to damage. The following sub-divisions deals with the procurement optimization for supplier selection after the changes inside the OEM assembly station. The same constraints when doing optimization before part logistics implementation are considered and the problems the suppliers will face with each constraint are briefly discussed.

5.3.1 Procurement Optimization with Volume Discount Constraint

This type of constraint is considered to be a system attribute constraint. This is one of the main constraint which gets hit badly as a result of in-house optimization. The main theme of this study is to reduce the bulk storage of parts in the warehouse leading to less damage and increased production process. All these simple things done in the supply chain will abruptly have an effect on the price the customer pays to buy an automobile irrespective of the type of vehicle. Once these flaws become impeccable without any delay and the supply chain process being visible and transparent to all the parties in the chain, the customer will end up paying 70 to 85% of what is being paid now.

Considering the importance of JIT part supply, an OEM should carefully buy the safety stock. This constraint would make sense for safety stock and hence the supplier has to do drop the volume discount to win the bidding process. The new reduced volume discount which should be quoted by suppliers are listed below,

Table 15. *New volume discount*

Lanes	Capacity		
	I	I also	II
A→B	8	100	7
B→C	8	100	3
C→A	8	100	2
C→B	8	100	100

With the new values in the table 15, the objective function is identified by implementing the constraints on the solver. The new values are blocked in yellow color to do a comparison with the previous version of the model. The constraints include,

- Non-negativity constraints
- Integer constraints
- Each lane can be carried with only 15 loads
- Volume discount constraint

Table 16. *Results table*

Lanes	I	I ALSO	II	Sum	Need
A→B	8	7	0	15	15
B→C	8	7	0	15	15
C→A	8	7	0	15	15
C→B	0	0	15	15	15
Sum	24	21	15		
Objective Value		29500			

From table 16, the objective function value is found to be $ 29500 which is lesser to the value obtained from the pre-part logistics implementation in the OEM. If this constraint has to be included, the supplier and OEM must think of a longer contract rather than storing the parts only for uncertain conditions.

5.3.2 Procurement Optimization with Level of Service Constraint

JIT part logistics directly affects the level of service provided by the suppliers. It is because the expectations from the suppliers are very high to leverage the service. This amplifies the pressure on the suppliers leading to increment in the standard of level of service. It was 92 percent before the JIT implementation but after the modification in the assembly station the percentage level would increase which forces the suppliers to increase or change their level of service. There is an increase in the level of service because the damage in the delivery of parts should be very minimum as the inspection should be done by the suppliers and they would pay a huge amount of penalty if there is any damage. In cases such as Just in Sequence, there should be almost close to 98 to 100 percentage as the parts such as seat and engine mounting will move directly from the supplier vehicle to the assembly station through the conveyor. In this case it is only the tow-trains which moves the parts from warehouse to the supermarket. The following table 17 describes the change in the percentage level after modification in the standard base level of service. This change breaks the stereotype in usual supplier bidding process as the criteria has changed and the only genuine suppliers can survive to get the contract.

Table 17. *Modified LOS percentage*

Level of Service Percentage			
Lanes	I	I Also	II
A→B	97	95	98
B→C	92	88	88
C→A	90	95	90
C→B	90	85	91

The standard LOS percentage has changed to 96 percent which is a direct hit to the suppliers who gave low level of service. They can either have the same level of service and get paid with less amount or increase their LOS. The former idea will lead to chaos as both the parties will be affected. The following table 18 describes the change in the price level with the modified standard LOS.

Table 18. *Modified cost of transportation*

Modified Transportation cost			
Lanes	I	I also	II
A→B	510	510	505
B→C	510	540	555
C→A	560	490	585
C→B	585	620	550

Since the percentage level in each lane has changed, the price level will also be changed due to the constraint. This will lead to a major change in the objective function value leading to change in the supplier compared to the previous scenario. Now the Mixed Integer Linear Programming is done again with the same method as done before for pre-part logistics implementation. The constraints considered in this MILP are,

- Non-negativity constraints
- Integer constraints
- Each lane can be carried with only 15 loads
- Volume discount constraint
- Level of service constraint

With the new restriction on the number of loads carried in each lane and the modified. The number of loads by each supplier in each lane is described in the table 19 below.

Table 19. *Results table*

Lanes	I	I ALSO	II	Sum	Need
A→B	5	2	8	15	15
B→C	5	10	0	15	15
C→A	5	10	0	15	15
C→B	0	0	15	15	15
Sum	15	22	23		
Objective value		31510			

After the model is inputted in the solver, the objective function value is changed to \$31510 and it makes sense that the price level has decreased but the level of service has increased. It provides indirect savings in the form of less damage and less time which actually increases the production level with limited resource. It is to be noted that this has a direct impact on the supplier bidding process as the standards have been raised. When compared with the previous objective value, there is a huge margin because of supermarket installation.

5.3.3 Procurement Optimization with Supplier Constraint

The suppliers will have to be aware of the lane selection and the number of loads being transported as the truck will be over loaded or it will change from Full Truck Load to Less than Truck Load. The supplier selection process also depends on the loads supplied for the entire year or the time frame quoted by the OEM. Once the demand from the OEM changes, the supplier should reduce the minimum total load carried on all the lanes. If it is not reduced, the supplier might end up losing the contract or end up paying higher price. In this case the supplier capacity reduced to 80% which is assumed to solve the optimization process. The new capacity constraint by each supplier is listed in the table 20.

Table 20. *New supplier constraint table*

	Capacity		
Lanes	I	I also	II
A→B	8	100	7
B→C	8	100	3
C→A	8	100	2
C→B	8	100	100
Sum	32	400	112

As the total sum is reduced, the objective function is again calculated with the new values quoted by the suppliers. The OEM in this case sets the minimum loads carried by each supplier as the buyer power increases due to decreasing demand. If the supplier doesn't comply by the number quoted by OEM then the supplier will lose the contract. The supplier constraint is implemented on the solver and the results of the optimization is listed with the new loads carried by each supplier on all the lanes.

Table 21. *Results table*

Lanes	I	I ALSO	II	Sum	Need
A→B	0	0	15	15	15
B→C	8	7	0	15	15
C→A	8	7	0	15	15
C→B	0	0	15	15	15
Sum	16	14	30		
Objective value		31595			

As you can see from the table 21, there is a difference in all the loads and the objective function value which leads to new criteria for supplier selection process. The objective function value has reduced because of the optimization done in the assembly station eventually the warehouse leading to change. There are high chances that most of the trucks will be running under LTL conditions. It means that the suppliers should adopt new technology to mitigate the new space constraint. The technological innovations for reducing the wastage are discussed in the next chapter.

5.3.4 Procurement Optimization with Minimum Dollar Constraint

From the assembly station I visited, there was not much of a price difference with respect to the variations in the optimization or changes done to the assembly station. Only the number of loads are going to change with the optimization. But with respect to the suppliers, the minimum dollar value will change because of the decrement in the number of loads. This is yet another disadvantage for the suppliers because the revenue is minimized. There are certain suppliers who strive to provide the parts with no profit and no loss. Those suppliers are a major threat to the ones who are not willing to sacrifice revenue under these conditions. Considering the same conditions as in the previous constraint on level supplier capacity, the minimum dollar value constraint is added to the pipeline. The number of constraints considered in determining the objective function are,

- Non-negativity constraints
- Integer constraints
- Each lane can be carried with only 15 loads
- Volume discount constraint
- Level of service constraint
- Supplier constraint
- Minimum dollar constraint

These constraints are inputted on the excel solver. The new minimum dollar value quoted by the suppliers are listed in the table below along with the capacity of each supplier.

Table 22. *New minimum dollar constraint*

	Capacity		
Lanes	I	I also	II
A→B	8	100	7
B→C	8	100	3
C→A	8	100	2
C→B	8	100	100
Sum	32	400	112
Min dollar	10000	8000	6000

The minimum dollar values for each supplier changes after the supermarket installation. With the new values and an added constraint, the problem is solved for limited number of stocks. The results are shown in the table 23 below,

Table 23. *Results*

Lanes	I	I ALSO	II	Sum	Need
A→B	0	0	15	15	15
B→C	8	7	0	15	15
C→A	8	7	0	15	15
C→B	8	2	5	15	15
Sum	24	16	20		
Min doll	13240	8450	10325		
Objective value		**32015**			

The results show that the there is a decrease in the objective function value. From the results it is understood that the revenue of the suppliers gets reduced due to the optimization of the assembly station. This can be mitigated only by the suppliers on optimizing their routes and all the other operations in general. Although OEM saves money and time in receiving the parts, the suppliers will be badly hit if they are given orders in a short time frame with modifications in the number of parts. The supplier industry will not allow these transformations immediately as it affects the revenue stream of the suppliers. If there are ways to improve the supplier visibility across the supply chain, OEM will understand the problems faced by suppliers. This can lead to being in harmony with suppliers and the solution can be gradually implemented. To reduce the penalty when parts are not delivered on time, suppliers should inform the OEM ahead of the delivery. This can happen only when both the parties know the location and status of the consignment. There are lot of third party companies providing real time asset monitoring services which can also be integrated into the ERP of both suppliers and OEM on a bigger scale. The next chapter describes the problems faced by automobile industry and the methodological implementation of integrating real time asset monitoring solutions in the automobile supply chain.

6. METHODOLOGICAL IMPLEMENTATION WITH EVALUATION AND DISUCSSION

In the previous chapters the procurement optimization for supplier selection or the procurement strategy of suppliers was seen as an effect of supermarket installation on the assembly station. Both the procurement strategies before and after the supermarket installation gave different results. This shows that the traditional culture of storing inventory in the form of safety and cycle stock is decreasing. On the other hand, the importance of JIT basis lean manufacturing practice started to raise as it gives less wastage and more savings on cost during the supply chain process. This directly increases the production efficiency in the assembly station as this practice provides visibility and transparency across the entire supply chain. The implementation of supermarket will eventually lead to less number of inventory in the warehouse. Limited inventory stocking means the suppliers need to provide only the required number of parts. This also means that the suppliers should not bring the damaged parts to the assembly stations leading to huge penalty to the OEMs. This problem of predictive analysis is solved by placing real time asset monitoring devices on each asset if needed. This brings total visibility and transparency through the real-time alerts and advanced journey planning solutions.

However, every action has its own consequences when adopting from the current system to a new system. There might be people who refuse to accept the system. There are certain rules and regulations which were followed for decades but it has to be formed from the scratch. It is to be noted that Indian government launched a new tax regime called Goods and Service Tax (GST) which is the centralization of all taxes to eliminate all kinds of indirect taxes (MastersIndia, 2017). With this new reform, the demo cars which were used for marketing and testing purposes are not considered to be capital goods and will have the same tax as the normal cars used for selling. Incentives provided by the dealers like free insurance, free accessories and warranties will be taxable in this new regime. This lead to chaos in the industry on whether to adapt this as a marketing strategy or not. Overall, the automobile industry is very fragile and hence the parties involved in the supply chain has to be aware of the problems and legal issues in manufacturing and transporting the parts. The buyers in this case (OEM) have full power over the supply chain. This chapter revolves around the problems faced by the automotive supply chain in a brief manner and the solutions to mitigate the problems. This chapter was needed as it is vital to know about the current problems before and after procurement optimization as some constraints will not even solve the core problem in the chain.

6.1 Problems faced by OEM and Suppliers in the Automotive Supply chain

Even after the revision of rules and new system adaptation in the industry, problems exist in the supply of parts to the OEMs. This is mainly due to the communication mishandling eventually leading to invisibility in the supply chain. A supplier is allotted a time to deliver the parts in the assembly station. Either the suppliers come in advance and wait for their slot to become available or they come late due to uncertainties which is uninformed most of the times. In the former case, the trucks cover up the space leading to chaos and delay in the delivery of all the trucks. In the later one, the suppliers do not inform the OEM because the OEM would search for alternative measures and the supplier will have to pay the penalty. But if it is uninformed, the suppliers will still pay the penalty but at the advent of delivering the parts to the assembly station. In both the cases although the suppliers get affected there is a huge loss to the OEM as it delays the assembly process and delay is converted into the customer price which is unnecessary. (Inspirage, 2016)

There are many suppliers located around the main assembly plant which is considered to be the periphery of the suppliers. Location is of utmost importance whenever the parts are needed in JIT basis. However, Suppliers in close proximity to the OEMs can only supply to one OEM which none of the suppliers are willing to do. This is very advantageous to OEMs as they will never run out of stock. But this is not possible for any supplier as they will also try to sell their parts to other OEMs. Audi has strategically partnered with DHL to provide parts on a JIT basis.

An important challenge faced by the automotive companies is the sheer amount of recalls in response to the detected defects and failures. Despite the fact that the company losses revenue, the more serious things to be considered is the passenger safety. Sometimes the entire supply chain has to be remodified in order to reduce the defects. This poses higher expectations on the suppliers to provide defect free parts. Yet another problem with the Tier 1 suppliers is that the demand is not stable like the Tier 2 suppliers as quantities will be ordered in bulk. Due to the changing customer preferences and higher expectations on the automobile manufacturers, the demand become volatile for which the companies should react fast and economically.

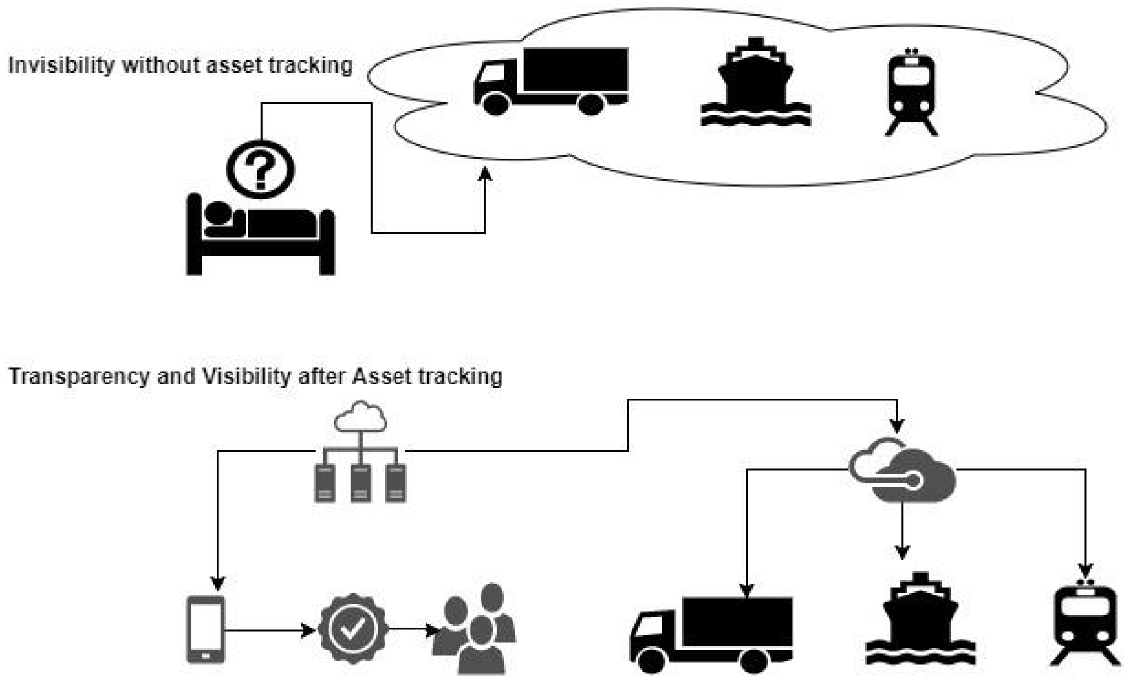
6.2 Implementation Of Real Time Asset Monitoring Solutions

Part logistics is one of the imperative aspects in the entire automotive supply chain. To make it efficient, it is not just possible by optimizing the supply chain rather a new thinking in the form of adopting technologies should be put into existence. An IoT based platform for communicating within the ERPs should be followed on all tiers of supply chain instead of just big players communicating with each other. In this way, even a tier 3 supplier will know the demand from the front end which is the customer side. Overstocking and out of stock problems were inevitable, but with IOT it is possible to make the changes (Tech Mahindra, 2017). One of the other major problem is sheer recalling of cars which is not new to the automobile manufacturers but it still creates an uncertain situation. Although the companies are trying to solve and reduce the recalling process, it is prevalent because of the glitches present in the supply chain which becomes untraceable. The possible solution to bring visibility and transparency in the supply chain is by performing IOT based transactions rather than communicating over phone or emails which certain industries started considering as obsolete process.

This brings us to the light of introducing IoT into the supply chain. One possible way is to monitor the assets remotely so that the company anticipate and react to any uncertainties. There have been improvements in the asset monitoring innovations in the industry. Many companies have used technology as a platform to enhance the supply solutions. The big players in the industry should adopt these inventions to improve the supply chain by having visibility on their products (ARC Insights, 2014).

The customers of these asset monitoring can be end user companies, 3PL companies, small transport providers, warehousing companies, suppliers, consumers who are concerned about their products. If the products are anticipated in advance, the capacity and the utilization of the facilities will be maximum. To anticipate the products, real time monitoring and tracking of the products is vital for the companies. This brings the companies one step closer in supplier relationships and brings transparency to the supply chain.

Figure 3. *Asset monitoring function providing visibility*



The above figure pictorially represents the advantages of asset tracking providing visibility to the stakeholders. These asset monitoring devices track each consignment in the truck and communicate about the status to the users. The device alerts the users whenever the truck is stuck in the traffic, face any accidents, consignments move in a different direction and any other uncertain scenarios apart from the ones stated by the users. The users receive notifications whenever the truck reaches a docking station or generally transit points during the entire journey. Route planning can also be optimized if there are constant delays in certain areas in the regular route.

The salient features of the asset monitoring devices are listed below,

- GPS/GSM based tracking of the assets
- Real Monitoring temperature and humidity
- Providing SOS alerts whenever the products face any uncertainty in transit and storage
- Track multiple assets in one shot using computer maps
- Alert drivers and owners of assets as per the need through SMS and web portal/Apps.

Some of the use cases of asset monitoring solutions in the automobile industry include,

1) Preventing unnecessary stock up of parts in the super market
2) Providing a clear visibility on the health of parts
3) Avoiding damage of parts during loading and unloading of parts
4) Controlling the power supply of various equipments by integrating artificial intelligence
5) Providing security during transit in the form of smart locks connected to the IoT gateway
6) Unit level monitoring of parts inside the assembly station using BLE devices connected to gateway. This is specifically helpful for OEMs having mixed model assembly lines.

Thus, to improvise the part logistic supply chain, asset monitoring devices shall be installed in order to have visibility and transparency across the supply chain. This reduces the waiting time of suppliers in the docking station and reduces the time in pickup of parts during milk run operations.

6.3 Evaluation And Discussion

The problems and solutions mentioned in the previous chapter are in correlation with the supermarket installations in the assembly station. The methodological implementation can be categorized into two stages. This section also explains the research questions mentioned in the beginning of thesis.

How does the effective utilization of Tow trains help in minimizing the inventory (safety and cycle stock) through proper scheduling and routing?

First stage is the implementation of supermarket which involves executing the routing and scheduling models discussed in the third chapter. In this way, the number of parts in the assembly station can be drastically reduced. The evaluation criteria for this stage is to analyze the free space and the employee comfort in working around the assembly station. The tow trains are allocated based on the need from the assembly stations. The consolidated routing and scheduling models ensures the timely arrival of tow trains from the supermarket. Cycle stock level is reduced because of the correct usage of parts and hence the safety stock level is also reduced. This forces the suppliers to provide higher level of service percentage. Since the thesis is purely research based, a word of mouth valuation was undertaken with the senior management people from one of the leading automobile manufacturing companies.

What is the alternative to free up the space in the assembly station leading to efficient production and damage free products?

Routing and scheduling models which are consolidated will provide exactly the required amount of parts in the assembly stations. This is achieved by installing the decentralized supermarket from which tow trains will deliver the parts required. Eventually, the amount of parts needed from the centralized warehouse gets reduced. JIT implementation with supermarket decreases the amount of orders from suppliers and expects the suppliers to provide in a shorter timeframe. The assembly station ends up having lot of free space for a systematic execution.

What are the effects of installation of super market and how does it affect the vendors?

The volatility in the demand increases as the parts are required only when it is needed. Supermarket ensures that limited amount of parts are sufficient for smooth flow of production. OEM will try to avoid overstocking of products in warehouse to ensure carrying cost and holding cost is reduced. Suppliers who were providing parts in bulk are forced to reduce the quantities leading to LTL from an existing FTL. This is one of the indirect reasons why JIT was not followed in the automobile part logistics. To ensure timely supply of parts OEM provides an extra profit for suppliers and OEM always have certain amount of storage (Li, 2015). The hit taken by the suppliers can be optimized through the supplier bidding process and by implementing real time asset monitoring solutions.

How real-time monitoring of assets helps in sustaining the manufacturer pressure and deliver the customer expectations?

Second stage in the implementation of thesis is enabling transparency and visibility to the automobile manufacturing companies and the suppliers providing the parts to them. Since it was possible to get access to an asset monitoring company, real time implementation was done to validate predictive analysis. This means that whether the damage of parts occurred or not during transit can be analyzed. The implementation didn't involve the exact automobile parts, but parts used for machinery assembly as this was the similar use case in relation with the thesis. The success criteria taken was the number of predictive alerts received and the pilferage attained at the end of transit. A series of alerts were received during transit in the form of SMS and E-mail. This validated the solution that once an uncertainty in the transit occurs, the companies are notified in advance enabling them to make quick changes in the station or opting to last mile delivery.

The partial implementation of supermarket solution and the real-time analysis of parts during transit confirms that asset monitoring device along with the customized optimization of part supply results in success. Although the supermarket installation is theoretical, real time monitoring of parts still backs and validates the solution.

7. CONCLUSION

The thesis started off with research on the assembly of automobiles beginning with the parts being delivered in the warehouse to the final assembly station. This study mainly focuses on the efficient movement of parts from the warehouse through the supermarket and then to the assembly station. Part logistics is given more importance because of the challenges faced on the front end. The sheer recalling of automobiles is a burden to the auto manufacturers as it hinders the reputation of the company. Supermarket is widely adopted in many countries which serves as temporary inventory holding compartment instead of directly moving the parts to the assembly station. The reason for supermarket installation is to reduce the overstocked inventory and provide the assembly station with parts only when it is required.

In the first half of the study, tow train scheduling and routing were discussed by describing already existing theoretical model and normalizing them into a standard procedure. The objective of normalizing was to make sure the readers understand the models and add the constraints according to have proper schedule and route. For this purpose, six models from different timeline were taken so that each model can add a value to do the tow train optimization. The mathematical models are basically Mixed Integer Linear Programming models with an objective function to solve and constraints to have a definite answer. This study specifically focuses on the tow train optimization and the benefits of adding supermarket in the Automobile assembly station. At the end of the first half, all the models were combined into a single table to explain about the constraints.

The second half of the thesis elaborates about procurement optimization by considering four different lanes and two suppliers. It is mainly discussed to show the effect of supermarket installation on the supplier bidding process. Use of supermarket improves the quality of the inventory level and reduces the quantity. This directly affects the inventory level in the warehouse which means that the supplier will have to provide only less number compared to the current process. The second part of the thesis deals with procurement optimization of automobile parts before supermarket installation and procurement optimization after the installation of supermarket. The constraints that are used in the optimization include non-negativity constraints, integer constraints, volume discount constraints, minimum dollar value constraints and supplier capacity constraints. The number of loads are changed with each addition of constraints. This part eliminates the need for overstocking of products for uncertain conditions such as rise in demand and supplier unavailability.

In the last part of the study, the major challenges faced by the automobile manufacturers were briefly discussed. One of the solutions was the introduction of supermarket into the assembly stations. But this solution alone cannot solve the problems faced by the auto industry. External factors such as technological advancements in the fields should be implemented as it connects the points in the different parts of the supply chain. An IOT based platform was briefly discussed involving asset monitoring devices to face the challenges in the automotive supply chain. These devices interact with the users and communicate the status of the consignments such as location and route. This is very secure in terms of product safety as the devices gives alerts on any uncertain conditions. The Automobile companies should invest more in providing transparency in the entire supply chain to reduce the waste.

Although many problems were discussed, there are certain glitches in the automotive supply chain which needs immediate attention to reduce the bottlenecks in the supply chain. Further research on the tow train scheduling and routing can be done to improvise the JIT method without any delay in the assembly station. Further new constraints can be tested and adopted so that the buyer power and supplier power becomes equal to have a smooth transaction and equal benefits for all players in the supply chain.

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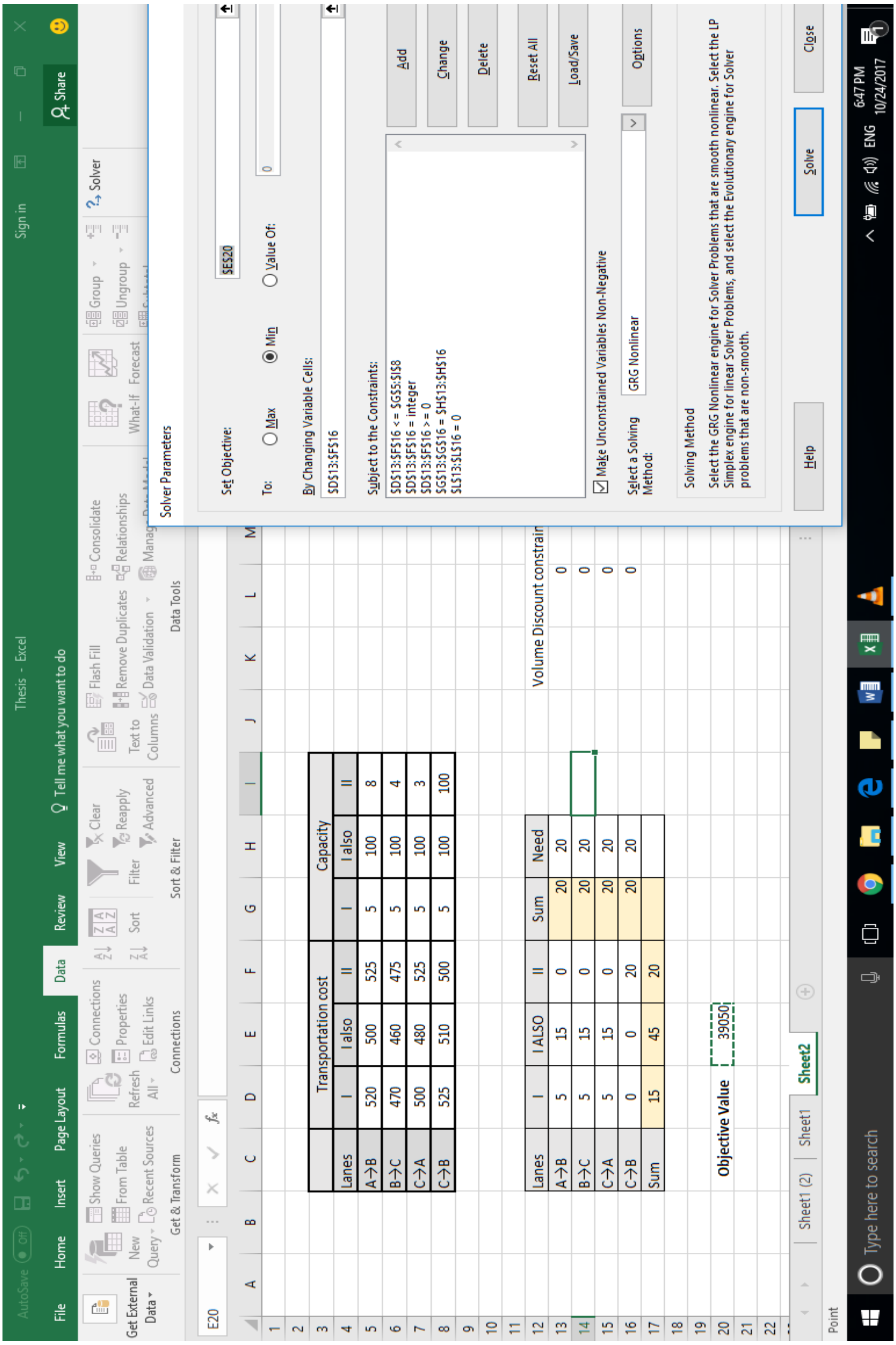
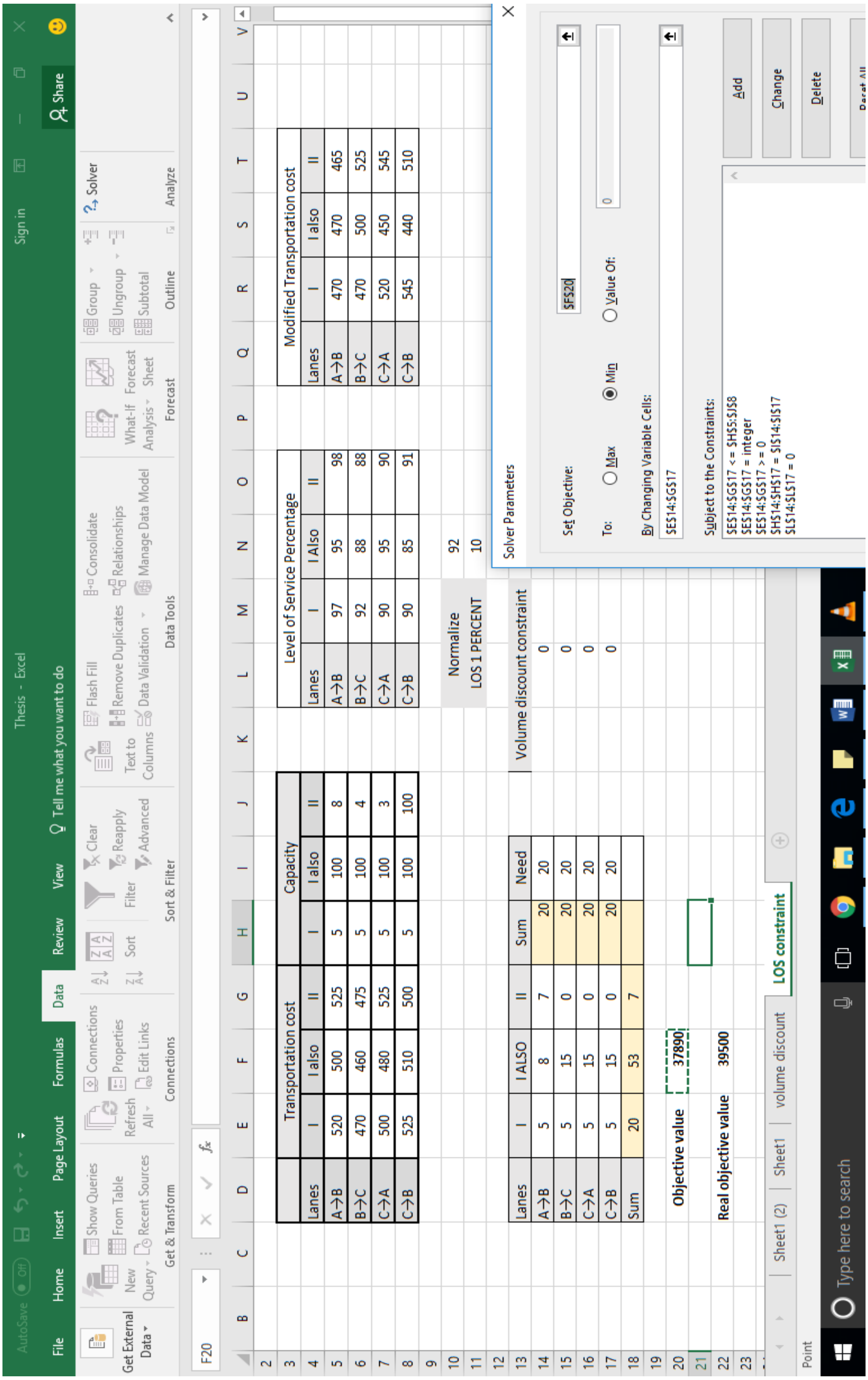
APPENDIX

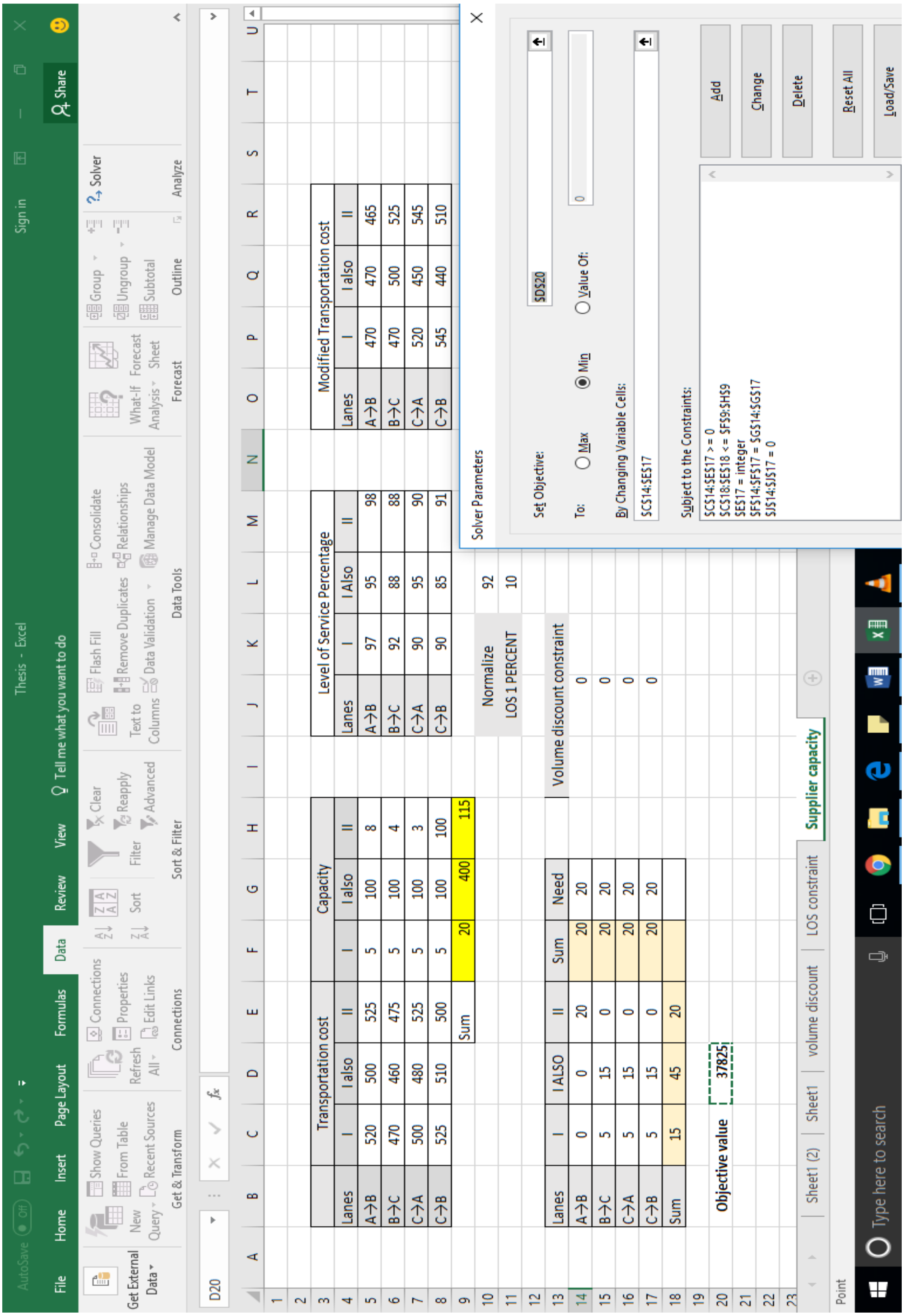
Appendix 1. Volume discount before Supermarket



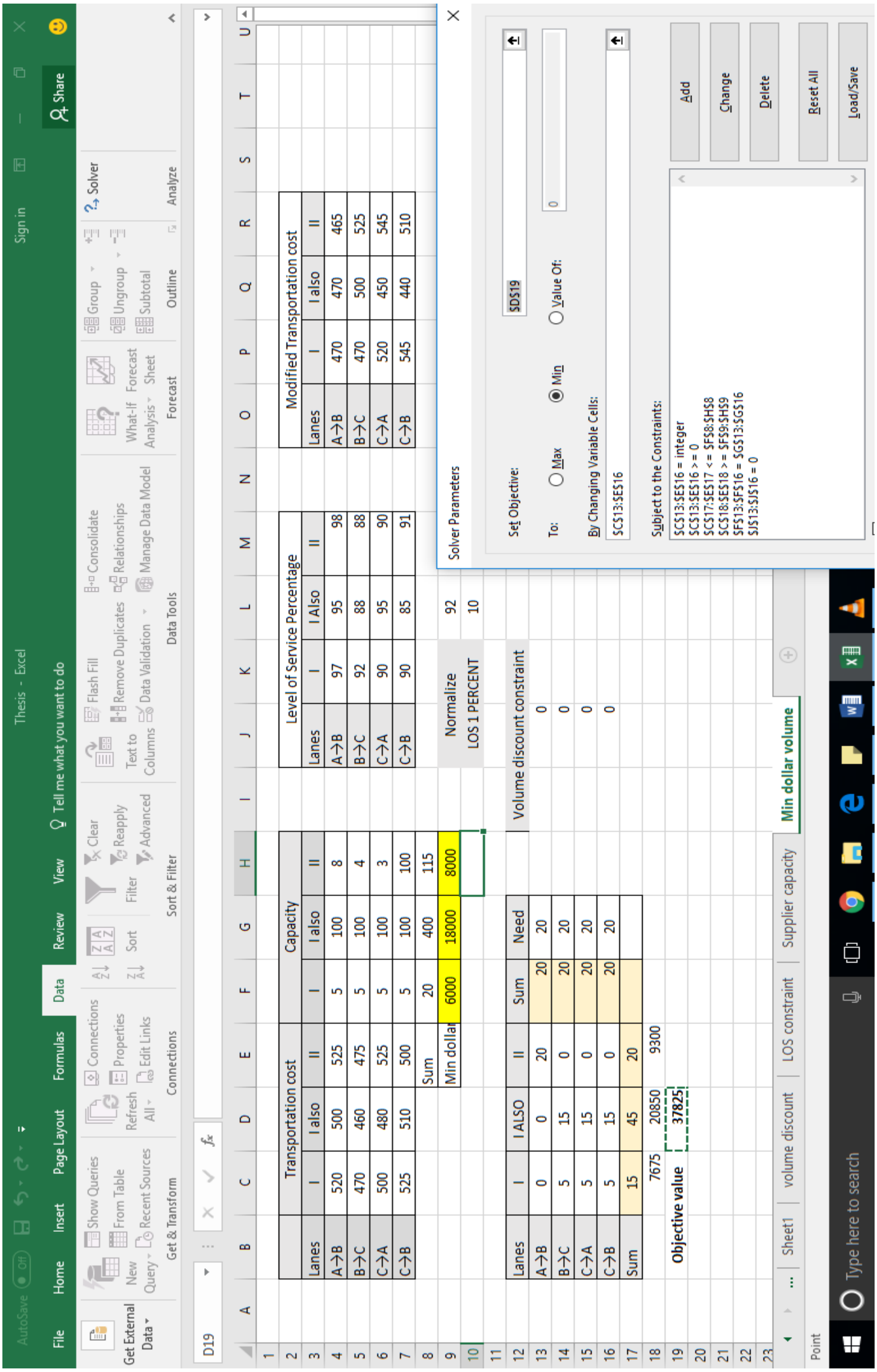
Appendix 2. LOS Constraint before Supermarket



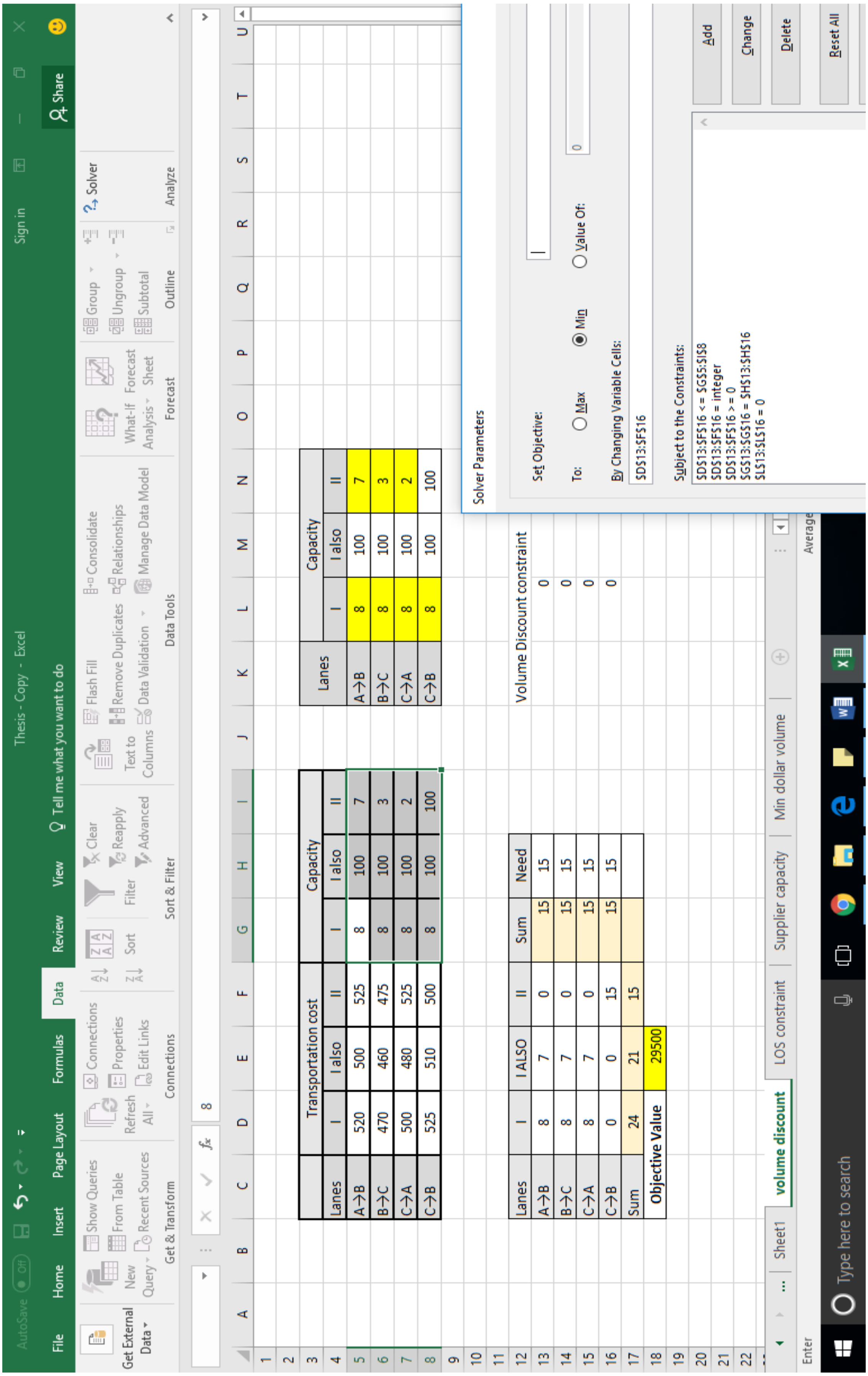
Appendix 3. Supplier constraint before Supermarket



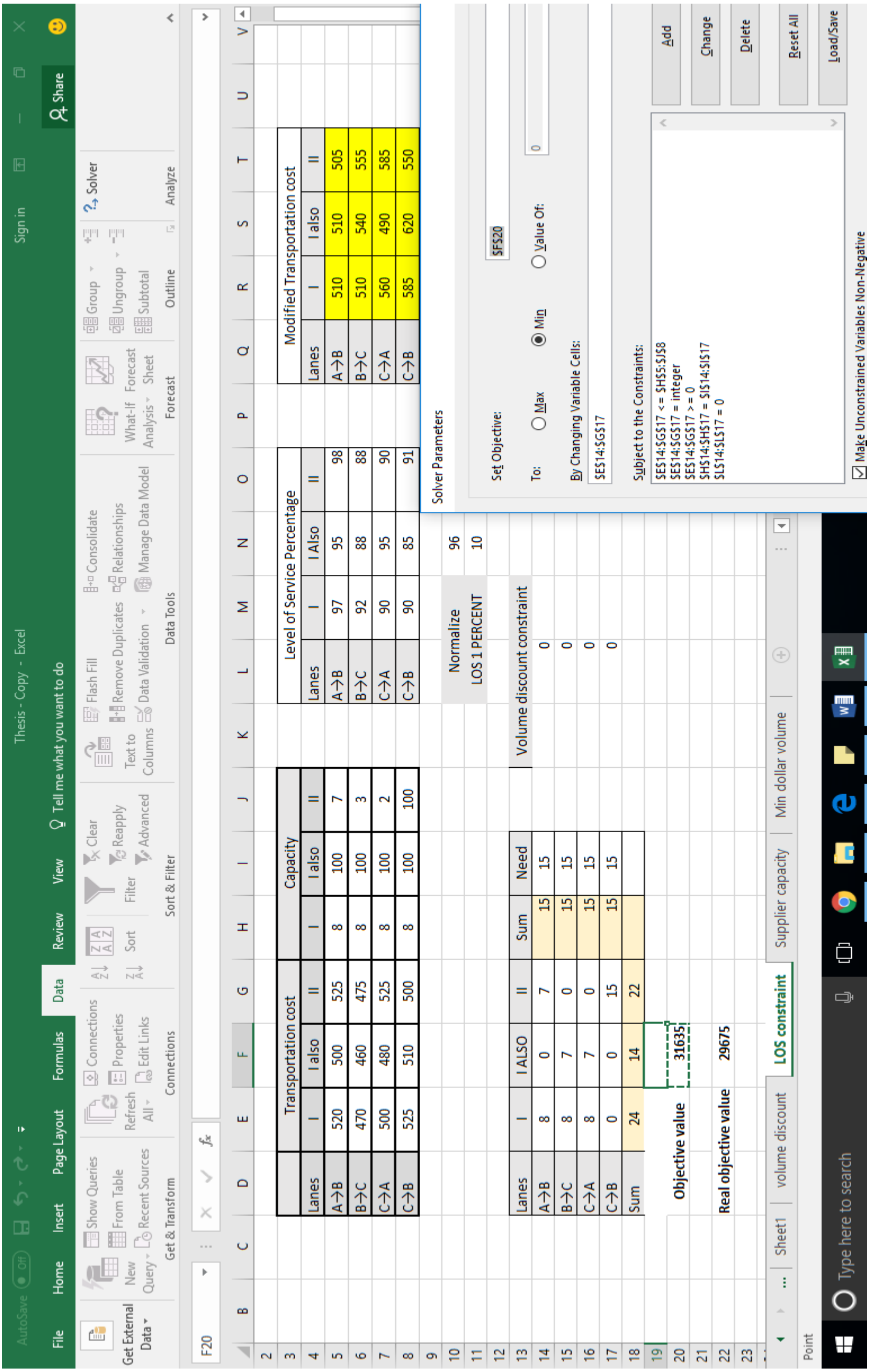
Appendix 4. Minimum dollar value before supermarket



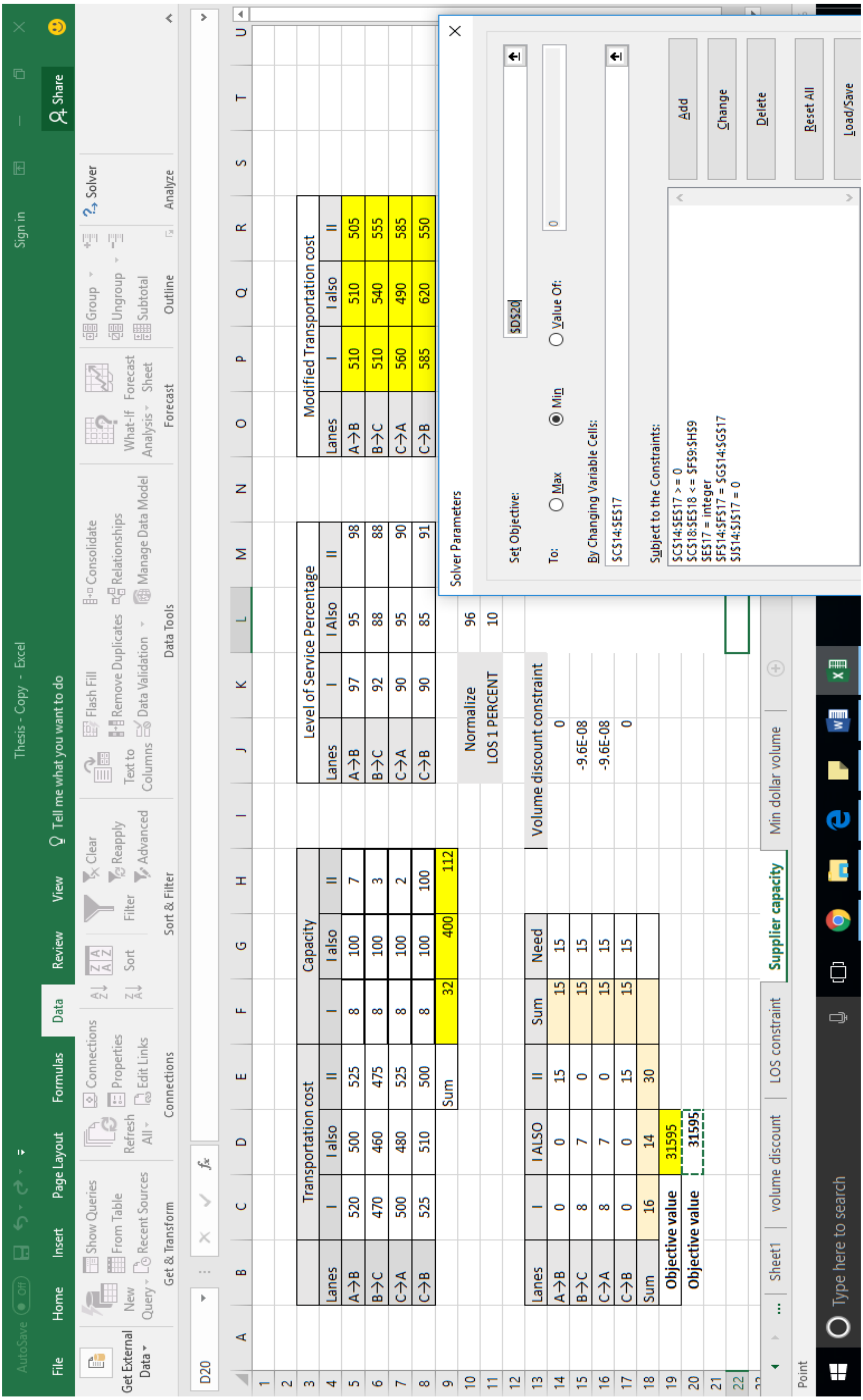
Appendix 5. Volume discount after supermarket



Appendix 6. LOS after supermarket



Appendix 7. Supplier constraint after supermarket



Appendix 8. Minimum dollar after Supermarket