ETM
ENGINEERING & TECHNOLOGY MANAGEMENT

# Optimization Modeling for Inventory Logistics

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## Abstract

The automotive industry in Thailand is ranked 3rd in the world by commercial vehicle production statistics, following USA and China.[1] With numbers like these, it is clear that the automotive industry makes up a large portion of the Thai economy. With such scale and impact, it is important for efficiency to be optimized. One way to reduce cost is to develop a model that will provide a viable and real optimization scenario in regards to logistics for an automotive parts company operating in Thailand.

The current business practice has 5 branches of an auto parts company maintaining separate inventories in order to meet their own seasonal demand and reduce their lead times. This independent viewpoint misses an opportunity for increased efficiency and effectiveness by utilizing surplus inventory in certain branches to cover deficits in others. This missed opportunity impacts the company’s competitiveness.

The goal of this project is to create the foundations of a tool to aid in the logistical decision making challenge of maintaining inventory between the 5 branches. This tool will be used to calculate the optimum purchasing strategy, using an EOQ calculation followed by a order distribution decision to reduce costs.

The model we created is able to perform these calculations, and is able to arrive at optimized solutions in relatively short order. It is useful as a tool for investigating the outcome of different ordering strategies ahead of time.

The model has far to go before it would be used in a production environment however. It will need to be able to take into account real world scenarios with all their uncertainty. This model could be expanded to support these situations.

## Literature review

Our research for this project involved a study into logistics as well as research of Thai economic issues and the auto industry in general. Our focus was on improving the way problems are solved for the auto parts distribution industry in Thailand. One of the authors works in the industry and has access to historical data to start the ground work on this project. In essence this is an exploratory project.[2]

Our Data gathering and research process was based on the model in Figure 1. We reviewed papers, books and articles from various sources on optimization and information on inventory logistics. We identified various key words and phrases to find the right sources and identify the abstracts to help with our search. This helped us to filter the relevant data and discard the data that was not applicable. We followed these steps for our data gathering.

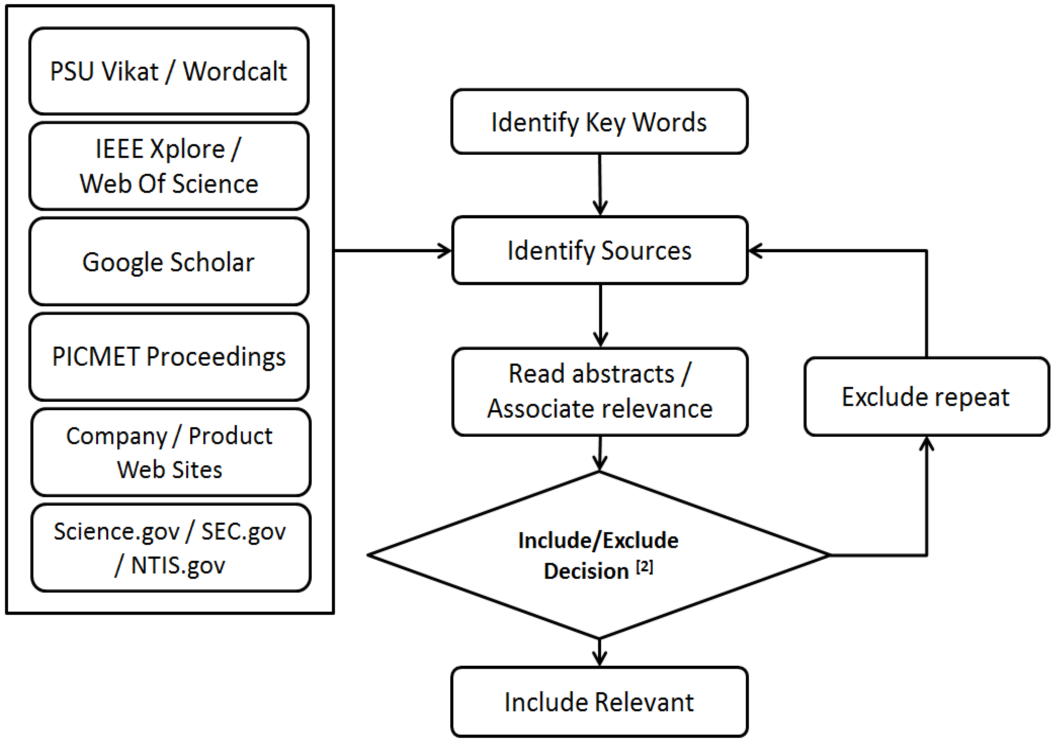



**Figure 1 - Literature Review Model**

## Review of Optimization Modeling

The birth of the Field of Optimization may have started with Johann Carl Fiedrich Gauss who solved an astronomy problem using what is known as the Gauss optimization method in the 1850s. As Jacob Mattingley at Stanford University described:

- *Optimization refers to a branch of applied mathematics concerned with the minimization or maximization of a certain function, possibly under constraints.* [3]
- *Optimization has evolved towards the study and application of algorithms to solve mathematical problems on computers.* [3]

Optimization has contributed in many areas including management, economics, finance, information retrieval, logistics and mathematical programing. [3], [4] There are many references to Optimization Modeling being used to find the maximization or minimization of a certain function. The model is used to find the best possible choice within a feasible region. Regardless of the application area, there are common steps to take when using Optimization Modeling.

- *Identify the problem and describe exactly the desired objective.*
- *Identify what is to be optimized*
- *Find the domains for all labeled variables*
- *Identify the constraints*
- *Identify the changing and none changing labeled quantities*
- *Find the relationships between given variables and constraints.*

- *Write out the objective in terms of just one variable.*
- *Finally optimize the objective.*[5]–[7]

Solving a system of linear inequalities was in early development by Joseph Fourier and Theodore Motzkin using a system of linear inequalities also known as the Fourier-Motzkin elimination or FME method. [8]Much later, Leonid Kantorovich developed the first linear programming method in 1939, to be used in World War II to reduce cost for the army and increase losses to the enemy.[9], [10] By 1947 George B. Dantzig made public the simplex method and John von Neumann developed the duality theory as a linear optimization solution. The theory of duality was also applied to the field of game theory.[11] Since then Optimization Modeling has branched out in many different directions and is used in many different fields. However, for the purposes of this research project, we will focus on the convex programming form of Optimization Modeling including Linear programming, Integer programming, and Stochastic programming as described below:

- **Convex programming** studies the case when the objective function is convex (minimization) or concave (maximization) and the constraint set is convex. This can be viewed as a particular case of nonlinear programming or as generalization of linear or convex quadratic programming.
    - **Linear programming** (LP), a type of convex programming, studies the case in which the objective function *f* is linear and the set of constraints is specified using only linear equalities and inequalities. Such a set is called a polyhedron or a polytope if it is bounded.
- **Integer programming** studies linear programs in which some or all variables are constrained to take on integer values. This is not convex, and in general much more difficult than regular linear programming.
- **Stochastic programming** studies the case in which some of the constraints or parameters depend on random variables.

The subfield model method that we will be using is a technique of Dynamic programming that is designed primarily for optimization in dynamic contexts (that is, decision making over time):

- **Dynamic programming** studies the case in which the optimization strategy is based on splitting the problem into smaller sub problems. The equation that describes the relationship between these sub problems is called the Bellman equation.

## Logistics Characterization

In small, local markets, companies must pay close attention to their bottom line. One of the most accessible ways to improve the bottom line is to reduce costs. Even with local suppliers and shorter distances it is still important to ensure optimized purchasing and shipping processes. Logistical Optimization is one method of doing that.

In reviewing research from Ballou [12], it has become clear that logistics is never a straight forward problem. Many times over the years, attempts have been made to work out the difficulties of measuring the revenue effects of logistics, however, there are always unknown factors at play. Ballou best describes several issues with logistics in customer service as follows:

> *Logistics customer service is the performance (output) of the processes associated with providing a product or service to customers and is an important, and often the most important, component of a firm's overall service offerings to their customers.* [12]

> *Logistics customer service is multi-dimensional, consisting of many variables, each of which may have different importance to various customer segments depending on the product or service, their locations, competitive setting, and their particular service needs.* [12]

> *Customer service is a basis for customer satisfaction, and customers respond positively through their patronage, market share, loyalty, and sales to the degrees of service being offered, which means that logistics customer service can be a basis for a firm's revenue generation initiatives.* [12]

> *The precise response from customers to various service offerings is difficult to measure accurately, which often leads to treating service as a constraint on strategy and operations while containing the costs of providing the service.* [12]

> *The difficulty of measuring the sales response to service is likely the reason for top managers viewing logistics as an area for cost containment rather than one from which to create a competitive advantage and increase sales.* [12]

The field of logistics has many terms of reference. From a general description, logistics is the organized movement of information, materials, and sometimes people. [13] As expressed by Rushton, "*Logistics = Supply + Materials management + Distribution*". [14] It takes skilled people in areas like purchasing and operations to manage logistics. Without these people and their understanding, management would be hard pressed to make logistical improvements. Logistics has an impact on, and is impacted by a host of external factors with far reaching and complicated relationships. This explains the constant challenge that is presented by this critical business process.

The primary goal of logistics is to provide the necessary level of customer service with an effective cost balance. While it is true that some companies do not invest heavily in logistical assets, an alternative is contracting through third party companies who can provide logistical services which cover monitoring, planning, and controlling. However logistical challenges are handled, it is an important aspect of maintaining a healthy, productive company. This project focuses on the logistics structure of the local organization, the only issues foreseen are geographical obstacles in nature.

## Methodology

EOQ

From the literature, it is evident that the Economic Order Quantity calculations have been used in inventory management even before World War II and the advent of computers to reduce stock replenishment cost. They used a term called minimum cost quantity to represent the economic order quantity then. This method is very beneficial to companies that need to order inventory repetitively at regular intervals. EOQ uses data like annual demand, cost of the order and the carrying costs to calculate the minimum quantity to be ordered at a time to have a low replenishment costs.[15]

Nonlinear programming

For solving the optimization models for EOQ and Inventory management which involves nonlinear equations, we need to opt for nonlinear programming. The Excel solver uses the GRG algorithm to solve the nonlinear programming. The algorithm which the GRG uses is called the steepest ascent method. From the literature, we can see that nonlinear programming is not always the best choice and needs to be used only when necessary. This is because the algorithm is prone to converging to a local optimum solution and fails to locate the global optimal solution that may be available. In order to increase our chances of getting to the global optimal solution, we run the solver for various starting points. We also cannot say the solution to the nonlinear program returned by the solver is the global optimal solution with 100% certainty.[4]

# Problem Background

## Industry Players

According to the Thailand Board of Investment report, produced in 2011, the automotive industry is a vital sector for the country's economy and is the country's second largest export industry. See Figure 2.

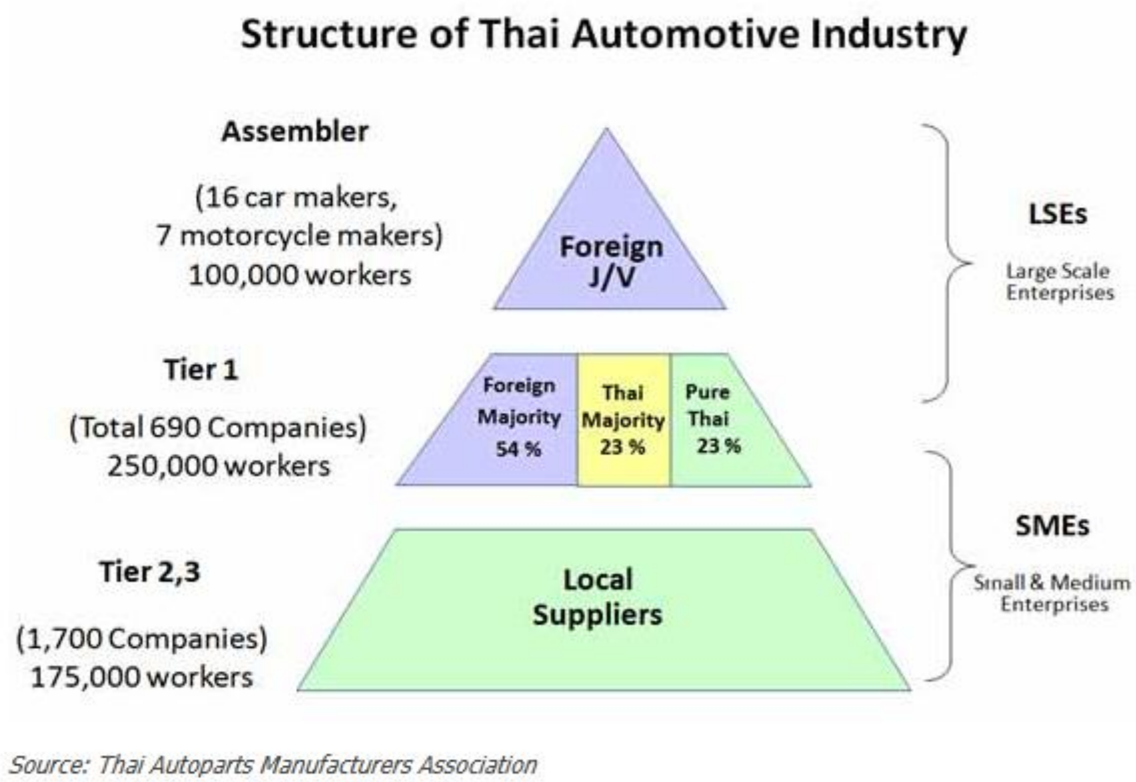
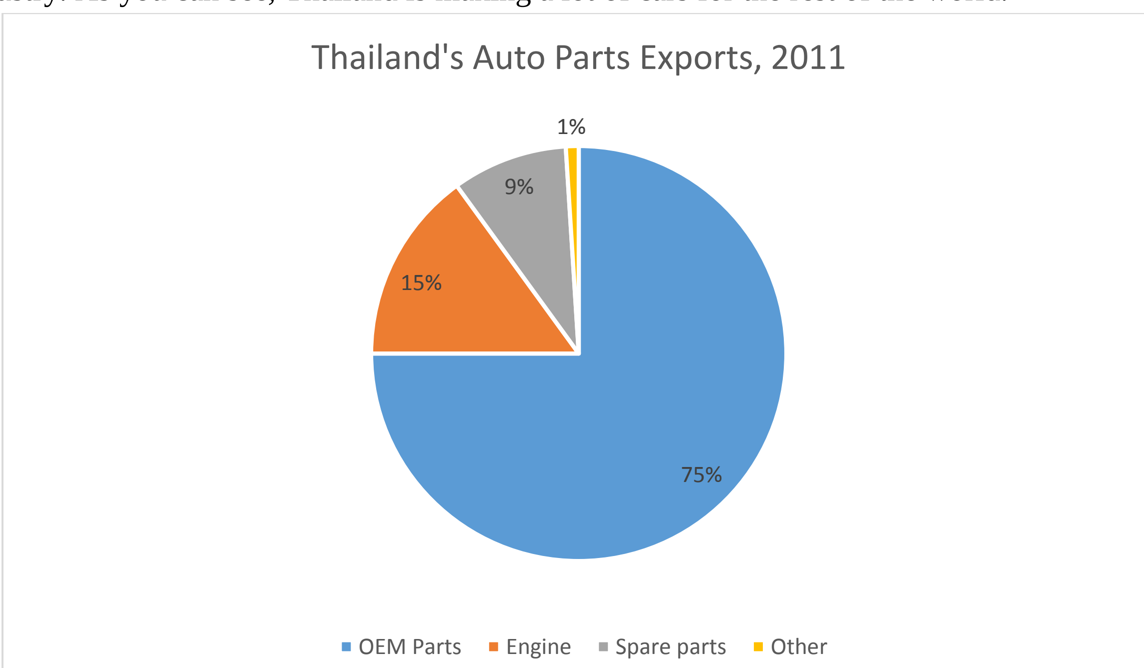



**Figure 2 – Automotive Market Suppliers** [16]

The following Graph 1 shows the breakdown of Thailand's auto part export industry. It shows that OEM (Original Equipment Manufacturer) parts are a major part of this expansive industry. As you can see, Thailand is making a lot of cars for the rest of the world.




Graph 1 - Thailand Auto Parts Industry breakdown [16]

## Current Business Process

Maintaining proper part inventory levels is a very costly aspect of doing business in the automotive industry. Reducing this cost is critical to a business's competitiveness. In order to accomplish this goal, the business process must be understood. For Isuzu, part orders can be made in two ways, either ordered directly from the headquarters, or ordered from a 3rd party supplier. Ordering from headquarters is preferred, as those parts will be guaranteed genuine Isuzu parts, and they will generally come at a lower cost. However, if there are issues in the supply chain, parts can alternatively be ordered through a local 3rd party supplier. The parts from these suppliers are not necessarily guaranteed to be genuine, and they come at a premium cost. Part orders sent to headquarters can be fulfilled in one of two ways as well. Headquarters will either decide to manufacture and ship the parts completely in house, or will contract them to be built at a factory and delivered to the dealer. Each of these methods come with different lead time requirements, and each has their advantages in certain situations. Our model operates based on this simple ordering scheme, and optimizes the quantities of parts ordered from each source to reduce the costs associated with this expensive component of the business process.

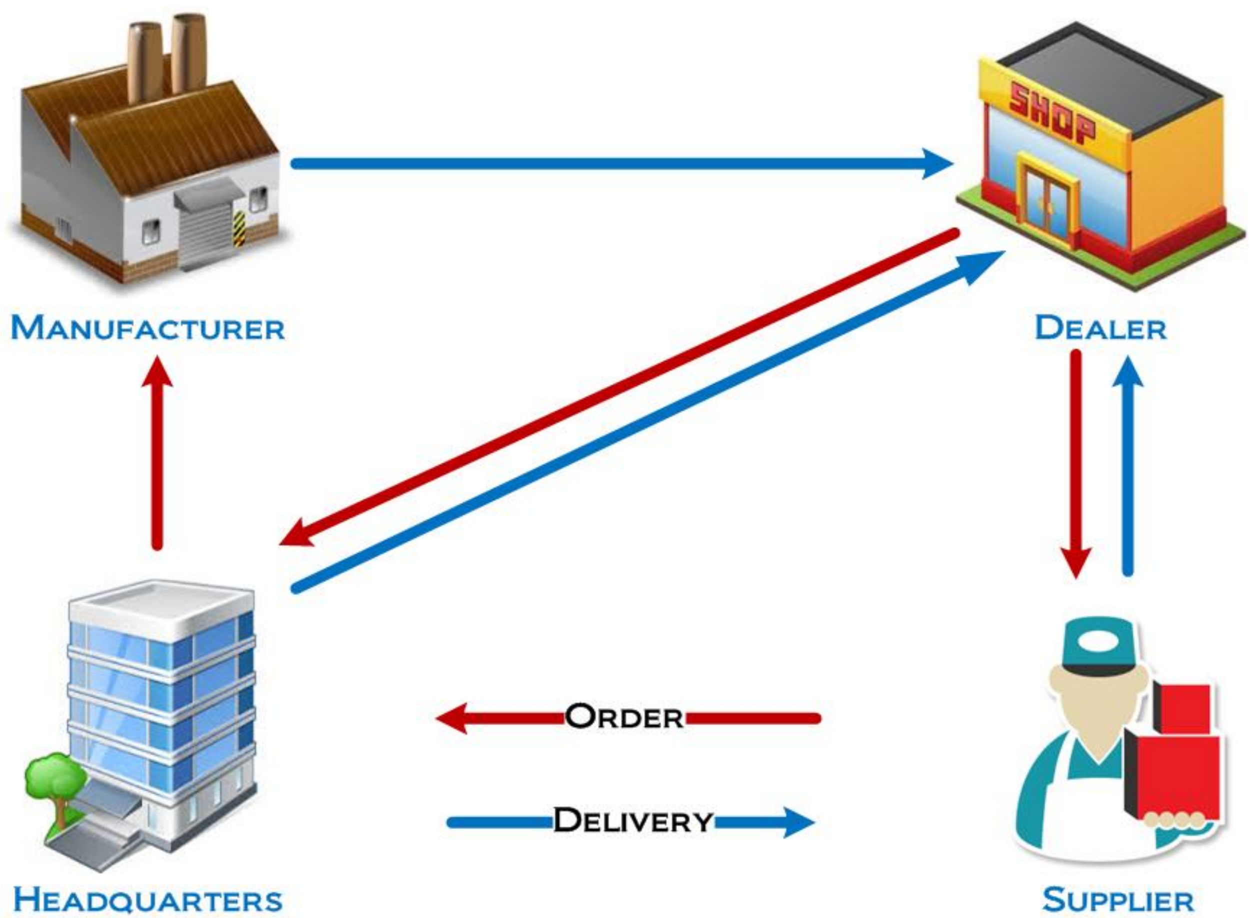



Figure 3 - Order and Delivery flow for Isuzu Auto Parts

As outlined in Figure 3, the current process for storing and ordering is; first, a branch of an auto parts dealer decides whether they need to order parts. If the part is needed, the stock manager will determine the quantity needed. Next, they will verify whether the part is available at other branches, at the headquarters, or at a 3rd party supplier. Based on this and other pricing and usage information, the stock manager will decide from where the parts will be ordered. The basic logical flow of ordering can be seen from Figure 4.

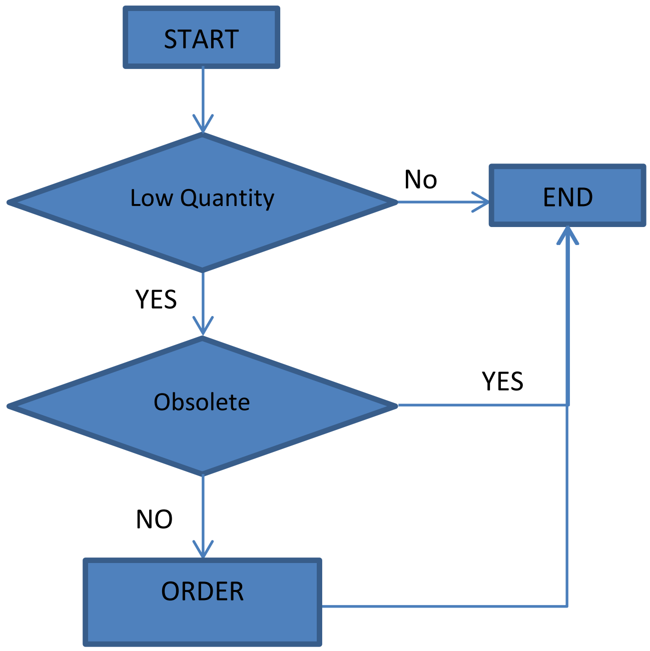



Figure 4 - Ordering Decision Flow

There are several opportunities for improvement in the current process. Identifying weak points, and reducing the reliance on estimation would help reduce shortages and surpluses due to human error. Also, increasing the communication between the branches could reduce the unnecessary duplication of inventory that could have been easily be transferred between branches.

### Problem Statement

The current business practice has each of the 5 part dealers maintaining separate inventories in order to meet seasonal demand and reduce lead times. This independent viewpoint misses an opportunity for increased efficiency and effectiveness by utilizing surplus inventory in certain branches to cover deficits in others. This missed opportunity impacts the company's competitiveness.

## The Goal of the Project

The current business process being utilized by Isuzu Auto Parts is based on supply and demand, and the location of a part. The goal of this project is to develop a basic optimization model that can be used to aid in supply chain logistical functions, and to achieve two main goals.

First is to calculate the minimum overall cost associated with part transportation and storage. The second is to increase efficiency for transportation of inventory between branches. To accomplish this we have focused on improving the transfer of inventory between dealers, and the efficiency of ordering inventory from an outside source. To ensure transparency and efficiency for the decision making process, standard optimization tools and methods have been used. By utilizing and deploying these standard tools we will develop a calculator to aid in ordering and logistics decisions.

## Scope

The scope of this research project is both narrow and broad. It is intended to apply to a specific company operating in Thailand. However, the concepts are universal enough to be applied to many industries in many countries. For the purposes of this project, we limit our research and consideration only to this one application of the auto parts supplier in Thailand. This is to allow us to remain focused on the modeling aspect, and not the intracacies of different industries.

It is important to us to have a model that makes an approach to a helpful solution for a real world problem. We also know that, due to our time limitations, we have to pick a very narrow suite of functionality to enable us to come up with an interesting result. To achieve this goal, it has been critical that our model is accessible enough to be manipulated, changed, and improved in the future. In this spirit, we have developed our model to function from the ground up, adding functionality as progress was made. We were eventually able to include an EOQ calculation in our model as part of the total inventory ordering process. Any sort of calculation that requires input from data regarding other parts, or other timeframes is out of the scope for this project.

## Optimization Model

This model focuses on optimizing the purchase and transfer of parts for and between 5 Isuzu Auto Parts dealerships. Cost and availability of parts from all dealerships are constraints in the formulation, and the location and distance information is used to determine the costs related to shipping parts between the dealers. A map showing the dealer locations, and table with the distances between them are below in Figure 5 and Table 1 respectively.

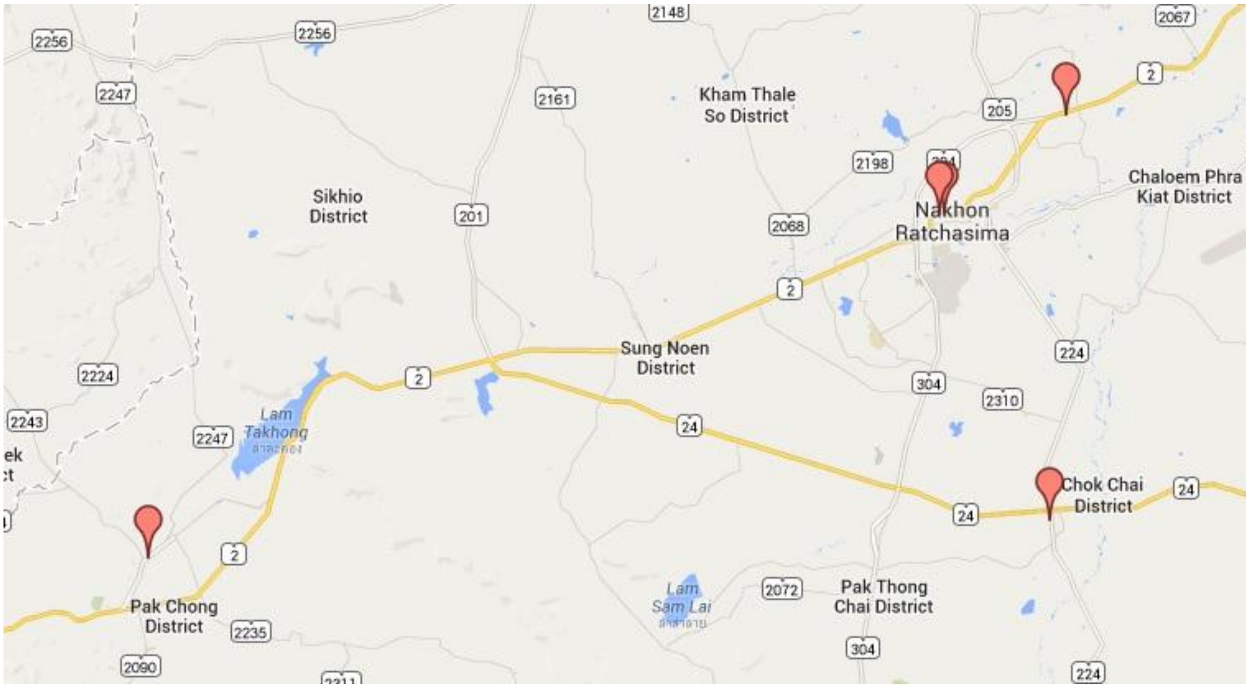



Figure 5 – Map of Isuzu Auto Parts Dealerships

| Dealer | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 0 | 34.5 | 0 | 86.5 | 16.9 |
| 2 | 34.5 | 0 | 41.1 | 93.1 | 46 |
| 3 | 0 | 41.1 | 0 | 86.6 | 16.9 |
| 4 | 86.5 | 93.1 | 86.6 | 0 | 104 |
| 5 | 16.9 | 46 | 16.9 | 104 | 0 |

Table 1 – Table of distances between dealers

This work will be limited to the local supply chain, including products stored at the dealerships, and ordered from three potential external sources. Even though the company does import and export materials, this study exclude that aspect from the scope to focus only on the local dealership inventory logistics.

As a team, the group has come up with a mathematical formula using fixed costs to provide tools and methods as ground work for Isuzu. Due to time constraints basic ground work on the tools and methods is all that can be done with the hope that it will be expanded and incorporated into their logistics model.

### Assumptions and Limitations

The model is currently useful, but has many significant limitations and assumptions that need clarification. It is important that the user understands these limits so they can better apply the information that is given.

Assumptions:

- A perfect world scenario and that everything will go according to plan.
- Orders are placed without an understanding of what other parts may be ordered.
- On time delivery.

Limitations:

- Fixed costs for shipping and parts. The model does not consider bulk or other discounts, or variations in shipping costs.
- The model does not calculate depreciation of stored parts, or have any way to monitor shelf life.
- Timing related limitations include a lack of support for delivery and lead-time data.
- Multiple time periods must be calculated by running the solver multiple times. This is also the case for multiple parts.
- There is no way for the model to plan for the future or make sacrifices on one part for benefits on another.

In its current form the model has very limited use and is not very powerful. Many assumptions have been made to test the basic functionality of the model but limit its applicability. With work it could be expanded to include the current limitations and reduce the number of assumptions, approaching a useful tool.

## Formulation

This optimization model is used to determine the optimum quantity, reducing the cost of goods to be ordered from each available source and shipped between each dealer. The dealers have limited storage capacity and no centralized warehouse to store the goods. Each part also has availability constraints, and minimum inventory levels. The optimization model meets these constraints, and outlines the most efficient ordering strategy for the dealers as a whole.

### Variables

The decision variables in the optimization model are:

$P^{O}_{i,l,k}$ = No. of parts to order for dealer k from source l for part i

$P^{S}_{i,j,k}$ = No. of parts to ship between dealers j and k

Where,

$i$ = part number

$j$ = dealer number

$k$ = dealer number

$l$ = source number

$Q_i$ = Order quantity for part i

$T_i$ = Ordering Number per year part i

Other variables used in the model are:

$C^P_{i,l}$ = Cost of the part $i$ from source $l$

$C^S_{j,k}$ = Shipping cost / mile between dealers j and k

$D_{i,k}$ = Demand for part i for dealer k

$E_{i,k}$ = Existing Inventory for dealer k for part i

$S^C_{i,k}$ = Storage capacity for dealer k for part i

$S^D_{j,k}$ = shipping distances between dealers j and k

$S^{SC}_{i,l}$ = source supply capacity for part i from l

$N_{i,j,k}$ = Binary integer indicating whether the part i is shipped between dealers j and k

$N_{i,j,k} = 1$ if $P^S_{i,j,k} >= 1$ for all i, j, k

$= 0$ if $P^S_{i,j,k} = 0$

$D^A_i$ = Annual Demand for part i

$C^I_i$ = Holding Cost of inventory in percent which is also opportunity cost

$C^O_i$ = Cost of placing an order which involves cost of handling and inspection

$C^D_{i,l}$ = Discount available for part i from source l given the minimum discount order is met

$M^D_{i,l}$ = Minimum parts to order of part i from source l to avail the discount.

## Economic Order Quantity (EOQ) Optimization

### Objective

The Objective is to minimize the Cost of ordering and opportunity cost and is as follows:

$$Min\ [Ti\ * C^O_i + (Q_i * C^I_i * \frac{\sum_{l=1}^{3} C^P\ i,l}{\sum_{l=1}^{3} l})/2)]\ \forall\ i$$

Where,

$T_i = D^A_i / Q_i$

### Constraints

The constraints for the model are:

Quantity Constraint $\mathrm{Q}i \geq 1$ and $\mathrm{Q}i \leq \mathrm{D^A}i \ \forall\, i$

Order times Constraint $\mathrm{T}i \geq 1$ and $\mathrm{T}i \leq \mathrm{D^A}i \ \forall\, i$

Integer Constraint $\mathrm{Q}i$ *and* $\mathrm{T}i$ *are integers*

Total demand Constraint $\mathrm{T}i * \mathrm{Q}i = \mathrm{D^A}i$

## Inventory Optimization

### Objective

The objective is to minimize the cost and is as follows:

$$\text{Min } [\sum_{i=1}^{n} \sum_{l=1}^{3} C^P{}_{il} * \sum_{k=1}^{5} (P^O{}_{ilk}) + \sum_{k=1}^{5} \sum_{j=1}^{5} \{(C^S{}_{jk} * S^D{}_{jk}) * \sum_{i=1}^{n} (N_{ijk})\}]$$

Where

$$C^P{}_{il} = C^P{}_{il} \text{ if } \sum_{k=1}^{5} (P^O{}_{ilk}) \leq \mathrm{M^D}i,l \quad \forall\, i,l$$

$$C^P{}_{il} = (1 - \mathrm{C^D}il) * C^P{}_{il} \text{ if } \sum_{k=1}^{5} (P^O{}_{ilk}) \geq \mathrm{M^D}i,l \quad \forall\, i,l$$

### Constraints

The constraints involved in the model are Storage capacity, Minimum Inventory, Demand and supplier capacity. The equations to satisfy these constraints is as shown below:

$$\textit{Meet Demand constraint } E_{ik} + \sum_{l=1}^{3} (P^O{}_{ilk}) + \sum_{j=1}^{5} (P^S{}_{ijk}) \geq D_{ik} \ \forall\, i,k$$

$$\textit{Storage Capacity constraint } E_{ik} + \sum_{l=1}^{3} (P^O{}_{ilk}) \leq S^C{}_{ik} \ \forall\, i,k$$

$$\textit{Supply Capacity constraint } \sum_{k=1}^{5} (P^O{}_{ilk}) \leq S^{SC}{}_{il} \ \forall\, i,l$$

$$\textit{Linking constraint } P^S{}_{ijk} - D_{ik} * N_{ijk} \leq 0 \ \forall\, i,j,k$$

Other constraints are that $\mathrm{P^O}_{i,l,k}$ and $\mathrm{P^S}_{i,j,k}$ should be integers and non-negative and $\mathrm{N}_{i,j,k}$ is binary

## Analysis

For the analysis of the optimization model, we have considered the historical data available for one auto part from Isuzu Auto Parts, for all their branches, for a given month. Using the historical data, we have calculated the maximum, minimum, average demand and the standard deviation for the demand on any given day. With the help of cumulative probability distribution curves, we have calculated the demand per day and demand per week for various percentages of meeting the demand. In the analysis, we have used the calculated demand per week for all dealers for a cumulative 99% percentage of meeting the demand as shown in Table 2.

| | Part1 | | | | |
|---|---|---|---|---|---|
| Day | Dealer 1 | Dealer 2 | Dealer 3 | Dealer 4 | Dealer 5 |
| 1 | 3 | 0 | 0 | 0 | 0 |
| 2 | 3 | 0 | 0 | 0 | 0 |
| 3 | 2 | 0 | 0 | 0 | 0 |
| 4 | 2 | 0 | 0 | 0 | 0 |
| 5 | 2 | 1 | 0 | 0 | 0 |
| 6 | | | | | |
| 7 | 2 | 0 | 0 | 0 | 1 |
| 8 | 0 | 3 | 10 | 0 | 0 |
| 9 | 2 | 1 | 8 | 0 | 1 |
| 10 | 3 | 2 | 0 | 0 | 0 |
| 11 | 7 | 1 | 3 | 0 | 0 |
| 12 | 1 | 1 | 1 | 0 | 0 |
| 13 | | | | | |
| 14 | 5 | 0 | 2 | 0 | 0 |
| 15 | 4 | 2 | 1 | 0 | 0 |
| 16 | 2 | 2 | 0 | 0 | 0 |
| 17 | 3 | 0 | 5 | 0 | 0 |
| 18 | 2 | 2 | 1 | 2 | 0 |
| 19 | 6 | 1 | 0 | 0 | 0 |
| 20 | | | | | |
| 21 | 2 | 0 | 3 | 0 | 2 |
| 22 | 5 | 1 | 5 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 0 |
| 24 | 6 | 1 | 10 | 2 | 0 |
| 25 | 4 | 0 | 2 | 3 | 0 |
| 26 | 2 | 2 | 3 | 0 | 0 |
| 27 | | | | | |
| 28 | 2 | 1 | 2 | 0 | 0 |
| 29 | 4 | 0 | 4 | 0 | 0 |
| 30 | 1 | 0 | 3 | 0 | 0 |
| 31 | 2 | 0 | 4 | 5 | 0 |
| Max | 7 | 3 | 10 | 5 | 2 |
| Min | 0 | 0 | 0 | 0 | 0 |
| Average | 2.85 | 0.78 | 2.48 | 0.44 | 0.15 |
| STD | 1.77 | 0.89 | 2.98 | 1.19 | 0.46 |
| Count | 27 | 27 | 27 | 27 | 27 |
| % to Comulative | | | 99% | | |
| Demand | 6.97 | 2.85 | 9.41 | 3.21 | 1.21 |
| Demand per Week | 41.81 | 17.11 | 56.47 | 19.24 | 7.25 |
| Demand per Week (round up) | 42 | 18 | 57 | 20 | 8 |

Table 2 - October 2013 Historical Data

From this Table, we have calculated the annual demand for part1 for each dealer and the company as a whole. For calculating the Economic Order Quantity (EOQ), we have assumed the ordering cost for handling and inspection would be 50 Baht (Thai Currency) and the opportunity cost or holding cost would be 10% of the average cost of the part from different sources in Baht. By using the EOQ formulations in the spreadsheet, and running the solver as GRG Nonlinear as shown in figure 6, we have calculated the optimal order quantity and the number of orders required.

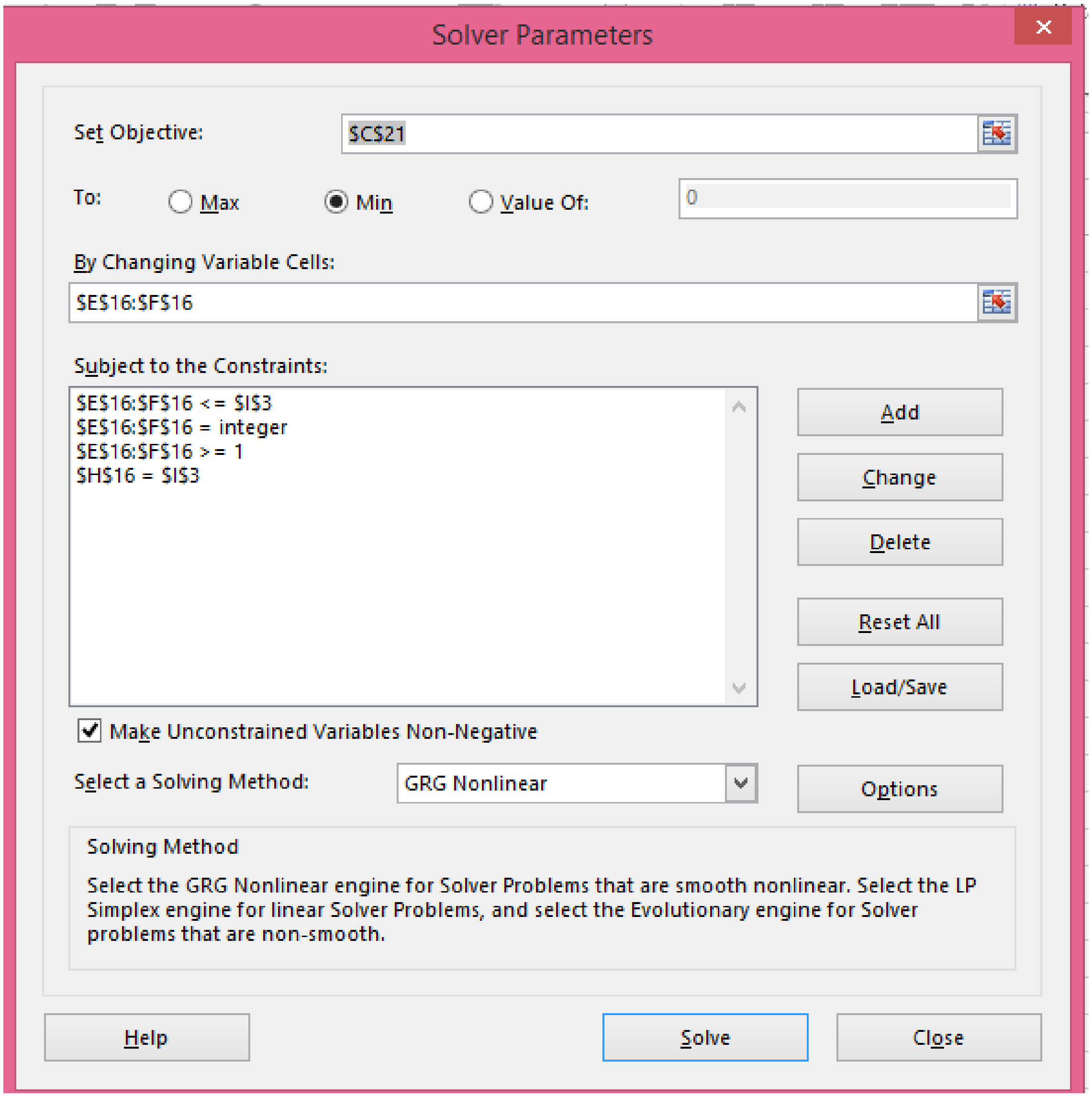



Figure 6 - EOQ Solver Parameters

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Team | | | | | | | | |
| 2 | | | | | | | | | |
| 3 | Data | demand for part 1 per week | | | 145 | | Annual demand | | 7540.0 |
| 4 | | | | | | | | | |
| 5 | | | Manufactu | Isuzu | Supplier | | | | |
| 6 | Cost of part 1 | | 40 | 30 | 50 | | | | |
| 7 | | | | | | | | | |
| 8 | | | | | | | | | |
| 9 | | | | | | | | | |
| 10 | | | | | | | | | |
| 11 | | | | | | | | | |
| 12 | Carrying Cost is 10% of cost of part from Manufactur | | | | | 4 | | | |
| 13 | Ordering cost per order | | | | | 50 | | | |
| 14 | | | | | | | | | |
| 15 | | | | | Q | Order times | | total order | |
| 16 | Decision Variables | | | | 419 | 18 | | 7542 | |
| 17 | | | | | | | | | |
| 18 | Carrying cost | | 838 | | | | | | |
| 19 | Ordering Cost | | 899.7613 | | | | | | |
| 20 | | | | | | | | | |
| 21 | Total Cost | | 1737.761 | | | | | | |

Table 3 - EOQ Optimization

In this optimization as shown in Table 3, we have found that we need to order 18 times in a year which is approximately once every 3 weeks, with an order quantity of 419 parts in order to keep our replenishment costs low and to meet the annual demand.

Now, using this optimal order information and historical data on existing inventory and storage capacity of each dealer, we can calculate the optimal number of parts to be ordered for each dealer from each source. We can also determine the optimal number of parts to be shipped from each dealer to each other dealer in an effort to provide lower cost parts to other branches. For the Inventory Optimization Calculation, we assumed supplier capacity for part1 as shown in Table 4.

| **Supplier Constraint** | **600** |
|---|---|
| Manufacturer | 0 |
| Isuzu | 300 |
| 3rd Party | 300 |

Table 4 - Supply Constraints

| Min. Quantity for discount | Supplier | Discount |
|---|---|---|
| 200 | 1 | 0.2 |
| 100 | 2 | 0.1 |
| 50 | 3 | 0.3 |

Table 5 – Minimum Discount Quantity.

In Table 4, we have put a value of 0 for the manufacturer supplier capacity as we know from the historical data that the manufacturer does not supply part 1 to the dealers. We also assumed the discounts each source would offer if a minimum order quantity was placed as shown in Table 5 – Minimum Discount Quantity.

Using the Inventory Optimization formulation mentioned in the earlier section in the spreadsheet, and running the solver using the GRG Nonlinear method as shown in the figure 8 below, the optimal number of parts to be ordered for each dealer and the number of parts to be shipped between dealers is calculated while keeping the cost of purchasing and shipping minimum.

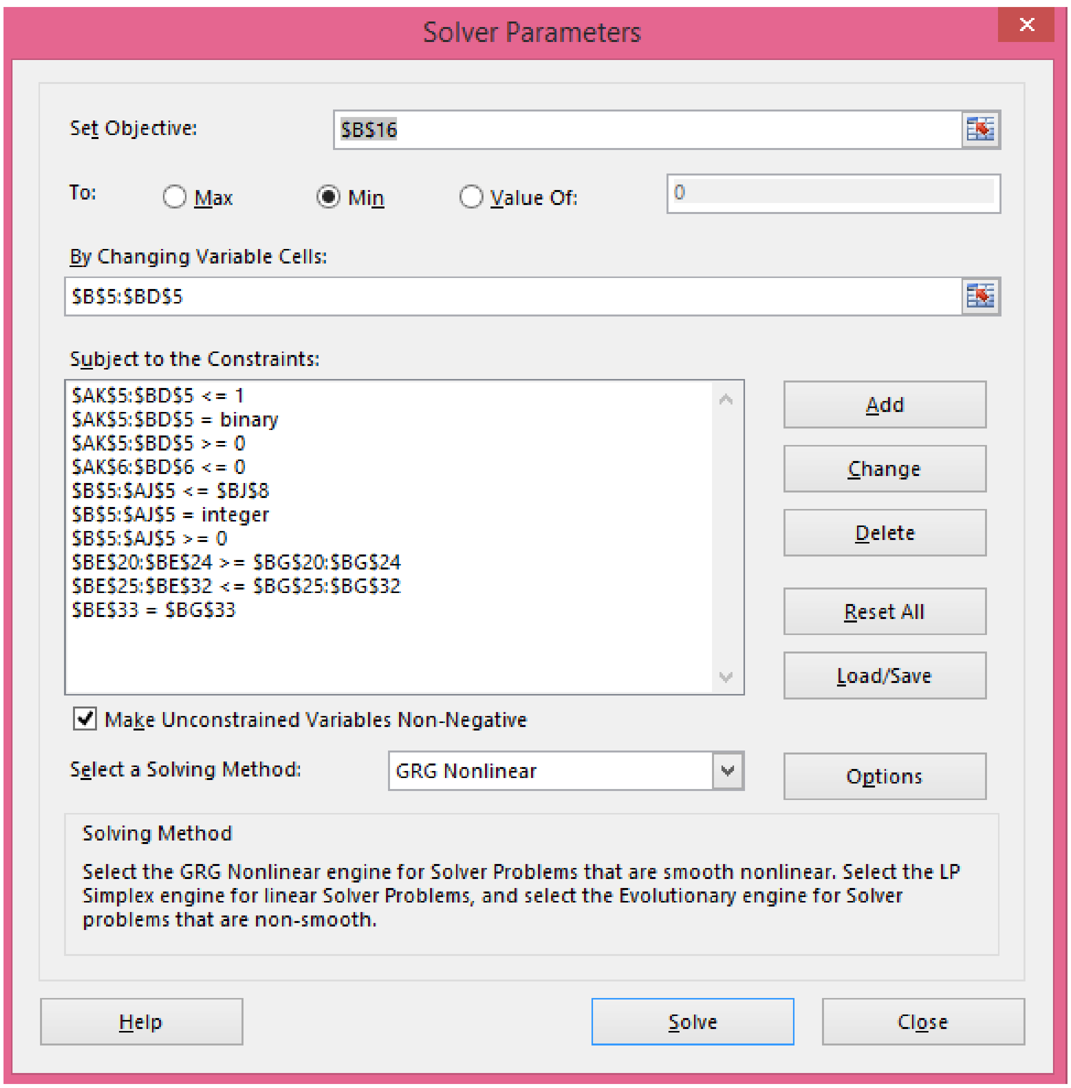



Figure 7 - Solver Parameters

From the inventory optimization see in Figure 7, we found that all dealers ordered parts from Isuzu first to meet their demand. Once the supply capacity from Isuzu was exceeded, the dealer 3 and dealer 4 ordered parts from 3rd party suppliers to meet their remaining demand. We also found that dealer 1 shipped parts from almost all dealers except dealer 4 due to a storage capacity constraint. Similarly, Dealer 3 shipped parts from dealer 1 and dealer 5 to meet the demand. The remaining dealers did not ship any parts from other dealers. This analysis shows us that the storage capacity of the dealer 1 and dealer 3 should be increased while reducing the storage capacity for other dealers in order to minimize the total cost by reducing the shipping cost.

We have also calculated the EOQ for meeting different percentages of demand and plotted a graph to show the maximum, minimum and average annual replenishment cost which includes cost of purchasing, ordering and holding of parts as shown in Figure 8 below.

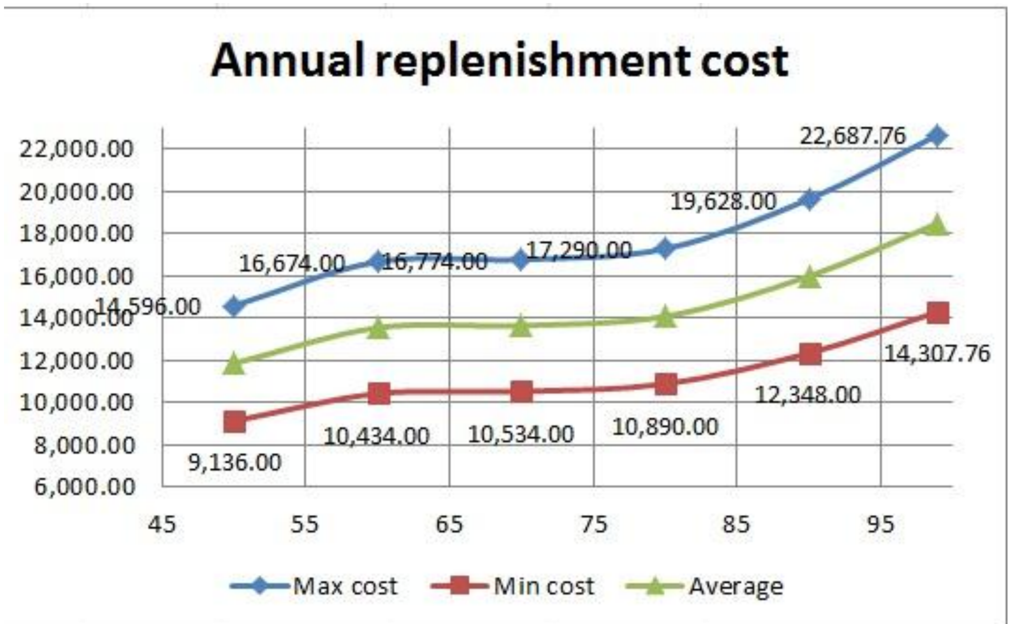



Figure 8 - Max, Min and Average replenishment costs

The above graph also shows that the replenishment costs are pretty much the same for meeting 60% to 80% of the demand and starts to increase exponentially for meeting 90% and 99% of the demand. This graph helps the dealership to understand the how the replenishment cost changes with respect to the percentage of demand met and decide whether to stock the part to meet 100% or only a percentage of the demand based on the demand fluctuations during the year.

## Applications

This model is designed to apply to a company with 5 retail locations that can order parts from 3 different types of sources, and can distribute parts between them for a fixed cost. It could be easily modified to account for different numbers of branches and sources. In its current state, the model can calculate a one-time optimal strategy for purchasing a quantity of a single part, given an expected demand. It can also calculate the quantity of the part that should be shipped between dealers to help meet demand at other sites. It can take into account constraints such as storage limitations, minimum inventory requirements, and maximum order restrictions. More constraints and calculations can be added to alter the purpose or increase the robustness without much difficulty.

## Conclusion

During our research into logistics, optimization, and the challenges that lie between, it became clear that the tool we were considering could be a very important part of business planning. We could also see the complexity and the challenges inherent in such a tool. It was important for us to narrow the focus, and limit the scope of the project to such a degree that our efforts were sufficient to make an impact. To that end, we identified the current business process and the target problem that exists. We set the goal of our optimization model so that we could make meaningful progress on a specific set of requirements. This goal was met with our optimization model. While there are many limitations, the functionality of this model is sufficient to calculate an inventory strategy to minimize cost both immediately, and through the year using EOQ. This model is however, intended as just a preliminary step toward application in a business environment.

## Future Research

Since we do not live in a perfect world, the model should be made more robust to take into account that everything does not go according to plan. Additionally in the future the project should have additional programming added to it using constraint satisfaction and the calculus of variations in order to harden the model and make it more usable.

- Constraint satisfaction studies the case in which the objective function $f$ is constant (this is used in artificial intelligence, particularly in automated reasoning).
- Calculus of variations seeks to optimize an objective defined over many points in time, by considering how the objective function changes if there is a small change in the choice path.

Other things to include would be support for more parts and time periods, pre-order and lead times, and variations in shipping costs. Item depreciation should also be included for future research as a part's value will change over time.

As we all know not every part will be ordered at the same time. This model does not take into account the varying order times, and is unable to calculate just-in-time delivery. As the solver needs to be run separately for each month and part, it is clear that the model cannot distinguish between them or set priorities. It also cannot take into account future availability, or demand.

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## Appendix 1 – Meeting Notes

Meeting notes 10/27/13

Minimized Cost

Cost: $C_1$*Cost of shipping

Decision Variable

How many to order each month

How many to ship between dealers

Constraints

Meet demand

Minimum inventory

Storage Capacity

CP = Cost of part

CS = Shipping Cost

D = Demand

Po = # parts to order

Ps = # parts to ship

M = Minimum Inventory

Data Tables

Existing Inventory

Cost of Part

Distance between Dealers

Cost of shipping part

Demand

Decision Variables

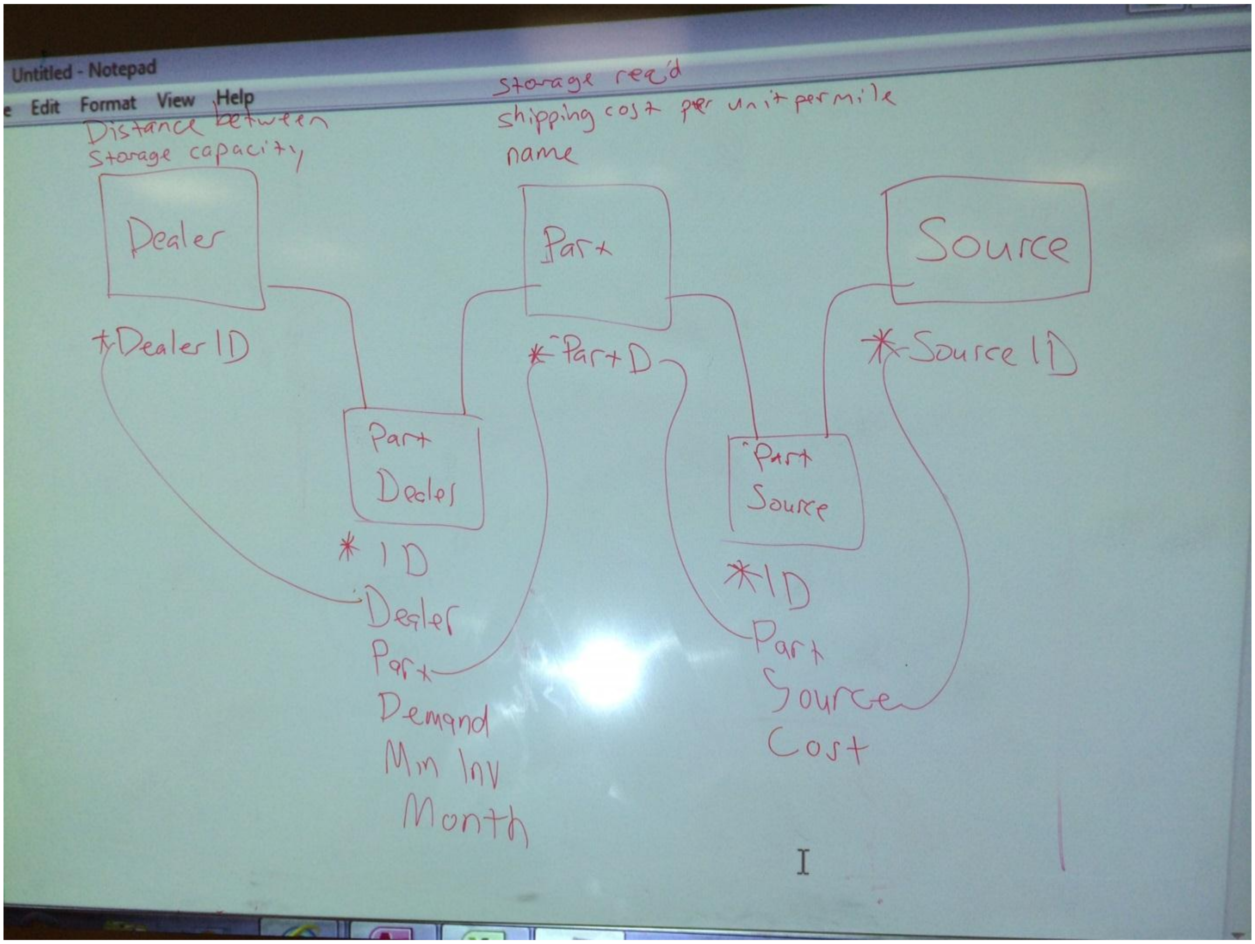
PART 1

# to order

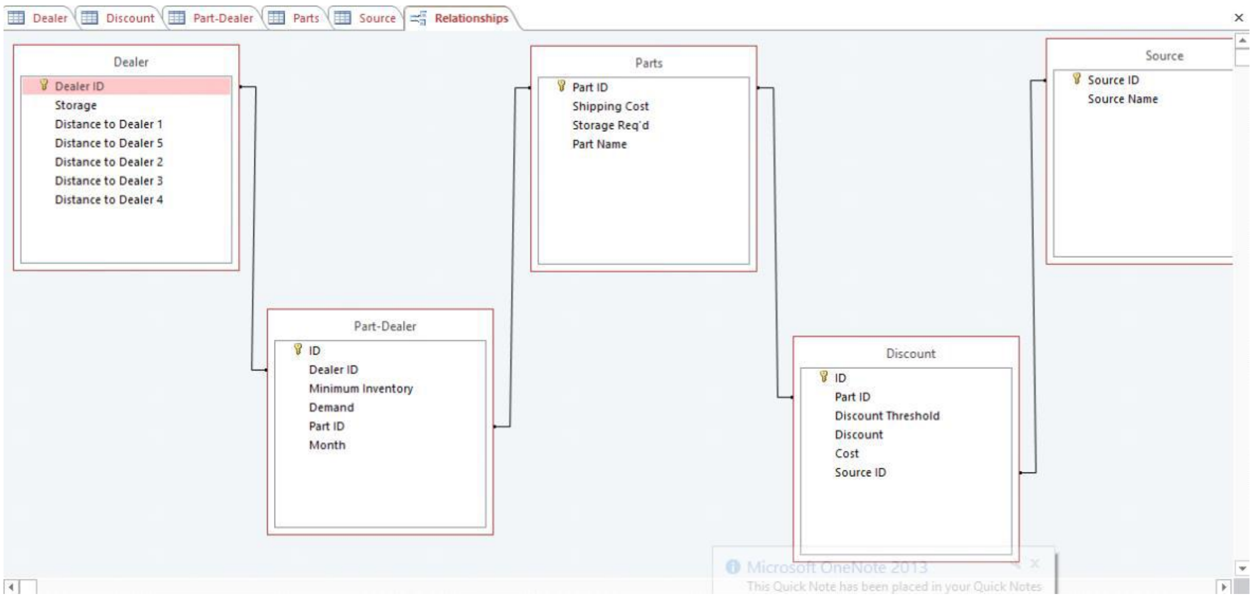
$Pi_1j_1k = \Sigma^3 j=1$

## Meeting notes 11/10/13

<u>Data Configuration and relationships</u>



Project Database Info-The relationships between the tables




Description for column names and units of measurement for:

Dealer table
Dealer id -A number assigned to dealers say 1 to dealer 1 (auto generated number)
Storage -Available storage at the dealer in sqft.
Distance to Dealer 1 -shipping distance between dealer and dealer1 in mi
Distance to Dealer 2 -shipping distance between dealer and dealer2 in mi
Distance to Dealer 3 -shipping distance between dealer and dealer3 in mi
Distance to Dealer 4 -shipping distance between dealer and dealer4 in mi
Distance to Dealer 5 -shipping distance between dealer and dealer5 in mi

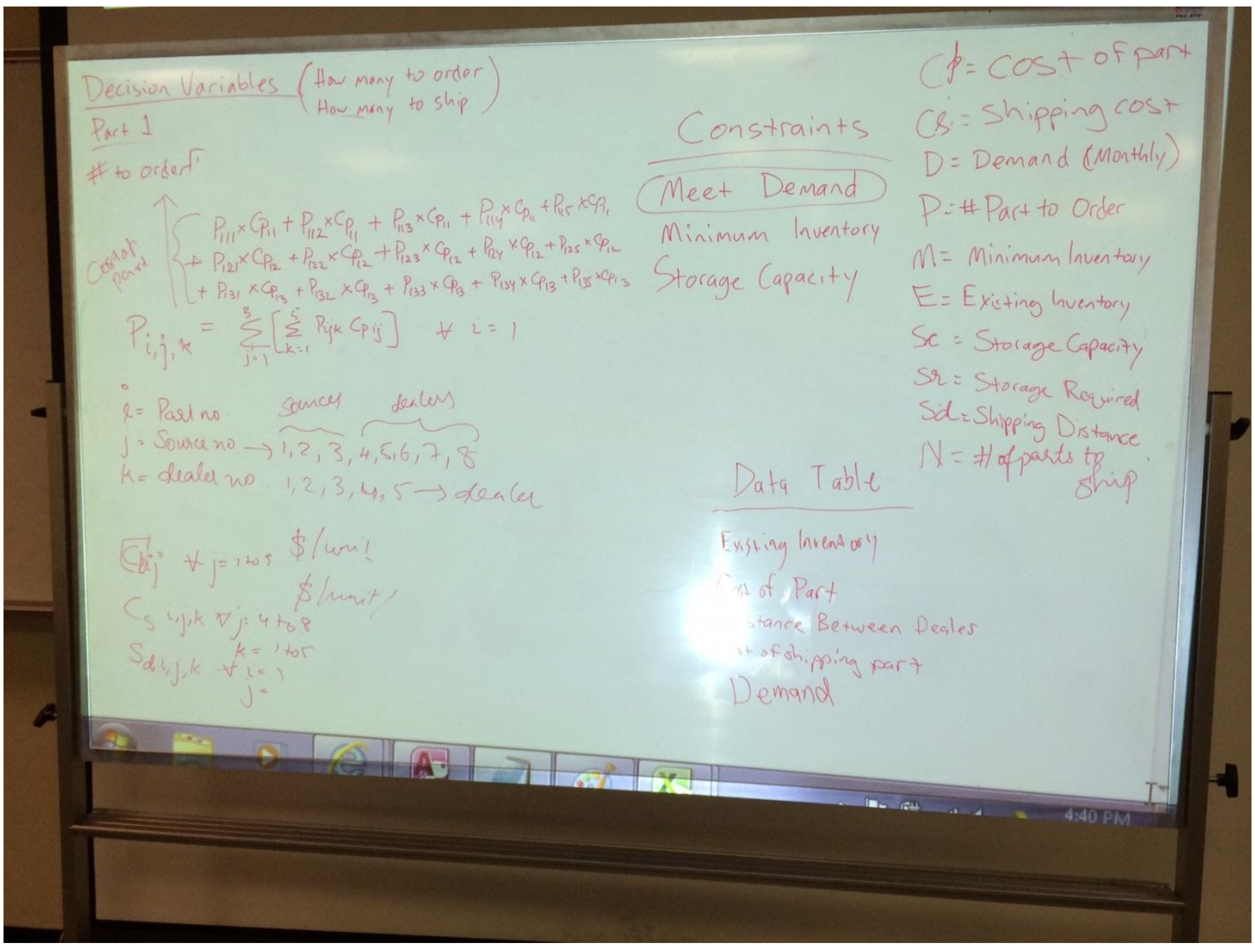
Parts table
Part id -a number assigned to parts (auto generated number)
Shipping Cost -Cost of shipping the part from one dealer to another in $/unit-mile
Storage Reqd -is the space required to store a unit of the part in sqft/unit
Part name -Name of the part for reference

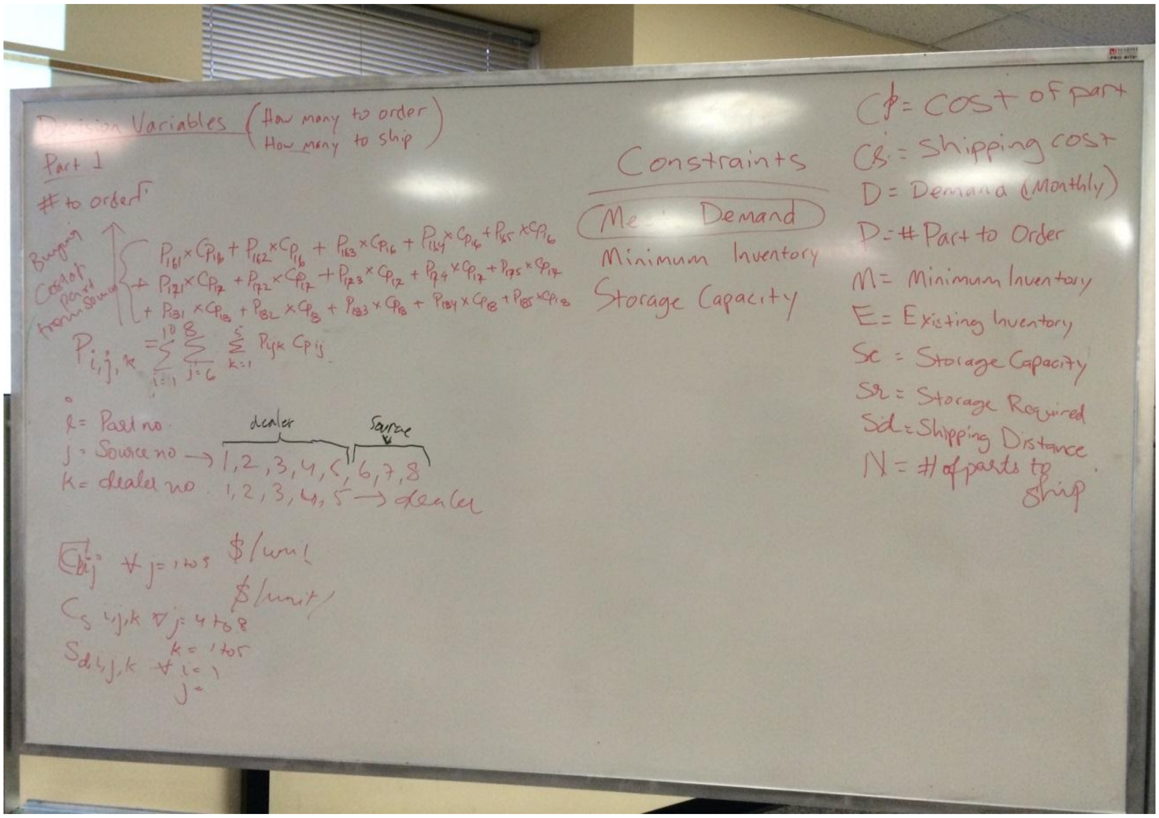
Parts Dealer table
Id -it is an auto generated number just for reference and to satisfy the primary key conditions in the table.
Dealer id -A number assigned to dealer
Minimum Inventory -Minimum inventory of a part required to be available at dealer in units
Demand -demand for the part for the dealer in units
Part id -a number assigned to parts
Month -the month of the year which is a number say 10 for OCT

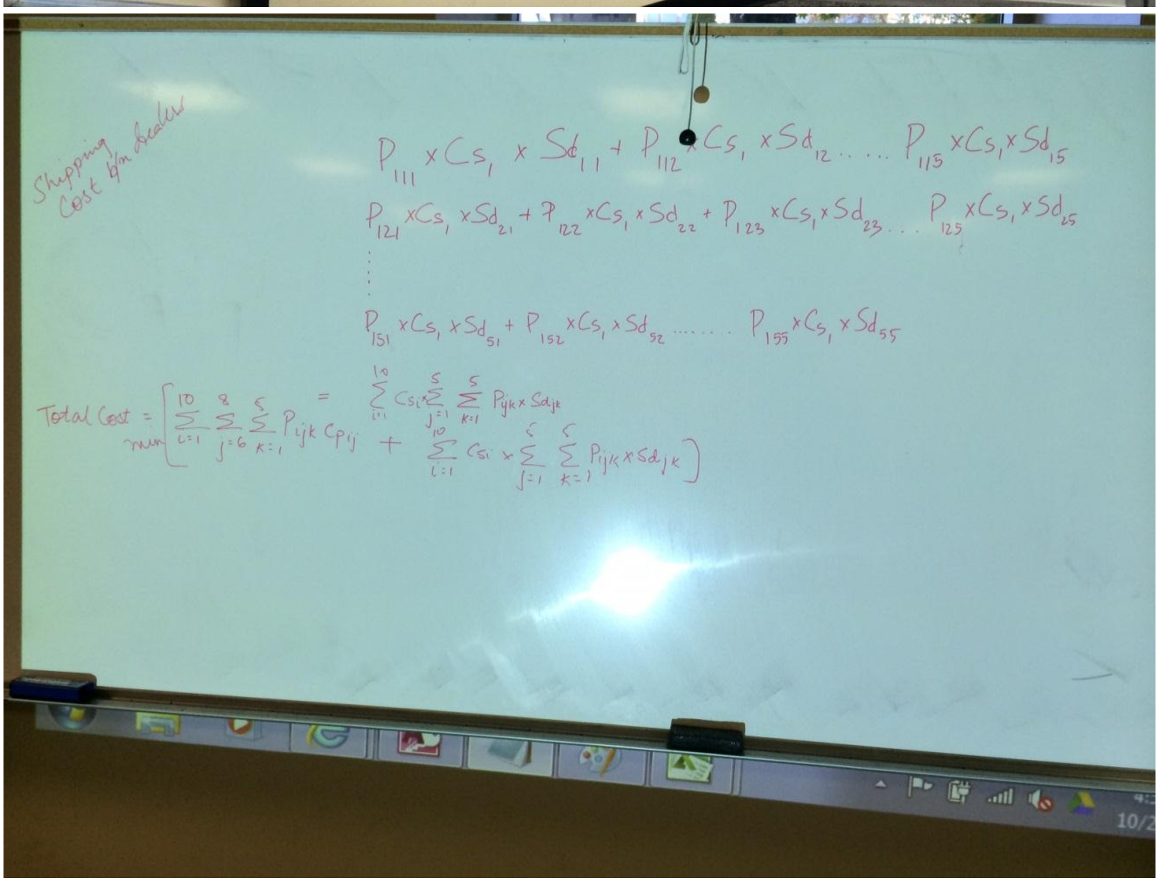
Source table
Source id - a number assigned to the source
Source name -name of the source for reference

Discount Table
Id -it is an auto generated number just for reference and to satisfy the primary key conditions in the table.
Part id -a number assigned to parts
Discount threshold -the minimum order number to avail a discount in units
Discount -the discount available in percentage
Cost -Cost of the part from the source in $/unit
Source id - a number assigned to the source

Formulation and Notes

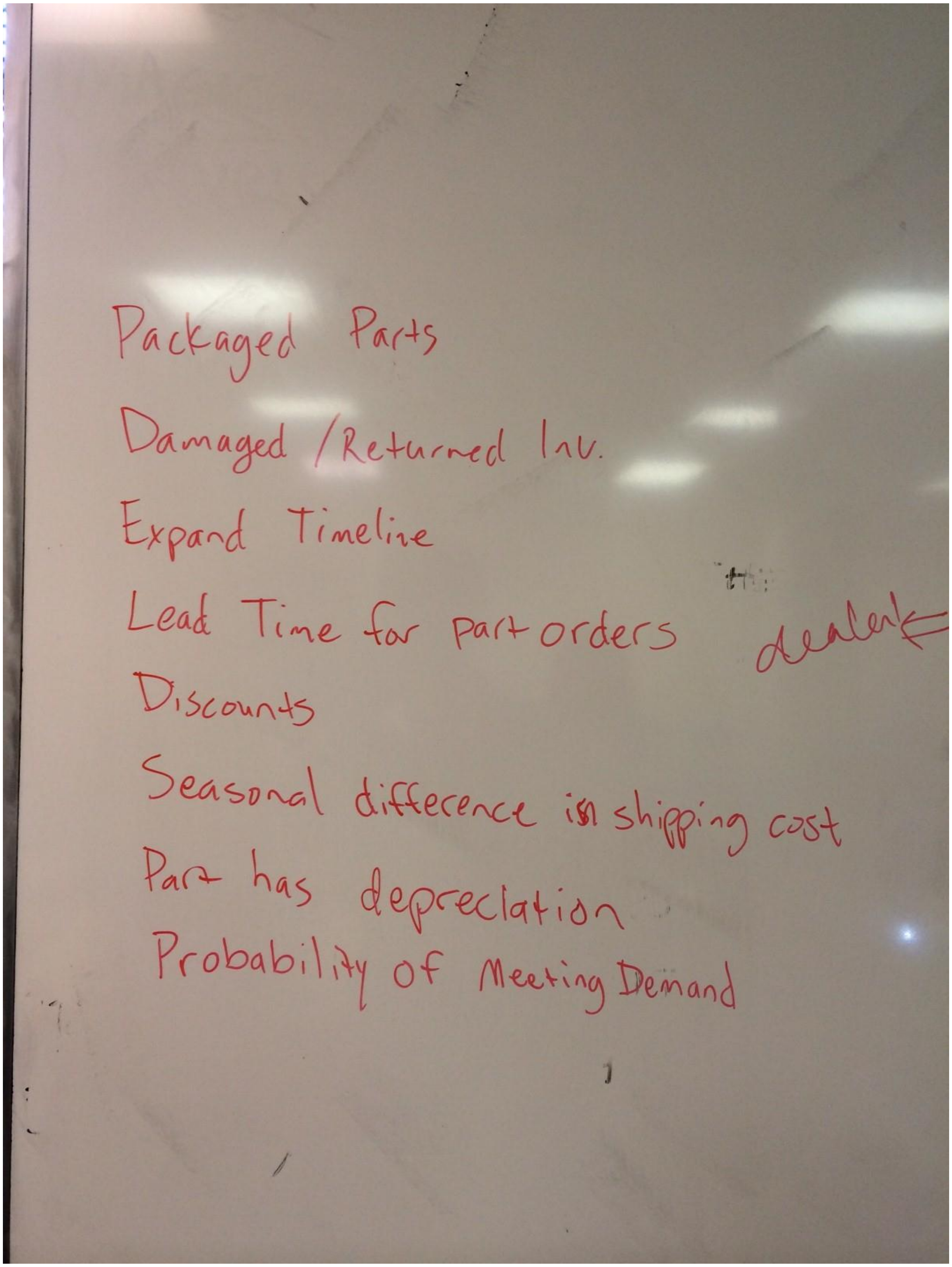



Decision Variables (How many to order / How many to ship)
Part 1
# to order
Constraints
Demand
Minimum Inventory
Storage Capacity
Cp = Cost of part
Cs = Shipping cost
D = Demand (Monthly)
P = # Part to Order
M = Minimum Inventory
E = Existing Inventory
Sc = Storage Capacity
Sr = Storage Required
Sd = Shipping Distance
N = # of parts to ship
i = Part no
j = Source no
k = dealer no
dealer
Source
1, 2, 3, 4, 5, 6, 7, 8
1, 2, 3, 4, 5 → dealer
$/unit


Shipping Cost b/n dealer
Total Cost =

Meeting notes 11/11/13

Possible Variables to add if time allows.



Meeting notes 11/17/13

Argument of per unit cost versus fixed cost for shipping of the parts. The team decided to run both to see which way was better. Other issues was figuring out liner equations problems when excel returned a nonlinear answer.

A discussion of using Binary N as a linking number.

The main issue within the group is dealing with part of the group wanting to do customization before we even get the primary formula to work with in the Excel program.

We were able to finally get the solver to run with none integer constraints.  There are some bugs to work out, but it is working.

The next step is to use integer constraints to see what happens. We tried it and it worked and it was fast.

Now we are going to each look at the additional options to include in the spread sheet and see if we can add them in.

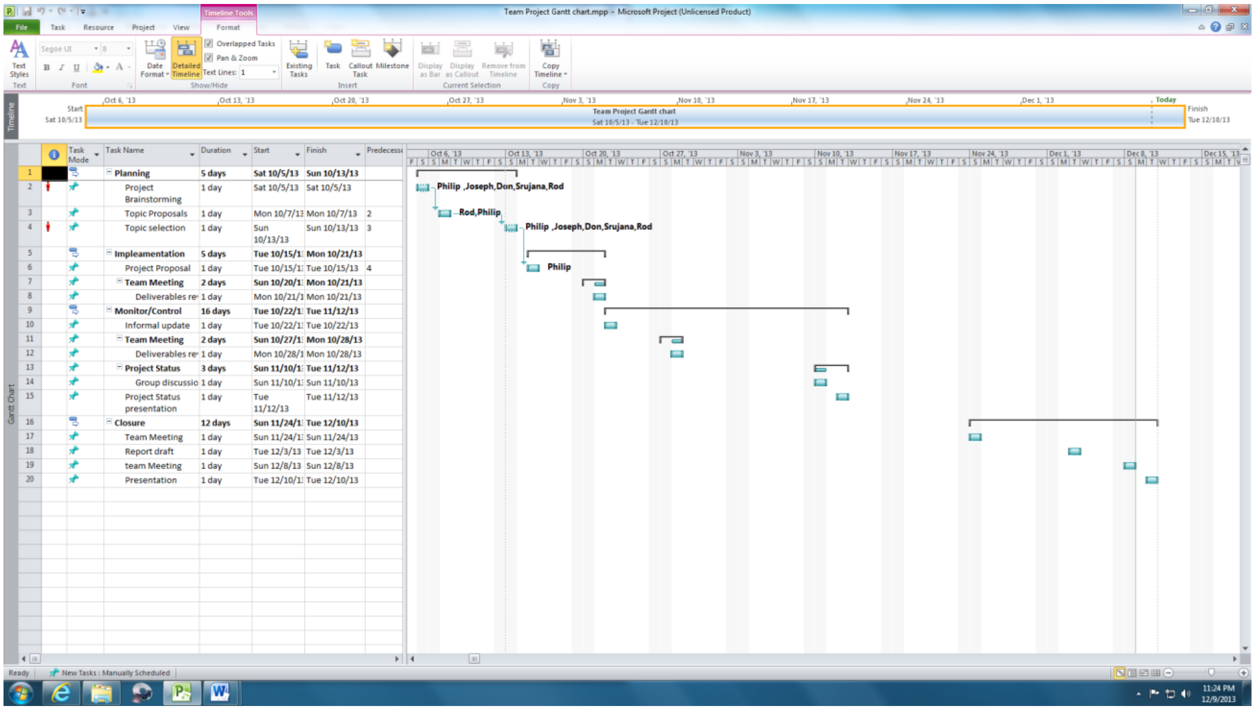
Probability - SJ

Time Line - Phil

Put data in data base. –Don

Research – Joe

## Appendix 2 - Gantt chart of Project




## Appendix – 3 Data

| Part 1 | | | | | |
|---|---|---|---|---|---|
| Column1 | Dealer 1 | Dealer 2 | Dealer 3 | Dealer 4 | Dealer 5 |
| Existing stock | 23 | 19 | 14 | 9 | 11 |
| Maximum Storage | 48 | 72 | 48 | 72 | 72 |
| Dealer 1 | 0 | 34.5 | 0 | 86.5 | 16.9 |
| Dealer 2 | 34.5 | 0 | 41.1 | 93.1 | 46 |
| Dealer 3 | 0 | 41.1 | 0 | 86.6 | 16.9 |
| Dealer 4 | 86.5 | 93.1 | 86.6 | 0 | 104 |
| Dealer 5 | 16.9 | 46 | 16.9 | 104 | 0 |

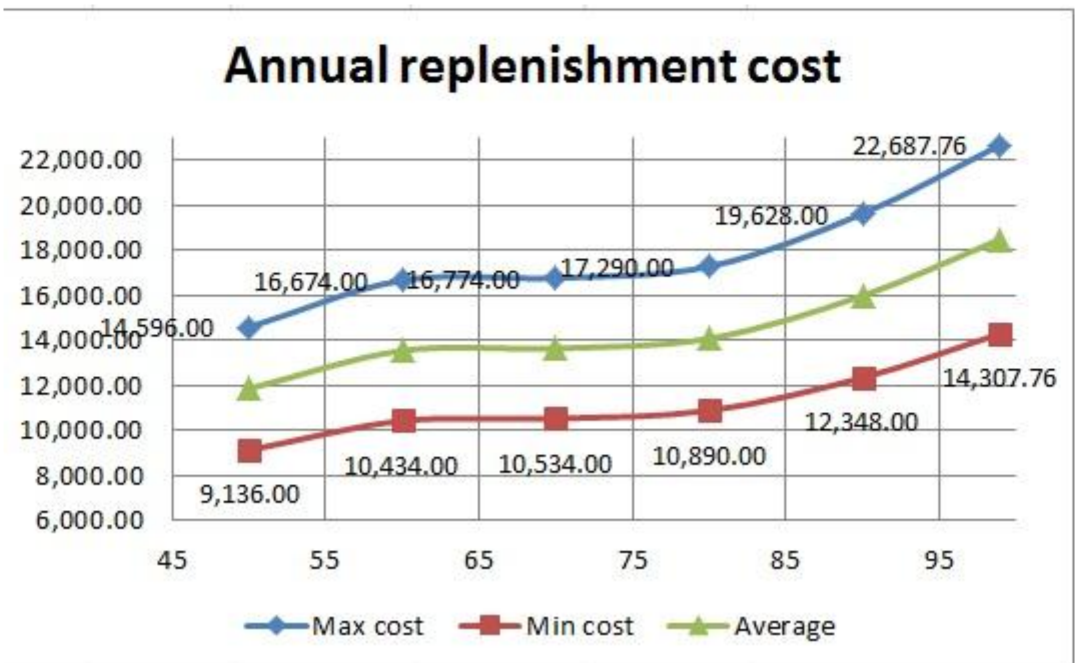
| | Part1 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Day | Dealer 1 | Dealer 2 | Dealer 3 | Dealer 4 | Dealer 5 | | | |
| 1 | 3 | 0 | 0 | 0 | 0 | | | |
| 2 | 3 | 0 | 0 | 0 | 0 | | | |
| 3 | 2 | 0 | 0 | 0 | 0 | | | |
| 4 | 2 | 0 | 0 | 0 | 0 | | | |
| 5 | 2 | 1 | 0 | 0 | 0 | | | |
| 6 | | | | | | | | |
| 7 | 2 | 0 | 0 | 0 | 1 | | | |
| 8 | 0 | 3 | 10 | 0 | 0 | | | |
| 9 | 2 | 1 | 8 | 0 | 1 | | | |
| 10 | 3 | 2 | 0 | 0 | 0 | | | |
| 11 | 7 | 1 | 3 | 0 | 0 | | | |
| 12 | 1 | 1 | 1 | 0 | 0 | | | |
| 13 | | | | | | | | |
| 14 | 5 | 0 | 2 | 0 | 0 | | | |
| 15 | 4 | 2 | 1 | 0 | 0 | | | |
| 16 | 2 | 2 | 0 | 0 | 0 | | | |
| 17 | 3 | 0 | 5 | 0 | 0 | | | |
| 18 | 2 | 2 | 1 | 2 | 0 | | | |
| 19 | 6 | 1 | 0 | 0 | 0 | | | |
| 20 | | | | | | | | |
| 21 | 2 | 0 | 3 | 0 | 2 | | | |
| 22 | 5 | 1 | 5 | 0 | 0 | | | |
| 23 | 0 | 0 | 0 | 0 | 0 | | | |
| 24 | 6 | 1 | 10 | 2 | 0 | | | |
| 25 | 4 | 0 | 2 | 3 | 0 | | | |
| 26 | 2 | 2 | 3 | 0 | 0 | | | |
| 27 | | | | | | | | |
| 28 | 2 | 1 | 2 | 0 | 0 | | | |
| 29 | 4 | 0 | 4 | 0 | 0 | | | |
| 30 | 1 | 0 | 3 | 0 | 0 | | | |
| 31 | 2 | 0 | 4 | 5 | 0 | | | |
| Max | 7 | 3 | 10 | 5 | 2 | | | |
| Min | 0 | 0 | 0 | 0 | 0 | | | |
| Average | 2.85 | 0.78 | 2.48 | 0.44 | 0.15 | | | |
| STD | 1.77 | 0.89 | 2.98 | 1.19 | 0.46 | | | |
| Count | 27 | 27 | 27 | 27 | 27 | | | |
| % to Cumulative | | | 70% | | | | | |
| Demand | 3.78 | 1.25 | 4.04 | 1.07 | 0.39 | per day | | |
| Demand | 22.68 | 7.47 | 24.26 | 6.40 | 2.32 | per Week | | |
| Demand per Week | 23 | 8 | 25 | 7 | 3 | per Week(round up) | | |
| Demand | 115 | 40 | 125 | 35 | 15 | For | 5 | Weeks |

| **Min. Quantity for discount** | **Supplier** | **Discount** |
|---|---|---|
| 200 | 1 | 0.2 |
| 100 | 2 | 0.1 |
| 50 | 3 | 0.3 |

| | Source to dealer | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dealer 1 | | | Dealer 2 | | | Dealer 3 | | | Dealer 4 | | | Dealer5 | | |
| | Po111 | Po121 | Po131 | Po112 | Po122 | Po132 | Po113 | Po123 | Po133 | Po114 | Po124 | Po134 | Po115 | Po125 | Po135 |
| **Decision Variables** | 0 | 29 | 26 | 0 | 0 | 25 | 0 | 133 | 1 | 0 | 80 | 0 | 0 | 0 | 0 |
| Binary Linkage | | | | | | | | | | | | | | | |
| **Data** | | | | | | | | | | | | | | | |
| Price of part 1 | 40 | 27 | 35 | 40 | 27 | 35 | 40 | 27 | 35 | 40 | 27 | 35 | 40 | 27 | 35 |
| Distance between dealer | | | | | | | | | | | | | | | |
| Cost of shipping/km in Baht | | | | | | | | | | | | | | | |
| Cost of shipping | | | | | | | | | | | | | | | |
| | Minimise | | | | | | | | | | | | | | |
| **Objective Function** | Cost | | | | | | | | | | | | | | |
| | 8527 | | | | | | | | | | | | | | |
| **Constraints** | | | | | | | | | | | | | | | |
| Dealer 1 Demand | 1 | 1 | 1 | | | | | | | | | | | | |
| Dealer 2 Demand | | | | 1 | 1 | 1 | | | | | | | | | |
| Dealer 3 Demand | | | | | | | 1 | 1 | 1 | | | | | | |
| Dealer 4 Demand | | | | | | | | | | 1 | 1 | 1 | | | |
| Dealer 5 Demand | | | | | | | | | | | | | 1 | 1 | 1 |
| Dealer 1 Capacity | 1 | 1 | 1 | | | | | | | | | | | | |
| Dealer 2 Capacity | | | | 1 | 1 | 1 | | | | | | | | | |
| Dealer 3 Capacity | | | | | | | 1 | 1 | 1 | | | | | | |
| Dealer 4 Capacity | | | | | | | | | | 1 | 1 | 1 | | | |
| Dealer 5 Capacity | | | | | | | | | | | | | 1 | 1 | 1 |
| Mfr Capacity | 1 | | | 1 | | | 1 | | | 1 | | | 1 | | |
| Isuzu Capacity | | 1 | | | 1 | | | 1 | | | 1 | | | 1 | |
| 3rd Party | | | 1 | | | 1 | | | 1 | | | 1 | | | 1 |
| Order Quantity | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| | Dealer to dealer | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | to dealer 1 | | | | to dealer 2 | | | | to dealer 3 | | | | to dealer 4 | | | | to dealer 5 | | | |
| | Ps121 | Ps131 | Ps141 | Ps151 | Ps112 | Ps132 | Ps142 | Ps152 | Ps113 | Ps123 | Ps143 | Ps153 | Ps114 | Ps124 | Ps134 | Ps154 | Ps115 | Ps125 | Ps135 | Ps114 |
| **Decision Variables** | 0 | 4 | 49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Binary Linkage | | | | | | | | | | | | | | | | | | | | |
| **Data** | | | | | | | | | | | | | | | | | | | | |
| Price of part 1 | | | | | | | | | | | | | | | | | | | | |
| Distance between dealer | 34.5 | 0 | 86.5 | 16.9 | 34.5 | 41.1 | 93.1 | 46 | 0 | 41.1 | 86.6 | 16.9 | 86.5 | 93.1 | 86.6 | 104 | 16.9 | 46 | 16.9 | 104 |
| Cost of shipping/km in Baht | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Cost of shipping | 69 | 0 | 173 | 33.8 | 69 | 82.2 | 186.2 | 92 | 0 | 82.2 | 173.2 | 33.8 | 173 | 186.2 | 173.2 | 208 | 33.8 | 92 | 33.8 | 208 |
| **Objective Function** | | | | | | | | | | | | | | | | | | | | |
| **Constraints** | | | | | | | | | | | | | | | | | | | | |
| Dealer 1 Demand | 1 | 1 | 1 | 1 | -1 | | | | -1 | | | | -1 | | | | -1 | | | |
| Dealer 2 Demand | -1 | | | | 1 | 1 | 1 | 1 | | -1 | | | | -1 | | | | -1 | | |
| Dealer 3 Demand | | -1 | | | | -1 | | | 1 | 1 | 1 | 1 | | | -1 | | | | -1 | |
| Dealer 4 Demand | | | -1 | | | | -1 | | | | -1 | | 1 | 1 | 1 | 1 | | | | -1 |
| Dealer 5 Demand | | | | -1 | | | | -1 | | | | -1 | | | | -1 | 1 | 1 | 1 | 1 |
| Dealer 1 Capacity | | | | | | | | | | | | | | | | | | | | |
| Dealer 2 Capacity | | | | | | | | | | | | | | | | | | | | |
| Dealer 3 Capacity | | | | | | | | | | | | | | | | | | | | |
| Dealer 4 Capacity | | | | | | | | | | | | | | | | | | | | |
| Dealer 5 Capacity | | | | | | | | | | | | | | | | | | | | |
| Mfr Capacity | | | | | | | | | | | | | | | | | | | | |
| Isuzu Capacity | | | | | | | | | | | | | | | | | | | | |
| 3rd Party | | | | | | | | | | | | | | | | | | | | |
| Order Quantity | | | | | | | | | | | | | | | | | | | | |

| | N121 | N131 | N141 | N151 | N112 | N132 | N142 | N152 | N113 | N123 | N143 | N153 | N114 | N124 | N134 | N154 | N115 | N125 | N135 | N114 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Decision Variables** | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | |
| Binary Linkage | 0 | -121 | -76 | 0 | 0 | 0 | 0 | 0 | -125 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | M= | 125 | |
| **Data** | | | | | | | | | | | | | | | | | | | | | | | |
| Price of part 1 | | | | | | | | | | | | | | | | | | | | | | | |
| Distance between dealer | | | | | | | | | | | | | | | | | | | | | | | |
| Cost of shipping/km in Baht | | | | | | | | | | | | | | | | | | | | | | | |
| Cost of shipping | | | | | | | | | | | | | | | | | | | | | | | |
| **Objective Function** | | | | | | | | | | | | | | | | | | | | | | | |
| **Constraints** | | | | | | | | | | | | | | | | | | | | | | | |
| Dealer 1 Demand | | | | | | | | | | | | | | | | | | | | | 131 | >= | 115 |
| Dealer 2 Demand | | | | | | | | | | | | | | | | | | | | | 44 | >= | 40 |
| Dealer 3 Demand | | | | | | | | | | | | | | | | | | | | | 144 | >= | 125 |
| Dealer 4 Demand | | | | | | | | | | | | | | | | | | | | | 40 | >= | 35 |
| Dealer 5 Demand | | | | | | | | | | | | | | | | | | | | | 11 | >= | 15 |
| Dealer 1 Capacity | | | | | | | | | | | | | | | | | | | | | 78 | <= | 80 |
| Dealer 2 Capacity | | | | | | | | | | | | | | | | | | | | | 44 | <= | 130 |
| Dealer 3 Capacity | | | | | | | | | | | | | | | | | | | | | 148 | <= | 150 |
| Dealer 4 Capacity | | | | | | | | | | | | | | | | | | | | | 89 | <= | 120 |
| Dealer 5 Capacity | | | | | | | | | | | | | | | | | | | | | 11 | <= | 70 |
| Mfr Capacity | | | | | | | | | | | | | | | | | | | | | 0 | <= | 0 |
| Isuzu Capacity | | | | | | | | | | | | | | | | | | | | | 242 | <= | 500 |
| 3rd Party | | | | | | | | | | | | | | | | | | | | | 52 | <= | 500 |
| Order Quantity | | | | | | | | | | | | | | | | | | | | | 294 | = | 330 |



## Appendix – 4 Optimization and EOQ Results from 50% to 99%

50%

| | | | |
|---|---|---|---|
| % to Cumulative | | 50% | |
| Annual demand assuming a 10% variance | | 2184.0 | |
| Carrying Cost is 10% of cost of part from Manufacturer | | 4 | |
| Ordering cost per order | | 50 | |
| | | | |
| | Q | Order times | total order |
| Decision Variables | 273 | 8 | 2184 |
| | | | |
| Carrying cost | 546.00 | | |
| Ordering Cost | 400.00 | | |
| | | | |
| Total Cost | 946.00 | | |
| Maximum annual replenishment cost | 14,596.00 | | |
| Minimum annual replenishment cost | 9,136.00 | | |

60%

| | | | |
|---|---|---|---|
| % to Cumulative | | 60% | |
| Annual demand assuming a 10% variance | | 2808.0 | |
| Carrying Cost is 10% of cost of part from Manufacturer | | 4 | |
| Ordering cost per order | | 50 | |
| | | | |
| | Q | Order times | total order |
| Decision Variables | 312 | 9 | 2808 |
| | | | |
| Carrying cost | 624.00 | | |
| Ordering Cost | 450.00 | | |
| | | | |
| Total Cost | 1,074.00 | | |
| Maximum annual replenishment cost | 16,674.00 | | |
| Minimum annual replenishment cost | 10,434.00 | | |

70%

| | | | |
|---|---|---|---|
| % to Cumulative | | 70% | |
| Annual demand assuming a 10% variance | | 3432.0 | |
| Carrying Cost is 10% of cost of part from Manufacturer | | 4 | |
| Ordering cost per order | | 50 | |
| | | | |
| | Q | Order times | total order |
| Decision Variables | 312 | 11 | 3432 |
| | | | |
| Carrying cost | 624.00 | | |
| Ordering Cost | 550.00 | | |
| | | | |
| Total Cost | 1,174.00 | | |
| Maximum annual replenishment cost | 16,774.00 | | |
| Minimum annual replenishment cost | 10,534.00 | | |

80%

| | | | |
|---|---|---|---|
| % to Cumulative | | 80% | |
| Annual demand assuming a 10% variance | | 4160.0 | |
| Carrying Cost is 10% of cost of part from Manufacturer | | 4 | |
| Ordering cost per order | | 50 | |
| | | | |
| | Q | Order times | total order |
| Decision Variables | 320 | 13 | 4160 |
| | | | |
| Carrying cost | 640.00 | | |
| Ordering Cost | 650.00 | | |
| | | | |
| Total Cost | 1,290.00 | | |
| Maximum annual replenishment cost | 17,290.00 | | |
| Minimum annual replenishment cost | 10,890.00 | | |

90%

| | | | | |
|---|---|---|---|---|
| % to Cumulative | | 90% | | |
| Annual demand assuming a 10% variance | | 5096.0 | | |
| Carrying Cost is 10% of cost of part from Manufacturer | | 4 | | |
| Ordering cost per order | | 50 | | |
| | | | | |
| | Q | Order times | | total order |
| Decision Variables | 364 | 14 | | 5096 |
| | | | | |
| Carrying cost | 728.00 | | | |
| Ordering Cost | 700.00 | | | |
| | | | | |
| Total Cost | 1,428.00 | | | |
| Maximum annual replenishment cost | 19,628.00 | | | |
| Minimum annual replenishment cost | 12,348.00 | | | |

99%

| | | | | |
|---|---|---|---|---|
| % to Cumulative | | 99% | | |
| Annual demand assuming a 10% variance | | 7540.0 | | |
| Carrying Cost is 10% of cost of part from Manufacturer | | 4 | | |
| Ordering cost per order | | 50 | | |
| | | | | |
| | Q | Order times | | total order |
| Decision Variables | 419 | 18 | | 7542 |
| | | | | |
| Carrying cost | 838.00 | | | |
| Ordering Cost | 899.76 | | | |
| | | | | |
| Total Cost | 1,737.76 | | | |
| Maximum annual replenishment cost | 22,687.76 | | | |
| Minimum annual replenishment cost | 14,307.76 | | | |

| % | QTY | Times | Max cost | Min cost | Average | Sample Ordering cost |
|---|---|---|---|---|---|---|
| 99 | 419 | 18 | 22,687.76 | 14,307.76 | 18,497.76 | 12,962 |
| 90 | 364 | 14 | 19,628.00 | 12,348.00 | 15,988.00 | 11,416 |
| 80 | 320 | 13 | 17,290.00 | 10,890.00 | 14,090.00 | 9,830 |
| 70 | 312 | 11 | 16,774.00 | 10,534.00 | 13,654.00 | 7,197 |
| 60 | 312 | 9 | 16,674.00 | 10,434.00 | 13,554.00 | 7,197 |
| 50 | 273 | 8 | 14,596.00 | 9,136.00 | 11,866.00 | 8,527 |