Inventory Reduction by Converting Make-To-Stock parts into Make-To-Order

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Abstract

A company produces over extremely many items and delivers to customer, and while these items are inexpensive, customers cannot be stocked out. If a stock out were to ever occur, the customer account would be lost and the penalty cost will be extremely high. Therefore, the company has to supply the items to customer without stock out. This in turn requires the company to store large amounts of inventory and operate some warehouses (close to customer sites) where this inventory can be located. The high inventory levels cause high carrying and warehouse operating costs. The objective of this project is to help the company reduce inventory levels and optimize their supply chain operations.

After careful statistical analysis of historical sales and inventory data, we determine that the demand is stationary for most items; hence the assumptions of the Economic Order Quantity (EOQ) model are satisfied. The novelty of the inventory reduction approach is converting some of the Make to Stock (MTS) items into Make to Order (MTO), and then proving via discrete event simulation that the production system is able to meet the composite MTS and MTO demand within a five day response time. We demonstrate that successful deliveries can be made when 60 major items (which constitute 85% of the demand) are MTS and the remaining 40 major items (which constitute 10% of the demand) and other low volume/frequency items are MTO. This results in a significant 44% reduction in inventory from current levels.

This report documents the details on the this paper in the following: (i) analysis of demand distribution for each item, (ii) selection of MTS and MTO items, (iii)

determination of EOQ for each of the MTS items, (iv) stochastic simulation modeling and analysis of the composite MTS and MTO model, (v) comparison of the simulation result with current real situation, (vi) simulation of the case where some additional MTS items could be switched to MTO items.

Dedication

To my wife and daughter:

They are my future and dream.

I do my best for them forever.

And I appreciate my parents.

Acknowledgement

I would much like to express my sincere gratitude to my advisor who is Dr. Nagi for his support, guidance, and encouragement. When I came to study here from South Korea, I had many difficulties as like different academic systems, cultures, and language. Above of all, the language was a big difficulty. It is still big difficulty. While I had been doing study and research, he encouraged and taught many things in detail. It is very helpful to me.

I would also like to thank many other staffs. They are very cooperative and kind. Even though I could not speak English well, they understood and helped anytime. Especially I really appreciate Mike Monberg and Gary Rosenberg.

Without them - Dr. Nagi, Mike Monberg, and Gary Rosenberg etc, I could not do this research. This thesis is a result of their cooperation.

Once more, I really appreciate all people for this thesis.

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Chapter 1

Introduction

1.1 Introduction

Often the items that produced by a company are relatively inexpensive; optimizing inventory level becomes a low priority. However, over excessive inventory carrying cost may occur and large warehouses are needed. Excess inventory may be been further compounded by the fact that the items may be essential to customers, and any stock out may be unacceptable – it would mean heavy penalties and lost customer goodwill to a point of losing the account. Hence, inventory levels are distributed, closer to customer sites, and the levels are fairly high. Nevertheless, the inventory value adds up at the various distributed sites and for an industrial case we estimated that $600,000 worth of inventory is in the system at any point in time. At modest inventory carrying cost rates (say 10% to 20%) this translates into lost opportunity cost for the capital tied up in inventory ($60,000 to $120,000 in annual costs). A fraction of savings in these distributed inventories will lead to reduction in inventory carrying costs and obsolescence. It will further lead to smaller warehouses and elimination of excessive operating costs, directly impacting the bottom line of the company.

This research has conducted a detailed analysis of the inventory situation for the various products at the distributed warehouses and customer locations, including the home facility near the main plant. The process begun with a detailed data analysis of product demand and trends at customer sites, development of statistical demand distributions, an understanding of service level expectations and collection of information on warehouse locations and inventory levels held. At first, inventory reduction is attempted by adjusting levels to the optimized inventory model such a

Economic Order Quantity (EOQ) value if the models are valid, and demonstrating that the service level expectation can be met at these lower levels. Second, converting some of the slower moving items from Make-to-Stock (MTS) to Make-to-Order (MTO) without affecting the 5 day delivery time is used to further reduce inventory levels. This required developing a market simulator of demand and discrete event simulation modeling using Arena to demonstrate that stock out will not occur. (The simulation modeling task replaced the earlier anticipated mathematical optimization model to optimize the joint warehouse location and inventory sizing problem. This is also because upon data analysis this paper determined that the company had very few items that are stared between customers for which inventory consolidation might have achieved.) A systematic literature review into the state-of-the-art in this field was also conducted to bring the best-in-class knowledge in the field of supply chain and inventory optimization. It is understood that the logistics situation is intertwined with the inventory replenishment plan. After EOQ calculations, we considered how the full truck load deliveries would affect the inventory costs.

The overall objectives of this thesis are summarized as follows: (1) Data collection and analysis on the inventory reduction problem; and (2) Simulation Modeling for supply chain optimization. The first objective provides inputs to the second and also serves as an ongoing mechanism for the company's future growth.

1.2 Research Approach

Data collection: An understanding of the products, customer sites, warehouse locations and logistics features of company’s current supply chain situation was the first task. To accomplish this, the research worked with the company’s management to collect company sales histories with historical annual volumes of products ordered (or consumed) by the customers. Furthermore, specific order information was also collected to develop demand distributions. Inventory levels for the various products were also collected. Queries from the Enterprise Resource Planning (ERP) System were written to assist the data gathering effort. This paper also studied the distribution system, how sales representatives interact with the clients and report back on sales composites that form the production forecasts. This paper assume to understand the impact of stock outs to customers, the penalties would be losing the account and deemed excessive. Inventory holding/carrying costs information was also determined using 5% interest rate. Set-up cost information for processing a batch of type A item or type B item products was also collected. Warehouse information and logistics costs were also collected.

Statistical Analysis: This involves fitting statistical distributions to the demand data collected. Minitab or Arena software's input analyzer was employed and goodness-of-fit tests were performed to determine the distribution and its parameters.

Inventory reduction through optimized policies and parameters: After data analysis I determined that the demand was stationary for most products, i.e., the mean value of the demand did not change with time (see also Section 3.1). Consequently, the simplest of inventory models referred to as the Economic Order Quantity (EOQ) was adopted. This research also performed literature review on the EOQ model with risk of the product being returned or never ordered again, with small probability. The safety stock was also determined by ensuring that largest (or almost largest) demand during order replenishment lead-time could be addressed (see Section 4). Thus, for Make-to-Stock items, a lot-reorder point system was proposed and verified through a simulation environment. This task was intended to specifically target the estimated $600,000 worth of inventory that is distributed in the current supply chain.

Supply chain modeling: It was less known that few items were common to multiple customers. Hence we had proposed formulating a mathematical model of the current supply chain network that will represent the flows of products from the main plant to the various warehouse locations and, finally, to customer sites. The mathematical model was to consider the joint optimization of location choices (for warehousing), logistics and inventory costs. Since the data analysis revealed that there was little or no commonality among items ordered by different customers, inventory consolidation or pooling or relocation was not very relevant. Hence, we replaced this effort by a simulation modeling task (see Sections 6 and 7).

Model Optimization: Once the simulation models were formulated, they were implemented in the ARENA simulation environment and testing was performed. This permitted us to test and validate various inventory reduction strategies such as converting some of the Make-to-Stock items to Make-to-order, and ensuring that no stock outs would occur within a 5 day replenishment lead-time.

In the remainder of the report, we present the current warehouse and delivery system of the supply chain in Section 2. Section 3 is devoted to the demand data analysis and collection of current inventory levels. The development of EOQ inventory model is presented in Section 4. Section 5 present the novel inventory reduction method of converting some of the MTS items to MTO. Sections 6 and 7 present two versions of the simulation model formulate and the results that were obtained. We conclude the benefit of our proposed inventory management system in Section 8.

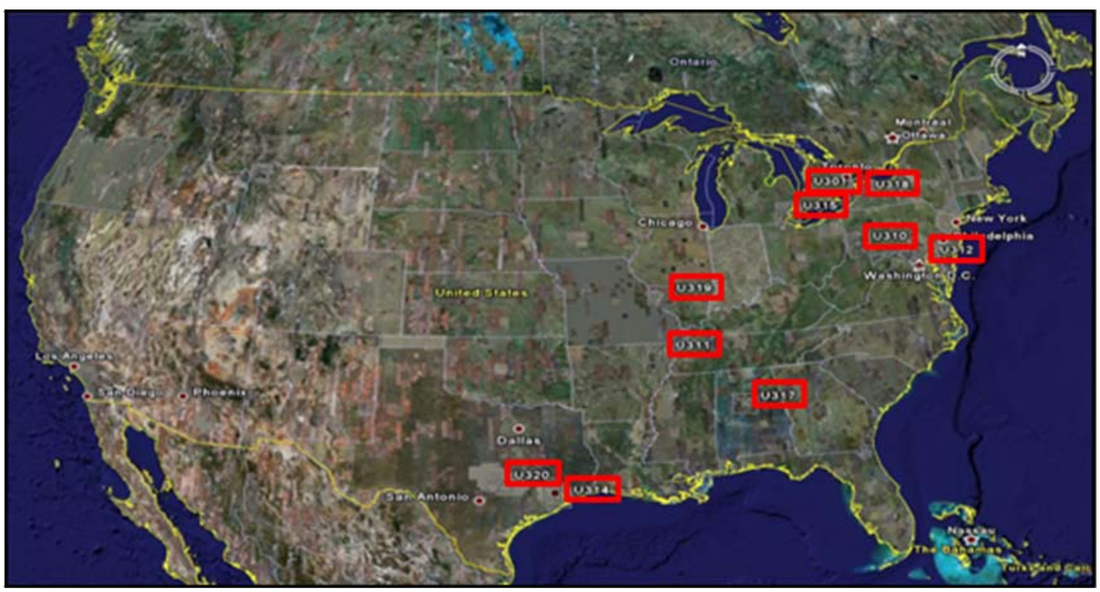
Chapter 2

Warehouse and Delivery Systems

2.1 Warehouse Locations

There are 11 warehouses in the supply chain, and one location is reserved for "in transit". A number of these warehouses are located next to high demand or consignment customers and store products that are relevant to that (or those regional) customer(s). Location U301 is for the warehouse at the company's main plant. U313 is not an actual warehouse, but is used to indicate the stocks that are in transit status. Figure 2.1 presents the warehouse code and distributed locations.

Figure 2.1: Warehouse locations



Most stocks are maintained at U301 (Main plant). The stocks in U301 are determined to be over 70%. The U318 warehouse is another warehouse near main plant.

If the stocks in U318 are added to U301, the portion should be over 80%. This means that most products are kept locally after production, and warehouses except U301 are used to service few major clients. Table 2.2 presents the stock levels at each warehouse for year 2006 (12 months).

Table 2.1: The stock portion of each warehouse

Warehouse	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Portion
U301	3474	3291	3194	3162	3174	3393	3094	3357	3368	3455	3137	2881	38980	**71.8%**
U310	311	258	239	161	208	162	163	161	162	99	118	64	2106	**3.9%**
U311	105	111	72	66	105	118	152	192	149	75	110	206	1461	**2.7%**
U312	145	125	121	147	91	172	172	170	167	128	114	158	1710	**3.2%**
U313	0	0	235	188	207	131	170	37	0	0	0	0	968	**1.8%**
U314	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.0%**
U315	228	67	106	76	19	89	59	81	68	50	56	41	940	**1.7%**
U316	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.0%**
U317	109	93	96	83	75	80	103	125	99	81	119	89	1152	**2.1%**
U318	407	528	501	542	495	524	443	486	417	291	418	392	5444	**10.0%**
U319	168	113	110	79	129	112	150	173	139	140	85	104	1502	**2.8%**
U320	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.0%**

2.2 Delivery System

There are two systems for delivery from the company to its clients. One is the direct delivery and another is the delivery via warehouse. The direct delivery is that products are delivered to clients from U301 or U318. Most products are delivered to clients by direct delivery. The other way - via a warehouse is that the products are once delivered to each warehouse and then transported to clients. If there is a return, it follows a reverse order. The clients can return the products to the company directly in direct delivery systems or to both the company and a warehouse in via delivery system. Figure 2.2 shows the delivery route of company.

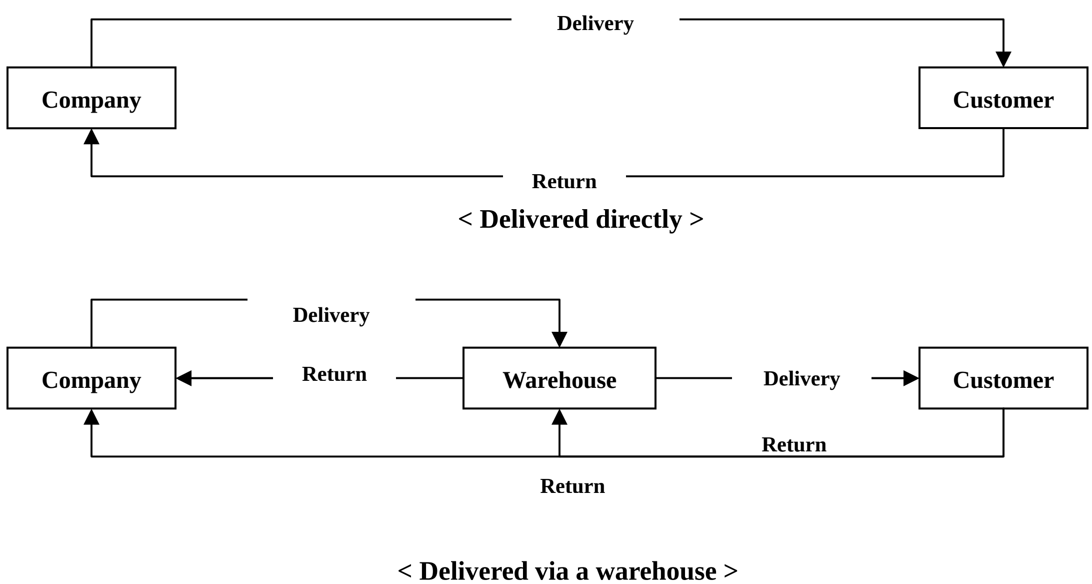


Figure 2.2: Delivery Route

2.3 Types of inventory

There are several types of inventories in manufacturing industrials. Although this is not the only ways to categorize inventory type, it is very common way in manufacturing industrials. The types of inventory are categorized blow. [1]

Raw material inventories: These inventories are the resource to make some products in manufacturing industrials.

Component inventories: These inventories are sometimes called to subassemblies. The component inventories have not yet make to final products in production systems.

Work-In-Process (WIP): The Work-In-Process is inventory that is waiting in the process or occupied to process. Work-In-Process includes both the first inventory (Raw material inventory) and the second inventory (Component inventory).

Finished Goods' inventories: Usually most people assume the finished goods to inventories. These inventories are also now to end items. These are final goods of the manufacturing systems. These inventories could be sold or delivered to clients at any time. This research is focused on finished goods' inventories. This thesis is focused on finished good's inventories and work-in-process.

2.4 Reasons of keeping inventories

This research is focused on the inventory management. High volume inventory levels are caused to high holding and capital cost. All production companies want to reduce their stocks but it is very difficult. There are several reasons why the inventories are held.

Economies of scale: It is probably lower cost to make high volume batches than low volume batches. When the setup cost is much higher than inventory holding, the high volume batches and inventory levels could be more economical for the future use. All cases must be checked to meet lowest costs during a manufacturing process.

Uncertainties: It should be mostly a major role why a firm hold or keep the inventories. The first uncertainty is the unstable demand. If the demand of clients is very stable or constant, a firm can make a production schedule properly. Inventory is a kind of buffering against the uncertainty of demand. The second uncertainty is lead time. Lead time could be defined as "the amount of time that elapses from the point that an order is placed until it arrives."[2] The last uncertainty is the supply system. The supply lines of raw materials like as crude oil or natural gas have many variables. When the gulf war occurred, the oil supply line from the Middle East Asia could be cut. The oil is the most important resource in most manufacturing industrials.

Speculation: The values of natural resources are very variable. If the value of natural resource like as oil is expected to increase, it may be more economical to buy large volumes at low current cost and keep them for the future consumption.

Transportation: In this case, the inventories are staying in a transportation system. For example, if some products are exporting from U.S.A to Asia by ship, it takes more than one month. As the result, the products would be changed to inventories during shipping.

Smoothing: Demand pattern for a production would be changed regularly or randomly.

Storing inventories can help not to make stock out when the demand are changed very randomly or unrepentantly.

Logistics: With getting development of logistics systems, all productions can be exported or imported around the world any time. Sometimes, the logistics systems must request minimum quantities to transfer. It means that mass volume quantities to transfer is much economical than reducing or keeping low inventories.

Control costs: The control cost is the cost of maintaining the inventory control system. Based on the control costs, we decide the quantities of inventory. Above the reasons, many firms have to keep high volume inventories. In this research, I will analyze all items' demand and look for the way to reduce inventory levels with satisfying clients' demands.

In the company's case, the uncertainty is the basic reason to keep high volume inventories. The demand trends (see figure 3.2) are very various so the company has a difficulty to predict future demand.

Chapter 3

Demand and Inventory Analysis

3.1 Demand trend

There are over 250 items in this industrial case. Even though there are many items, top 60 items compose over 85% of all demand because there are many sample cases or very small quantity demand items. The sample cases are prototype items before mass production is undertaken by the client. The demand data gathered are from April 2005 till November 2006, which is a total of 20 months. Hence a decision was made in consultation with the management that this project would focus on top 60 items. Unless otherwise indicated, all weight unit of this project is metric ton (MT). Figure 3.1 shows top 60 items' demand on each month compared with the total demand.

- Total Demand for 20months: 50,371.1 MTs
- Top 60 items for 20 months: 43,672.3 MTs
- Top 60 items: 86.69% of all demands

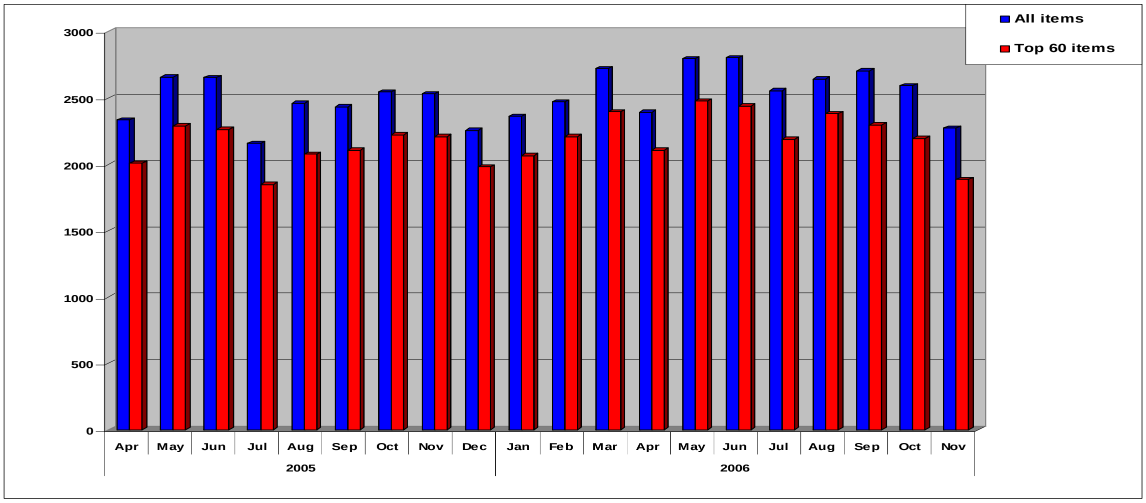


Figure 3.1: Graph comparing demand of top 60 items with total demand (20 months)

3.2 Top 60 items

As mentioned earlier, the top 60 items are over 85% of the total demands. Table 3.1 presents the total demand for 20 months and mean of demand for top 60 items.

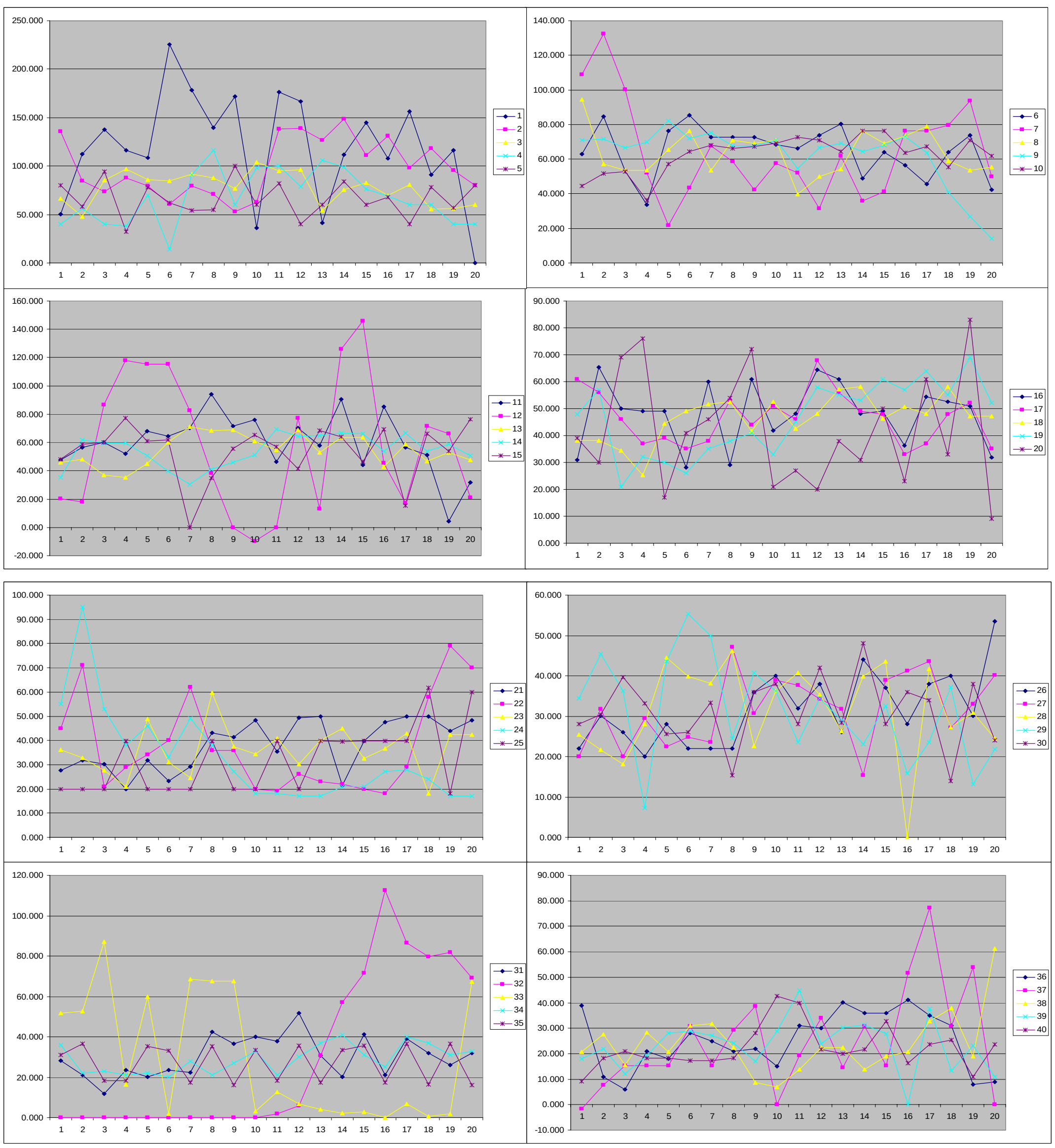
Table 3.1: The total and mean demand for top 60 items

Rank	Total Demand for 20 months	Mean of Demand per month	Rank	Total Demand for 20 months	Mean of Demand per month
1	2389.134	119.457	51	328.038	16.402
2	1975.032	98.752	52	320.597	16.030
3	1554.006	77.700	53	306.173	15.309
4	1352.232	67.612	54	270.247	13.512
5	1322.220	66.111	55	269.342	13.467
6	1298.187	64.909	56	263.719	13.186
7	1283.847	64.192	57	260.773	13.039
8	1273.689	63.684	58	260.361	13.018
9	1255.681	62.784	59	255.828	12.791
10	1255.638	62.782	60	249.478	12.474
11	1199.751	59.988	61	243.425	12.171
12	1168.042	58.402	62	242.614	12.131

13	1093.250	54.663	63	234.053	11.703
14	1090.442	54.522	64	234.024	11.701
15	1081.275	54.064	65	233.147	11.657
16	960.762	48.038	66	232.525	11.626
17	932.157	46.608	67	198.676	9.934
18	931.681	46.584	68	186.046	9.302
19	930.161	46.508	69	182.521	9.126
20	840.136	42.007	70	167.827	8.391
21	762.407	38.120	71	163.031	8.152
22	758.130	37.907	72	155.356	7.768
23	724.299	36.215	73	154.220	7.711
24	659.113	32.956	74	150.592	7.530
25	638.204	31.910	75	147.144	7.357
26	634.580	31.729	76	145.024	7.251
27	632.127	31.606	77	138.351	6.918
28	631.399	31.570	78	131.634	6.582
29	628.261	31.413	79	129.275	6.464
30	626.226	31.311	80	127.008	6.350
31	601.463	30.073	81	126.510	6.326
32	596.864	29.843	82	124.148	6.207
33	581.139	29.057	83	124.021	6.201
34	579.098	28.955	84	115.213	5.761
35	538.297	26.915	85	113.400	5.670
36	503.087	25.154	86	109.586	5.479
37	494.278	24.714	87	108.593	5.430
38	476.542	23.827	88	101.443	5.072
39	468.311	23.416	89	92.774	4.639
40	443.615	22.181	90	78.380	3.919
41	436.586	21.829	91	78.014	3.901
42	412.771	20.639	92	69.399	3.470
43	411.014	20.551	93	69.398	3.470
44	398.433	19.922	94	68.013	3.401
45	373.765	18.688	95	63.773	3.189
46	349.459	17.473	96	63.504	3.175
47	339.651	16.983	97	63.502	3.175
48	338.927	16.946	98	58.010	2.901
49	333.058	16.653	99	52.891	2.645
50	329.308	16.465	100	52.070	2.604

3.3 Demand Trend Analysis

Most of the top 60 items do not show a seasonal pattern or other trends. The demand pattern of each item is irregular but the mean value is invariant over time. This makes it a bit hard to forecast future demands, but lends itself well to standard inventory models. Figure 3.2 presents the demand pattern of each item for 20 months.



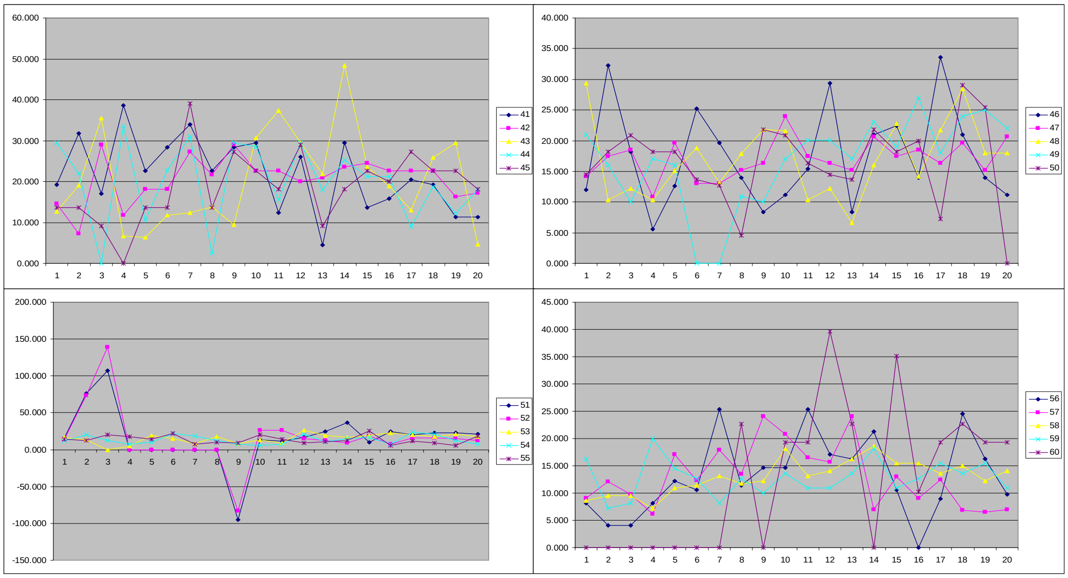


Figure 3.2: Demand pattern for each item

3.4 Inventory Analysis

While there are a large variety of items stored in inventory, again the top 60 items in terms of demand also occupy a large proportion of the stored inventory. Inventories of the top 60 items are over 60% for each month of the year 2006 (12 months). This makes sense because the top 60 items have high demand and high inventory to react to these high demands. Table 3.2 shows total inventory levels of all items and top 60 items.

Table 3.2: Inventory levels of items

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Total	5080.6	4589.3	4678.4	4507.9	4522.0	4786.3	4524.3	4787.2	4573.4	4324.3	4203.4	3963.1	**4545.0**
Top 60	3366.2	2968.4	3140.5	2960.3	3029.2	3277.9	3096.7	3328.1	3126.6	3018.1	2620.8	3174.8	**3092.3**
Ratio	**66.3%**	**64.7%**	**67.1%**	**65.7%**	**67.0%**	**68.5%**	**68.4%**	**69.5%**	**68.4%**	**69.8%**	**62.3%**	**80.1%**	**68.0%**

3.5 Average Inventory level for top 60 items

In addition to the total inventory analysis, we also conducted the average inventory calculations for the top 60 items. Table 3.3 presents the average inventory levels of the top 60 items.

Table 3.3: Average inventory levels of top 60 items

Rank	Average	Rank	Average	Rank	Average
1	40.692	21	57.139	41	29.754
2	131.44	22	111.42	42	31.051
3	84.59	23	30.433	43	47.647
4	53.939	24	103.43	44	14.307
5	27.968	25	20.673	45	12.849
6	103	26	38.331	46	17.035
7	47.079	27	50.688	47	35.779
8	83.764	28	65.15	48	49.966
9	85.833	29	24.228	49	34.234
10	66.66	30	39.211	50	18.449
11	52.919	31	55.25	51	116.79
12	9.0261	32	63.541	52	90.081
13	100.83	33	8.3682	53	47.721
14	102.04	34	42.407	54	14.494
15	33.738	35	25.859	55	28.905
16	30.258	36	30.874	56	48.479
17	91.058	37	40.815	57	54.298
18	56.831	38	31.961	58	26.588
19	75.096	39	67.695	59	21.662
20	120.86	40	20.673	60	18.944

Chapter 4

Inventory Modeling

4.1 EOQ (Economic Order Quantity)

The EOQ model is the simplest and most fundamental of all inventory models. It describes the important trade-off between fixed order costs and holding costs, and is the basis for the analysis of more complex systems. Since the demand is more-or-less stationary, the assumptions of this model are satisfied for the company's case. However, we must also consider the joint inventory-logistic system optimization. One truck load capacity is 20 MTs. Hence it is desirable to have the batch size at either the EOQ or multiples of truck loads. The company's current production quantity (Q) per batch for items is 20 MTs or 40 MTs, which corresponds to one truck load or two truck loads. In the simulation models (Sections 6 and 7) we compute long term inventory costs assuming the batch size to be set at EOQ or 20 MTs or 40 MTs for comparison purposes.

4.2 Variables for EOQ

There are some assumptions and variables for EOQ. The demand rate is known and is a constant λ unit per unit time. The unit time may be days, weeks, month, etc. Shortages are not permitted. There is no order lead time in the simplest version. The costs for EOQ are setup cost and holding cost. The setup cost at $K is per positive order placed. The setup cost depends on the production lines at company: One is for a Type A item and another is for a type B item. The holding cost at $h is per unit held, per unit time. The holding cost depends on where an item is kept. The warehouses have different holding cost per unit time. The holding cost also includes capital cost. The capital cost is assumed at an annual interest rate of 5%. The formula of EOQ (Q*) is presented below:

$$Q^* = \sqrt{\frac{2K\lambda}{h}}$$

Where

- Monthly Demand (λ)

  : Average Demand for 20 months of each of the top 60 items

- Setup Cost (K)

  : $30 / batch (Type A item)

  : $ 1 / batch (Type B item)

- Holding Cost (h)

  : Storage Cost + Capital Cost (5% annual interests)

Table 4.1 shows the total holding costs.

Table 4.1: Holding cost

Warehouse	Capital Cost	Storage Cost	Holding Cost	Warehouse	Capital Cost	Storage Cost	Holding Cost
U301	4.166	0	**4.166**	U315	4.166	3	**7.166**
U310	4.166	2.1	**6.266**	U317	4.166	2.9	**7.066**
U311	4.166	5.1	**9.266**	U318	4.166	2.5	**6.666**
U312	4.166	4.2	**8.366**	U319	4.166	2.123	**6.289**

4.3 EOQ of top 60 items

The EOQ of each top 60 items is determined by K (Setup), λ (Demand), and h (Holding). Table 4.2 presents the EOQ values for the top 60 items. Type B items have small EOQ because the setup cost is very low. The items that EOQ is less than 6 MTs are type B items.

Table 4.2: EOQ of top 60 items

Rank	Warehouse	EOQ	Rank	Warehouse	EOQ	Rank	Warehouse	EOQ
1	U301	**42**	21	U301	**19**	41	U301	**18**
2	U301	**38**	22	U318	**24**	42	U319	**15**
3	U315	**26**	23	U301	**19**	43	U301	**18**
4	U311	**22**	24	U301	**22**	44	U301	**17**
5	U301	**6**	25	U301	**4**	45	U301	**3**
6	U310	**25**	26	U318	**22**	46	U301	**3**
7	U310	**25**	27	U301	**4**	47	U301	**16**
8	U318	**24**	28	U301	**22**	48	U318	**13**
9	U318	**24**	29	U301	**22**	49	U318	**3**
10	U301	**6**	30	U318	**22**	50	U301	**16**
11	U301	**6**	31	U311	**4**	51	U301	**16**
12	U301	**30**	32	U301	**14**	52	U301	**16**
13	U301	**29**	33	U318	**4**	53	U301	**15**
14	U317	**22**	34	U301	**3**	54	U301	**3**
15	U318	**23**	35	U319	**20**	55	U301	**14**
16	U301	**5**	36	U318	**16**	56	U312	**10**
17	U301	**26**	37	U312	**15**	57	U301	**14**
18	U301	**5**	38	U312	**14**	58	U301	**3**
19	U301	**26**	39	U301	**13**	59	U301	**3**
20	U318	**18**	40	U301	**18**	60	U301	**3**

Chapter 5

Make-To-Stock (MTS) and Make-To-Order (MTO)

5.1 Introduction to MTS and MTO production strategies

Traditional production systems produce products and store them as inventory until they are sold. This is referred MTS (Make-To-Stock), and it is prevalent in environments where the product is standard, demand needs to be fulfilled immediately, and the demand may or may not be known with certainty. In order to reduce inventory and increase the level of customization, some firms have designed their production systems to produce a product only after it is ordered. Such systems are called MTO (Make-To-Order). Demand requires an order fulfillment lead time in MTO systems, and therefore might not be appropriate for all products/customers. Briefly put, MTS allows stocks and MTO does not allow stocks.

- MTS (Make-To-Stock): Stock allowed
- MTO (Make-To-Order): Stock not allowed

It is an interesting inventory reduction strategy to convert some of the MTS items to MTO, since there would be no stock held for the MTO items. It is challenging however to determine which items should be converted to MTO because of the possibility of stocking out a customer. During a rolling window of time if all replenishments of MTS items and the MTO item orders that have arrived are not satisfied within the permissible 5 day lead time, a stock out could occur. This will have severe consequences for the company. Hence, we undertake a discrete even simulation study that will start with a reasonable MTO item set and validate "no-stock-out" condition through a random demand generation (market simulator) and simulated production. If a stock out condition occurs, the MTO set can be reduced until the no-stock-out compliance is reached. The following section presents our approach.

5.2 MTS and MTO items

Before setting up a simulation model, this research separates the items to MTS or MTO. MTS items are assumed to be the top 60 items. The top 60 items are major items and the demand is very high and irregular. So the top 60 items are appointed to MTS to respond to customer orders immediately. MTO items are the next 40 items. The next 40 items (61^{st} ~ 100^{th}) are not very high demand so there may be no problem to respond to customer demands without stocks in the 5 day lead time. Items behind MTS and MTO (from 101^{st} item) could be ignored because the average demands of each item are less than 2.5 MTs. These items are sample cases, discontinued items, or very rare demand items. Table 5.1 shows the MTS and MTO items.

Table 5.1: Partition of items into MTS and MTO items

Section	# of items	Portion of Demand	Mark	# of Type A item	# of Type B item
MTS	60 (1^{st} ~ 60th)	85.69%	Major items	43	17
MTO	40 (41^{th}~ 100th)	10.57%	Minor items	30	10
Others	About 150	3.74%	Few demand or sample items	-	-

Chapter 6

Simulation 1

6.1 Purpose

The first simulation is to compare total costs when each item's batch is set to EOQ, 40 MTs, or 20 MTs. The total costs consist of inventory holding cost and setup cost. The purpose of this simulation is to establish the best inventory-logistical choice, and assess the compromise in total cost if EOQ is changed to one truck load or two truck loads. This batch size decision is only applied only to the MTS items because MTO models are not allowed to keep stocks. The 1st simulation shows the total number of setup times and inventory levels. Another purpose of this simulation is to generate a distribution of inter order arrival times, which was not available to us from the company data. We need this information in simulation 2 (Section 7), where orders have to be generated on a continuous time basis (rather than monthly).

6.2 Algorithm of simulation 1

This simulation is to check inventory levels and setup times to calculate total costs. The basic concept is that demand is fulfilled from inventory (subtracted) and reorder decision is made. The demand distribution is formulated on a monthly basis because we did not have access to individual customer orders (or at least production and inventory levels on a continuous time basis). All MTS items are assumed to have initial inventory levels and the initial inventories are subtracted by monthly demand distribution. Once the inventory levels are subtracted, the inventory levels are checked for whether the inventory levels have reached (or are below) the re-order points. If the inventory levels are below the re-order points, the inventory levels are added to one batch size (EOQ, 40 MTs, or 20 MTs) and setup time is recorded. Or if the inventory levels are more than a re-order point, there is no production. The changes of inventory levels are recoded every time. The length of running simulation is 24 months. Figure 6.1 presents the algorithm of 1st simulation. The details are summarized as follows:

- Simulation Tool: ARENA Version 5.0
- Initial Inventory Level: Maximum Demand in any month
- Re-order point: Maximum Demand * Lead time
- Demand distribution: calculating based on 20 months data
- Length of simulation: 24 months

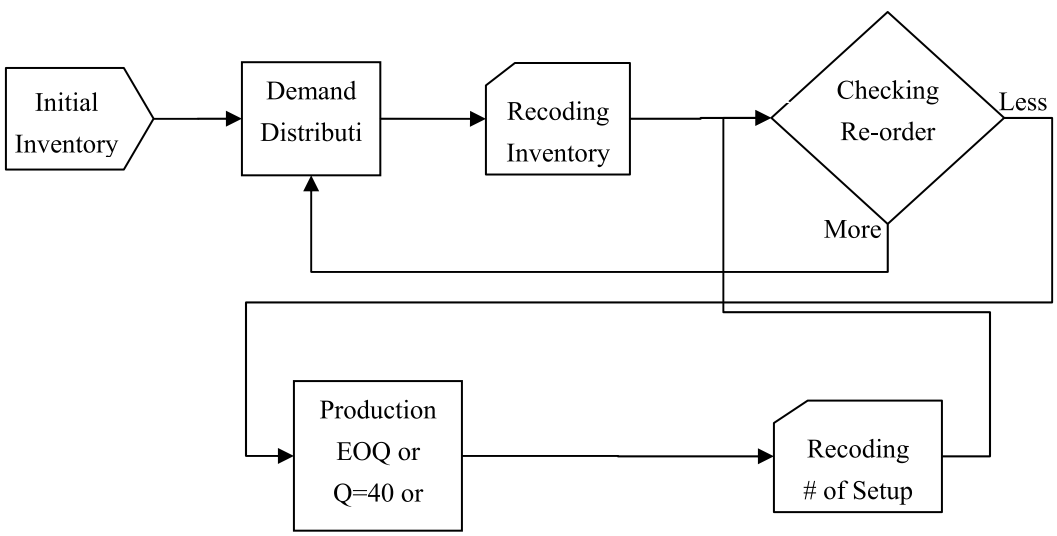


Figure 6.1: Algorithm of 1st simulation

Table 6.1 is the max demand, re-order point, and demand distribution of top 60 items.

Table 6.1: variables for 1st simulation

Rank	Max Demand	Re-order Point	Demand Distribution
1	225.25	205.3	0.12 + ERLA(0.111, 3)
2	148.42	131.93	0.17 + 0.831 *BETA(0.521, 0.912)
3	104.32	91.35	0.17 + 0.831 * ETA(0.299, 0.455)
4	116.02	104.72	0.12 + EXPO(0.255)
5	100.01	88.97	LOGN(0.177, 0.161)
6	85.47	74.63	0.17 + LOGN(0.447, 0.378)
7	132.44	121.72	0.17 + 0.831* BETA(0.395, 0.55)
8	94.34	83.71	UNIF(0.12, 1)
9	81.94	71.45	0.17 + EXPO(0.316)
10	76.2	65.71	LOGN(0.157, 0.125)
11	94.12	84.1	LOGN(0.164, 0.128)
12	145.67	135.91	UNIF(0.12, 1)
13	71.3	62.17	0.26 +LOGN(0.372, 0.305)
14	69.16	60.06	0.26 + LOGN(0.234, 0.177)
15	77.11	68.08	TRIA(0.06, 0.0737, 0.18)
16	65.38	57.36	TRIA (0.06, 0.0737, 0.18)
17	68.01	60.22	0.26 + LOGN(0.378, 0.245)
18	58.06	50.28	0.07 +EXPO(0.0356)
19	69.01	61.24	0.26 + LOGN(0.428, 0.425)
20	83.01	75.99	UNIF(0.12, 1)
21	49.98	43.61	0.26 + LOGN(0.313, 0.271)
22	79.01	72.68	TRIA(0.02, 0.903, 1)
23	59.78	53.73	UNIF(0.17, 1)
24	95.01	89.51	UNIF(0.17, 1)
25	61.68	56.36	0.04 + 0.18 * BETA(1.17, 1.25)
26	53.41	48.11	0.45 + 0.551*BETA(0.0794, 0.0486)
27	47.17	41.89	0.04 + GAMM(0.0319, 3.3)
28	46.26	40.99	UNIF(0.26, 1)
29	55.33	50.09	NORM(1.5, 0.645)
30	48.008	42.77	UNIF(0.26, 1)

31	51.81	46.86	0.07 + LOGN(0.0595, 0.035)
32	112.5	107.51	2 * BETA(0.386, 0.901)
33	87.09	82.23	LOGN(0.327, 0.582)
34	41	36.17	0.06 + 0.12 *BETA(0.967, 1.55)
35	36.66	32.16	TRIA(-0.001, 0.901, 1)
36	41	36.8	UNIF(-0.001, 1)
37	77.11	72.98	UNIF(-0.001, 1)
38	61.14	57.16	TRIA(-0.001, 0.901, 1)
39	44.72	40.8	TRIA(-0.001, 0.479, 1)
40	42.63	38.93	TRIA(-0.001, 0.901, 1)
41	38.55	34.9	UNIF(-0.001, 1)
42	29.03	25.58	0.45+0.551*BETA(0.0774, 0.0402)
43	48.35	44.92	-0.001 + 1*BETA(0.0248, 0.0248)
44	33.47	30.14	UNIF(-0.001, 1)
45	39	35.88	EXPO(0.302)
46	33.6	30.68	TRIA(0.08, 0.0912, 0.36)
47	23.95	21.11	0.45 + 0.551 * BETA(1.54, 0.244)
48	29.393	26.56	TRIA(-0.001, 0.901, 1)
49	27.005	24.22	0.07 + LOGN(0.142, 0.108)
50	29.03	26.28	-0.001 + 1 * beta(0.229, 0.0606)
51	107.04	104.3	-0.001 + EXPO(0.247)
52	138.7	136.03	-0.001 + EXPO(0.161)
53	26.49	23.93	-0.001 + 1 * beta(0.132, 0.0393)
54	23.804	21.54	0.08 + ERLA(0.079, 2)
55	25.22	22.97	TRIA(-0.001, 1, 1)
56	25.31	23.1	UNIF (-0.001, 1)
57	24.04	21.86	UNIF(-0.001, 1)
58	18.59	16.42	NORM(0.229, 0.0344)
59	19.95	17.82	0.08 + 0.921 *BETA(0.523, 1.59)
60	39.68	37.6	EXPO(0.416)

Figure 6.2 is a screen capture of ARENA simulation.

Figure 6.2: Capture of 1st simulation

6.3 Result of 1st simulation

Recall that the total cost is the sum of holding cost and setup cost. EOQ is expected to provide the lowest total cost, but the corresponding holding cost and setup cost terms of EOQ may be greater than or less than the one truck load or two truck load case. For example, some type B items have very small EOQ, which is less than 6 MTs, so the setup cost is very high but inventory levels are much less. The inventory levels and setup time depend on initial inventory, EOQ, and demand distribution. Table 6.2 shows all kinds of cost for EOQ, one truck load, and two truck loads cases.

Table 6.2: Total cost of EOQ, Q=40 and Q=20

Rank	EOQ	EOQ			Q=40			Q=20			Benefit
		Holding Cost	Setup Cost	Total Cost	Holding Cost	Setup Cost	Total Cost	Holding Cost	Setup Cost	Total Cost	
1	42	12850	1890	14740	12866.6	1950	14816.6	11783.5	3870	15653.5	913.504

2	38	5466.8	1740	7206.8	5467.34	1830	7297.34	4390.24	3660	8050.24	843.442
3	26	6197.99	1950	8147.99	7311.35	1290	8601.35	5703.01	2550	8253.01	453.358
4	22	8656.59	2610	11266.6	10709.8	1440	12149.8	8693.25	2850	11543.3	883.184
5	6	2971.1	249	3220.1	4895.79	38	4933.79	3729.31	75	3804.31	1713.69
6	25	5549.59	1350	6899.59	6181.06	960	7141.06	4891.66	2100	6991.66	241.461
7	25	11663.1	1830	13393.1	12634.3	1140	13774.3	11130.5	2280	13410.5	381.23
8	24	5971.28	1650	7621.28	6632.77	1170	7802.77	5476.55	2340	7816.55	195.264
9	24	3787.13	1800	5587.13	4897.02	1140	6037.02	3308.91	2280	5588.91	449.881
10	6	1394.93	242	1636.93	2587.74	37	2624.74	1684.42	73	1757.42	987.81
11	6	3391.42	236	3627.42	5351.03	36	5387.03	3955.13	71	4026.13	1759.61
12	30	10364.4	1290	11654.4	11172.6	930	12102.6	10207.9	1860	12067.9	448.204
13	29	2563.08	1320	3883.08	2997.66	960	3957.66	2020.58	1890	3910.58	74.5868
14	22	4261.26	1500	5761.26	5923.79	900	6823.79	4020.12	1770	5790.12	1062.53
15	23	5256.98	1620	6876.98	6300.94	900	7200.94	5101.06	1800	6901.06	323.966
15	23	5256.98	1620	6876.98	6300.94	900	7200.94	5101.06	1800	6901.06	323.966
16	5	1276.69	243	1519.69	3235.02	31	3266.02	1891.17	61	1952.17	1746.33
17	26	3055.01	1260	4315.01	3729.91	840	4569.91	2730.07	1650	4380.07	254.892
18	5	476.248	234	710.248	2184.31	30	2214.31	1351.11	59	1410.11	1504.06
19	26	3339.01	1200	4539.01	4130.55	810	4940.55	2964.07	1590	4554.07	401.54
20	18	8371.82	1830	10201.8	10195.6	840	11035.6	8689.73	1650	10339.7	833.788
21	19	2702.1	1440	4142.1	4591.66	690	5281.66	3138.98	1380	4518.98	1139.57
22	24	5068.84	1200	6268.84	6305.72	720	7025.72	5167.15	1440	6607.15	756.885
23	19	4928.19	1230	6158.19	6701.35	600	7301.35	5234.83	1170	6404.83	1143.16
24	22	6730.1	1140	7870.1	7842.42	630	8472.42	6675.94	1260	7935.94	602.322
25	4	2757.04	226	2983.04	4604.58	21	4625.58	3604.74	41	3645.74	1642.54
26	22	2788.74	1020	3808.74	3480.3	570	4050.3	2813.74	1140	3953.74	241.556
27	4	1983.61	191	2174.61	4656.12	20	4676.12	3020.98	39	3059.98	2501.51
28	22	2344.48	1020	3364.48	3327.66	570	3897.66	2339.04	1110	3449.04	533.176
29	22	3048.48	990	4038.48	3973.33	600	4573.33	2723.53	1410	4133.53	534.852
30	22	1622.97	990	2612.97	2700.45	600	3300.45	1237.49	1380	2617.49	687.48
31	4	2690.14	196	2886.14	5036.57	20	5056.57	3836.69	40	3876.69	2170.43
32	14	19240.1	1500	20740.1	21408.4	630	22038.4	19369.9	1500	20869.9	1298.24
33	4	6077.87	269	6346.87	7819.25	27	7846.25	6736.09	54	6790.09	1499.39

34	3	1331.83	243	1574.83	4744.4	19	4763.4	2788.47	37	2825.47	3188.57
35	20	1892.05	930	2822.05	3058.53	480	3538.53	1892.05	930	2822.05	716.48
36	16	3175.43	1110	4285.43	4127.44	450	4577.44	3498.54	900	4398.54	292.008
37	15	9162.33	1230	10392.3	11062.1	450	11512.1	9595.62	930	10525.6	1119.81
38	14	9262.47	1050	10312.5	11621.7	390	12011.7	9613.84	750	10363.8	1699.21
39	13	4440.76	1500	5940.76	7159.71	480	7639.71	5486.51	960	6446.51	1698.95
40	18	2511.23	930	3441.23	3752.7	450	4202.7	2586.22	900	3486.22	761.468
41	18	2149.39	900	3049.39	3187.06	420	3607.06	2187.22	900	3087.22	557.674
42	15	1849.01	990	2839.01	3383.76	390	3773.76	2251.74	750	3001.74	934.751
43	18	4514.07	450	4964.07	5755.54	210	5965.54	4755.7	390	5145.7	1001.47
44	17	2656.02	630	3286.02	3951.65	270	4221.65	2951.81	540	3491.81	935.626
45	3	2428.24	118	2546.24	4074.58	9	4083.58	3241.38	18	3259.38	1537.34
46	3	1462.72	151	1613.72	3379.08	12	3391.08	2212.6	48	2260.6	1777.36
47	16	1341.15	780	2121.15	2574.28	330	2904.28	1574.44	630	2204.44	783.136
48	13	2712.42	960	3672.42	4785.54	330	5115.54	3185.7	630	3815.7	1443.13
49	3	1589.22	136	1725.22	4595.02	11	4606.02	3128.5	46	3174.5	2880.81
50	16	1976.09	750	2726.09	3042.59	300	3342.59	2209.39	600	2809.39	616.496
51	16	12930.2	510	13440.2	14896.6	210	15106.6	13396.8	420	13816.8	1666.35
52	16	17349.1	420	17769.1	17903.1	180	18083.1	17549	330	17879	314.078
53	15	1729.75	690	2419.75	2958.72	270	3228.72	1958.88	510	2468.88	808.97
54	3	856.712	119	975.712	2748.08	9	2757.08	1664.92	18	1682.92	1781.36
55	14	1600.93	660	2260.93	3283.99	240	3523.99	2200.83	480	2680.83	1263.06
56	10	3384.49	870	4254.49	6479.91	240	6719.91	4472.07	450	4922.07	2465.42
57	14	1612.84	720	2332.84	2811.94	270	3081.94	1978.74	510	2488.74	749.104
58	3	494.456	107	601.456	2448.31	9	2457.31	1448.47	17	1465.47	1855.85
59	3	791.067	98	889.067	2811.58	8	2819.58	1645.1	15	1660.1	1930.51
60	3	2546.05	130	2676.05	4233.28	10	4243.28	3400.08	20	3420.08	1567.22

As mentioned above Table 6.2, total costs of EOQ are less than one or two truck loads. The cumulative total cost of all items assuming EOQ batch sizes is $321,135, which is compared to the one truck load and two truck load batch sizes as $314,667 and $386,101, respectively. Table 6.3 shows the relation between cumulative total costs for the three batch sizes and Figure 6.3 is a graph of costs.

Table 6.3: Cumulative total and component cost comparison

	Holding Cost	Setup Cost	Total Cost
EOQ	$266,597.1	$54,638	$321,135.1
Q=40	$356,684.2	$29,417	$386,101.2
Q=20	$282,495.9	$59,172	$341,667.9

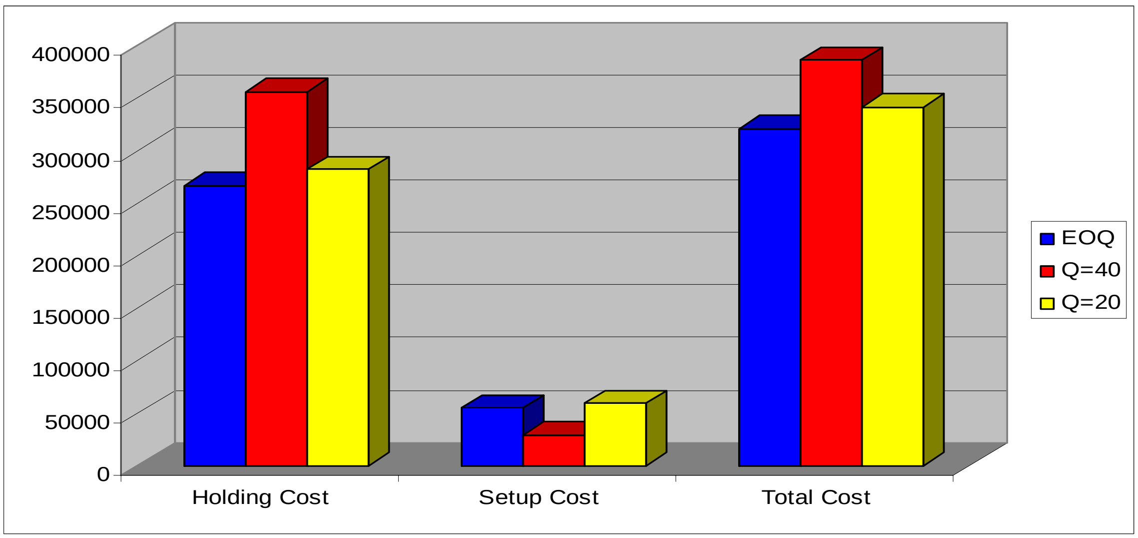


Figure 6.3: Graph of costs

Chapter 7

Simulation 2

7.1 Purpose

The purpose of the second simulation is to check whether all orders can be delivered within the contract 5 day lead time. As already mention in Section 1, clients do not allow back orders. The second simulation is assumes 60 MTS items and 40 MTO items, and simulates market demand from the results of simulation 1 order inter-arrival time distributions. These orders and sent to the production simulator that will "produce" orders according the specified policy (MTS with EOQ, and MTO) and determine if all MTS replenishments and MTO orders are met without stock-out.

7.2 Algorithm

This simulation algorithm implementation is complex, but it can be described in a simple way. Marked demand is generated from the demand distributions (inter-order arrival time and fixed order size[1]). The production line schedules orders on a first come first serve basis. There are three production line components: weight car, Type A item, and Type B item. All production orders go through the weight car line and then are separated to the Type A item line or Type B item line. Items which are passed through lines have to be completed in one day since the remaining 4 days are for the transportation process. If orders are not completed within the day, a stock-out condition

[1] Strictly speaking the order quantity should be random as well, which is approximated to mean value for MTO and EOQ for MTS items.

would be noted.

- Order arrival rate
  : Generated from an order arrival distribution
  : MTS is based on data of 1st simulation
  : MTO is based on historic order data
- Order Quantity
  : MTS is EOQ
  : MTO is average demand for an order
- Weight car
- Type A item Line
- Type B item Line

Figure 7.1 presents the algorithm of 2nd simulation. It is clear from the decision box that there are two types of items, MTS and MTO, and all items have to pass the weight car line before being separated to Type A and Type B item.

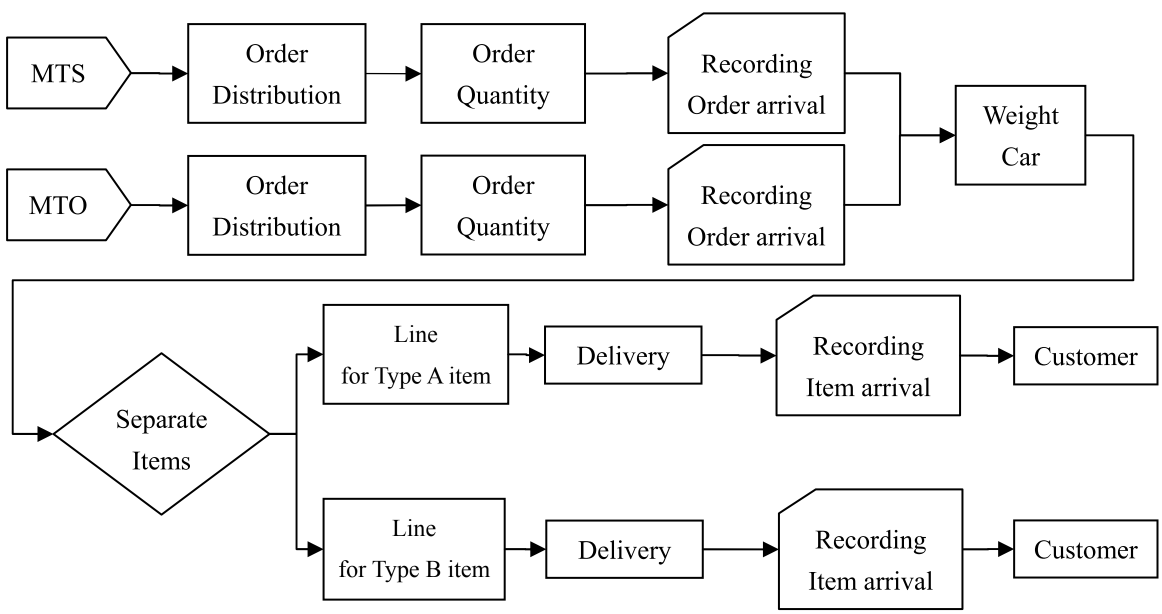


Figure 7.1: Algorithm of 2nd simulation

Table 7.1 shows all arrival distribution and order quantity of all items. All items have various arrival distributions.

Table 7.1: All variables of 2nd simulation

Rank	Arrival Distribution	Quantity a order	Rank	Arrival Distribution	Quantity a order
1	0.12 +ERLA(0.111, 3)	42	51	-0.001 + EXPO(0.247)	16
2	0.17 + 0.831 *BETA(0.521, 0.912)	38	52	-0.001 + EXPO(0.161)	16
3	0.17 + 0.831 * BETA(0.299, 0.455)	26	53	-0.001 + 1*beta(0.132,0.0393)	15
4	0.12 + EXPO(0.255)	22	54	0.08 + ERLA(0.079, 2)	3
5	LOGN(0.177, 0.161)	6	55	TRIA(-0.001, 1, 1)	14
6	0.17 + LOGN(0.447, 0.378)	25	56	UNIF(-0.001, 1)	10
7	0.17 + 0.831 *BETA(0.395, 0.55)	25	57	UNIF(-0.001, 1)	14
8	UNIF(0.12, 1)	24	58	NORM(0.229, 0.0344)	3
9	0.17 + EXPO(0.316)	24	59	0.08+0.921*BETA(0.523,1.59)	3
10	LOGN(0.157, 0.125)	6	60	EXPO(0.416)	3
11	LOGN(0.164, 0.128)	6	61	-0.5 + 5 * beta(1.87, 2.22)	7
12	UNIF(0.12, 1)	30	62	-0.5 + 7 * beta(0.525, 1.31)	8
13	0.26 + LOGN(0.372, 0.305)	29	63	-0.5 + 7 * beta(0.254, 1.06)	14
14	0.26 + LOGN(0.234, 0.177)	22	64	TRIA(-0.5, 1.85, 4.5)	6
15	TRIA(0.06, 0.0737, 0.18)	23	65	-0.5 + WEIB(2.5, 4.67)	6
16	TRIA(0.06, 0.0737, 0.18)	5	66	-0.5 + 7*beta(1.65, 2.2)	5
17	0.26 + LOGN(0.378, 0.245)	26	67	TRIA(-0.5, 0.8, 1.5)	7
18	0.07 + EXPO(0.0356)	5	68	0.5 + WEIB(2.03, 1.78)	4
19	0.26 + LOGN(0.428, 0.425)	26	69	TRIA(0.5, 3.53, 4.5)	3
20	UNIF(0.12, 1)	18	70	-0.5 + 5*beta(2.22, 1.82)	4
21	0.26 + LOGN(0.313, 0.271)	19	71	-0.5 + GAMM(0.312, 4.96)	8

22	TRIA(0.02, 0.903, 1)	24	72	-0.5 + 5* beta(0.51, 0.798)	5
23	UNIF(0.17, 1)	19	73	TRIA(-0.5, 2, 3.5)	6
24	UNIF(0.17, 1)	22	74	-0.5 + GAMM(0.308, 4.49)	7
25	0.04 + 0.18 * BETA(1.17, 1.25)	4	75	POIS(2.2)	3
26	0.45+0.551* BETA(0.0794, 0.0486)	22	76	-0.5 + 6 * beta(0.33, 0.907)	7
27	0.04 + GAMM(0.0319, 3.3)	4	77	-0.5 + WEIB(1.92, 1.92)	6
28	UNIF(0.26, 1)	22	78	-0.5 + 3 * beta(0.79, 0.903)	7
29	NORM(1.5, 0.645)	22	79	NORM(0.9, 0.539)	7
30	UNIF(0.26, 1)	22	80	NORM(2.7, 1.31)	2
31	0.07 + LOGN(0.0595, 0.035)	4	81	-0.5 + 5 * beta(2.39, 1.31)	2
32	2 *BETA(0.386, 0.901)	14	82	-0.5 + beta(2.44, 1.53)	2
33	LOGN(0.327, 0.582)	4	83	-0.5 + 5*beta(0.449, 1.53)	10
34	0.06 + 0.12 * BETA(0.967, 1.55)	3	84	TRIA(-0.5, 0.75, 3.5)	5
35	TRIA(-0.001, 0.901, 1)	20	85	-0.5 + 4 * beta(1.64, 2.08)	5
36	UNIF(-0.001, 1)	16	86	-0.5 + 5 * beta(1.36, 1.36)	3
37	UNIF(-0.001, 1)	15	87	-0.5 + 4 * beta(1.29, 2.16)	5
38	TRIA(-0.001, 0.901, 1)	14	88	NORM(0.833, 0.553)	1
39	TRIA(-0.001, 0.479, 1)	13	89	TRIA(-0.5, 2, 4.5)	3
40	TRIA(-0.001, 0.901, 1)	18	90	0.5 + LOGN(1.71, 1.96)	4
41	UNIF(-0.001, 1)	18	91	-0.5 + EXPO(0.9)	10
42	0.45+0.551* BETA(0.0774, 0.0402)	15	92	-0.5 + 3 * beta(2.95, 1.48)	3
43	-0.001 + 1 *beta(0.0248, 0.0248)	18	93	-0.5 + EXPO(1)	7
44	UNIF(-0.001, 1)	17	94	0.5 + EXPO(0.95)	2
45	EXPO(0.302)	3	95	TRIA(-0.5, 4.1, 7.5)	1
46	TRIA(0.08, 0.0912, 0.36)	3	96	NORM(1.2, 0.812)	3
47	0.45 + 0.551 *BETA(1.54, 0.244)	16	97	-0.5 + WEIB(1.3, 1.87)	5
48	TRIA(-0.001, 0.901, 1)	13	98	-0.5 + WEIB(2.2, 2.25)	2
49	0.07 + LOGN(0.142, 0.108)	3	99	-0.5 + WEIB(0.911, 1.91)	10
50	-0.001 + 1 * beta(0.229, 0.0606)	16	100	-0.5 +WEIB(1.69, 1.86)	3

Figure 7.2 is a screen capture of ARENA for 2nd simulation. Each item has arrival distributions and order quantity encoded in the process boxes.

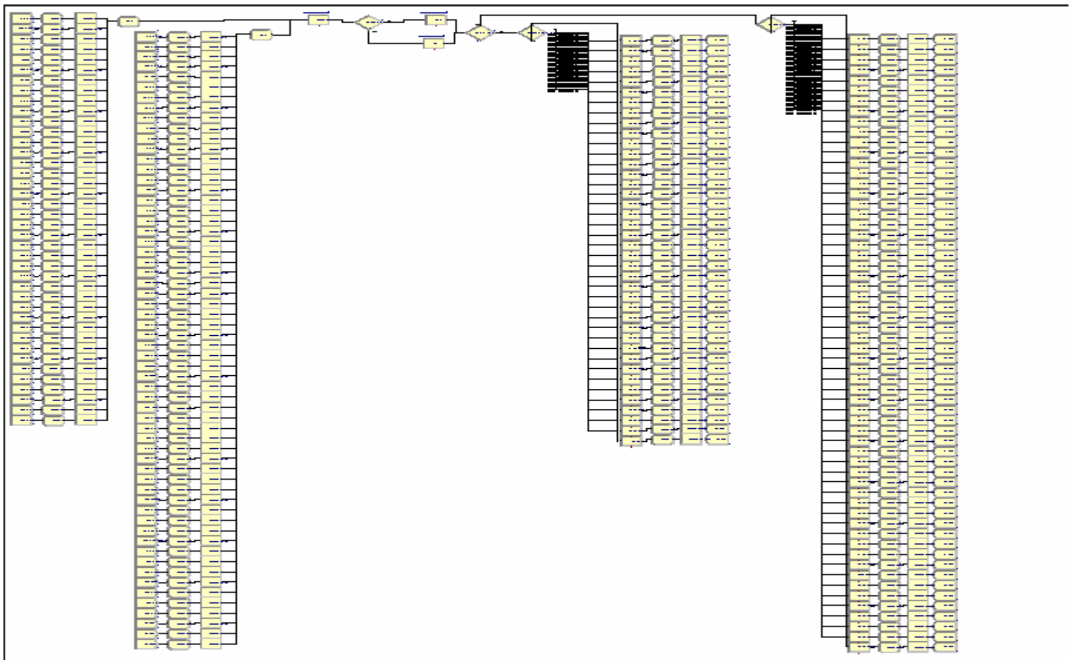


Figure 7.2: Capture of 2nd simulation

7.3 Result

The simulation was run for two years (24 months) and there was no back order detected in the 2nd simulation. All items are arrived to clients within 5 days. It means that the production lines (weight car, line of type B item, and line for Type A item) have enough capacity to react to the MTO orders and MTS orders (from the EOQ model for top 60 items). Therefore, the proposed MTS/MTO division of items and EOQ batch size for MTS items is a viable strategy for the company to adopt.

Chapter 8

Conclusions

8.1 Batch size for MTS items

As mentioned the above section, EOQ is more economical than one truck load or two truck loads. The cumulative total cost of EOQ items are $321,135 but the all total costs of one truck load and two truck loads is $314,667 and $386,101. The cumulative total cost of EOQ model is 93.90% and 83.17% of the cumulative total cost of one truck load and two truck loads. The EOQ models for top 60 items can reduce the total cost, which includes holing and setup cost. However, the closed or one truck load or two truck load can be assumed with marginal increase in total costs. This is expected to result in a better inventory-logistics plan. However, we were not able to repeat our second simulation under this scenario and confirm this for no stock-out specifically.

8.2 Inventory Levels

When actual inventory levels and simulation inventory levels are compared, the simulation inventory levels are less than actual inventory levels. The actual inventory levels are the average monthly inventory levels for 2006 and the simulation inventory levels are average inventory levels for 24 months. However some items' actual inventory levels are less than simulation inventory levels. Table 8.1 shows actual and simulation inventory levels. The inventory level comparisons are performed for MTS models and the Figure 8.1 is a graph of each item's inventory levels.

Table 8.1: Inventory levels of actual and simulation

Rank	Actual Inventory	Simulation Inventory	Rank	Actual Inventory	Simulation Inventory
1	40.7	123.4	31	55.3	**16.1**
2	131.4	**52.5**	32	63.5	83.1
3	84.6	**34.6**	33	8.4	58.4
4	53.9	**37.8**	34	42.4	**8**
5	28	28.5	35	25.9	**18.5**
6	103	**35.4**	36	30.9	**20.2**
7	47.1	74.5	37	40.8	55
8	83.8	**35.8**	38	32	44.7
9	85.8	**22.7**	39	67.7	**21.2**
10	66.7	**13.4**	40	20.7	24.1
11	52.9	**29.2**	41	29.8	**20.6**
12	9	99.5	42	31.1	**11.8**
13	100.8	**24.6**	43	47.6	**43.3**
14	102	**24.5**	44	14.3	25.5
15	33.7	**31.5**	45	12.8	23.3
16	30.3	**12.3**	46	17	**14**
17	91.1	**29.3**	47	35.8	**12.9**
18	56.8	**6.2**	48	50	**16.3**
19	75.1	**32.1**	49	34.2	**9.5**
20	120.9	**15.4**	50	18.4	19
21	57.1	**16.2**	51	116.8	122.5
22	111.4	**48.7**	52	90.1	171.4
23	30.4	**29.6**	53	47.7	**16.6**
24	103.4	**64.6**	54	14.5	**8.2**
25	20.7	26.5	55	28.9	**15.4**
26	38.3	**26.8**	56	48.5	**16.2**
27	50.7	**12.6**	57	54.3	**15.5**
28	65.2	**22.5**	58	26.6	**4.7**
29	24.2	29.3	59	21.7	**7.6**
30	39.2	**15.6**	60	18.9	24.4

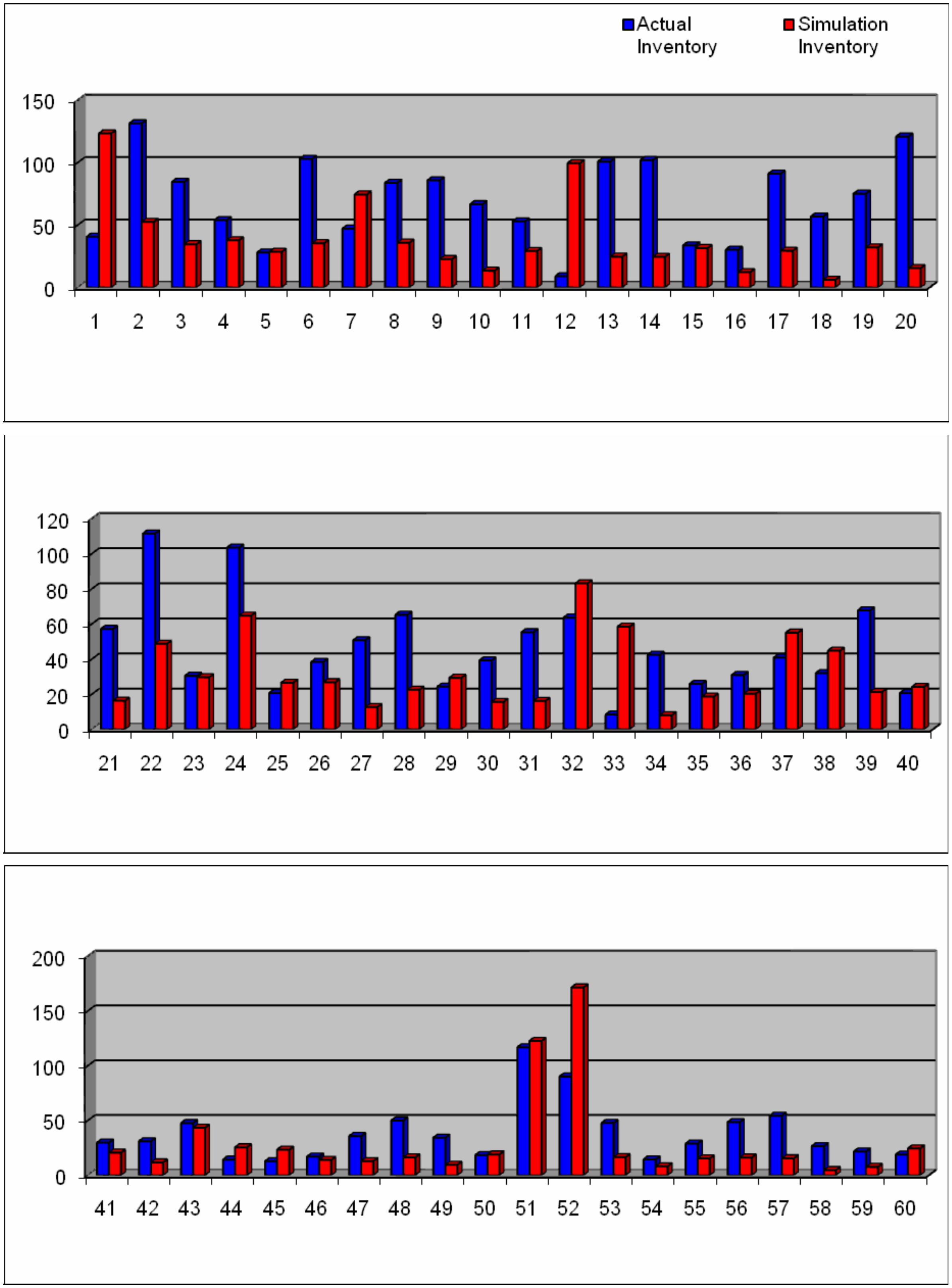


Figure 8.1: Graph of inventory levels

The EOQ models can decrease the inventory levels by 35% from actual inventory levels. The sum of all average inventory levels of EOQ is 1,993 MTs and the sum of all average inventory levels of actual situation is 3,092 MTs. Figure 8.2 show the sum of all average inventory levels of actual and simulation. Additionally, the actual inventory of 1448 MTs of MTO items would not be required. This represents a total 44% reduction of inventory.

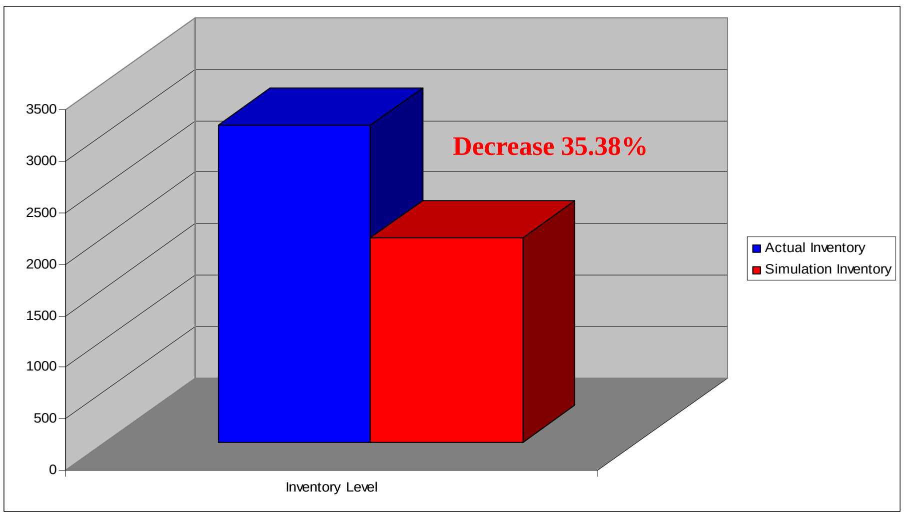


Figure 8.2: Graph of sum of inventory levels

8.3 Back order verification

There is no back order situation when batch size is EOQ for MTS items with 40 MTO items on the simulation. So the EOQ model is applied without any extension of line capacity. The company has adequate capacity for implementing the proposed scheme.

8.4 Some changes in MTS and MTO items

After review with company personnel, some 12 changes of MTS and MTO items were recommended. Previous 2 MTS items are actually half MTS and half MTO. The half of total demands is corresponded by MTS systems and the other half demands is corresponded by MTO systems. Further 5 MTS models were switched to MTO. For the 5 MTS models which are switched to MTO items, 5 MTO items are switched to MTS to fill MTS items. Table 8.2 is the summary of changes.

Table 8.2: Summary of changes

Rank	Status	
	Previous	Now
1	Only MTS	Half MTS and half MTO
12	Only MTS	Only MTO
19	Only MTS	Half MTS and half MTO
22	Only MTS	Only MTO
24	Only MTS	Only MTO
51	Only MTS	Only MTO
52	Only MTS	Only MTO
61	Only MTO	Only MTS
62	Only MTO	Only MTS
63	Only MTO	Only MTS
64	Only MTO	Only MTS
65	Only MTO	Only MTS

With the changes, the new total costs (holding and setup) are obtained. The new results also show that the EOQ model is more economical than one truck load or two truck loads. Table 8.3 and Figure 8.3 show the new result.

Table 8.3: Total cost of new EOQ

Rank	EOQ	EOQ			Q=40			Q=20			Benefit
		Holding Cost	Setup Cost	Total Cost	Holding Cost	Setup Cost	Total Cost	Holding Cost	Setup Cost	Total Cost	
1	42	5912.3	990	6902.3	6558	810	7368	5474.9	1590	7064.9	**465.73**
19	26	3339	1170	4509	4130.6	810	4940.6	2964.1	1590	4554.1	**430.64**

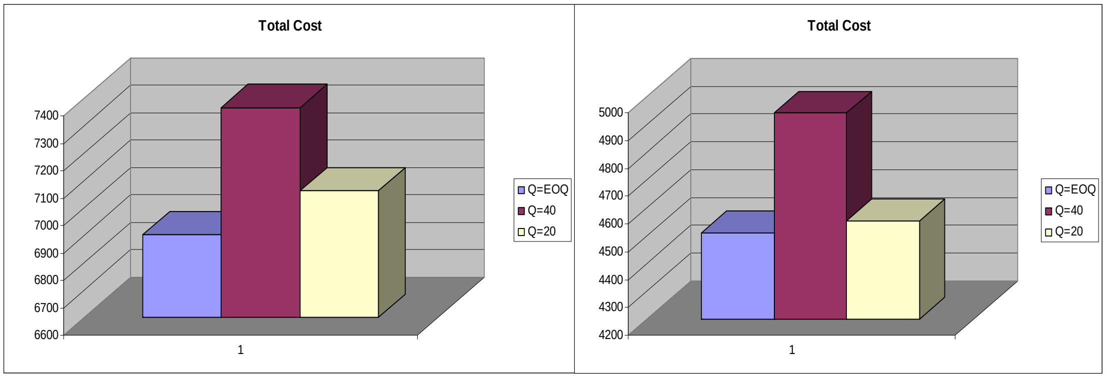


Figure 8.3: Graph of total cost

The inventory levels of the 2 items are less than only MTS systems. When the 1st item is an only MTS, the inventory levels are 123.38 MTs but the inventory levels are just 56.77 MTs in half MTS and half MTO. When 19th item is an only MTS, the inventory levels are 32.06 MTs but the inventory levels are just 22.06 MTs in half MTS and half MTO. Even though the simulation levels of both only MTS and half MTS for the 1st item is still higher than actual inventory levels, the inventory levels of half MTS is less than only MTS. Figure 8.3 show the each inventory levels of half MTS items.

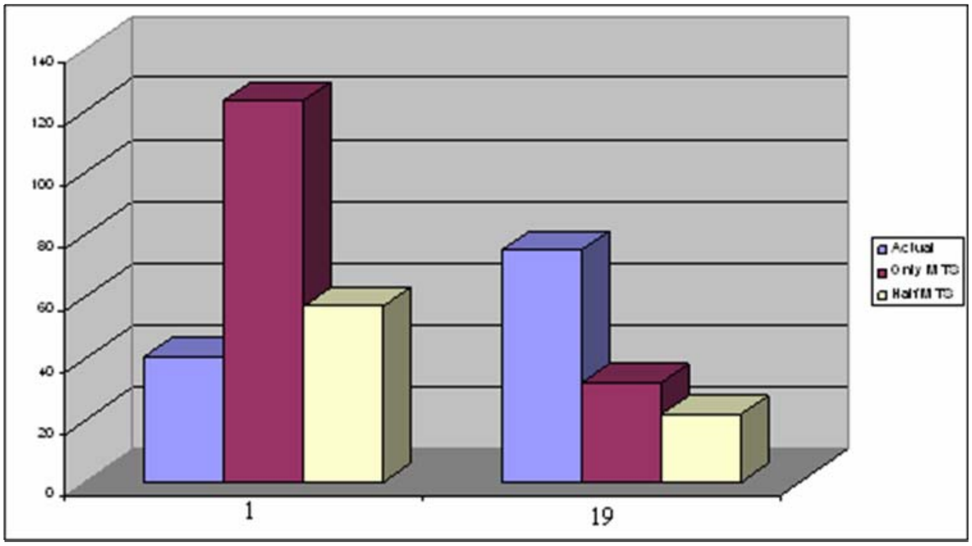


Figure 8.4: Graph of inventory levels

Finally, when the all changes like half MTS and switching MTS and MTO are applied, the all items are arrived to client within 5 days. There is no back order.

8.5 Summary of Conclusions

The inventory levels could be reduced by converting Make-To-Stock into Make-To-Order. The simulation result shows that how many inventories could be reduced and how much a company could save. In this industrial case, there are 100 items that are 60 Make-To-Stock items and 40 Make-To-Order items. In the 60 Make-To-Stock items, the inventory levels are reduced when EOQ model is applied and in the 40 Make-To-Order items, the all orders can be arrived to clients without back order. If some items of the 60 Make-To-Stock items have stable order arrival distribution or constant order arrival ratio, the items could be also converted into Make-To-Order items and the inventory levels are reduced. In all real industries, inventory can be reduced by converting Make-To-Stock into Make-To-Order.

Chapter 9

Future work

9.1 Implementing EOQ on SAP/R3

Bradly D. Hiquet said “From simple beginning and the idea of three engineers in 1972 in Mannheim, Germany SAP has grown be the market leader in client/ server enterprise applications. They now employ over 12,000 people in 40 different countries and are the fourth-largest independent software company in the world today. Still, with all these things of outstanding internal growth, they dwarf next to what they have given the business world today: a truly integrated information management system. There are over 1,000 business processes built into the SAP/R3 software system. This means that real-time data integration has been achieved. This haring or information can be both internally among divisions, plants, or departments and externally with vendors and customers. SAP’s goal is simple: Provide a better return on information.”[8]

SAP/R3 is the most famous and powerful information software in the world. The company has been using SAP/R3 for their business. However the company does not use the MRP module of SAR/R3 completely. In additional, there is a problem to implement EOQ on SAR/R3.

The SAR/R3 data is stored by material number instead of item type in the company. The material number is granted by packing methods of each item. One item could have several material numbers by packing methods. For this reason, an item demand could be segregated into several demands. This makes it tricky to apply EOQ on SAP/R3 because EOQ is calculated on the assumption which one item has only one total demand not multiple demands (or it represents the cumulative demand of different packing methods). The EOQ does not consider demands for each packing method. Figure 9.1 is a graphical representation of this problem.

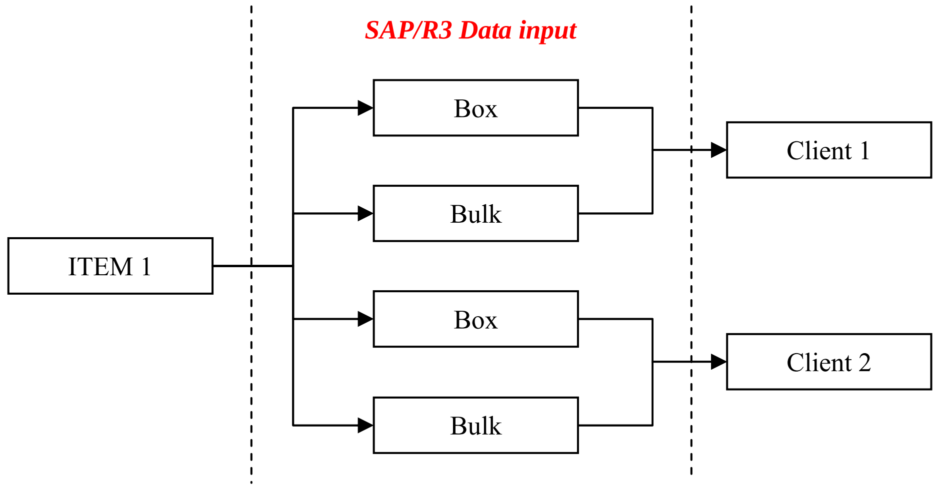


Figure 9.1: Algorithm of problem

The suggested approach to solve this problem is that all EOQs for each packing method are calculated and applied on SAP/R3. Based on historic data for each material number, all EOQ could be calculated and applied on SAR/R3. Or another suggested approach is that the demand portion of each packing method is calculated and EOQ should be divided by the portion and implanted on SAP/R3. Figure 9.2 is a summary of suggested approach.

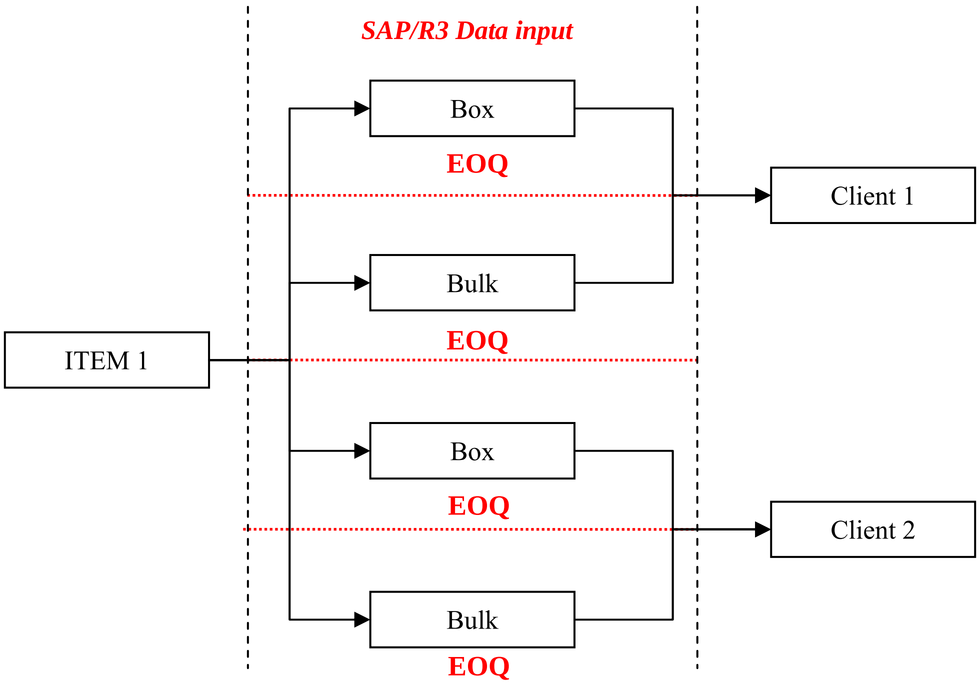


Figure 9.2: Suggested solution

Even though SAP/R3 is a very powerful ERP tool, it is useless when the customization is not enough. To be more powerful SAP/R3, the customization has to be installed correct. For the future work, EOQ should be tried to implement on SAP/R3 to be more powerful ERP tool.

9.2 EOQ with transportation Cost

The EOQ does not reflect transportation cost. There are different transportation costs from the plant to warehouse. There are many types of cost related with transportation. For example, transportation cost per vehicle-mile, marginal transportation cost per item or distance unit, fixed transportation cost for a shipment, independent of size, and fixed handling cost etc. If the transportation cost is zero or there does not need transportation system, the EOQ is an optimal size for one batch. But if the EOQ would reflect the transportation cost, the EOQ should be changed. The future work is to find the relationship between EOQ and transportation cost as like logistics systems.

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