INVENTORY MANAGEMENT: A CASE STUDY OF AN ELECTRIC INDUSTRY COMPANY

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A Thesis Submitted in Partial Fulfillment of Requirements

for the Degree of Master of Engineering in Engineering Management

The Regional Centre for Manufacturing Systems Engineering

Chulalongkorn University

Academic Year 2012

การจัดการสินค้าคงคลัง: กรณีศึกษาอุตสาหกรรมเครื่องใช้ไฟฟ้า

นายสรกฤตย์ เหล็กกล้า

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตร์มหาบัณฑิต

สาขาวิชาการจัดการทางวิศวกรรม ภาควิชาศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต

คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

ปีการศึกษา 2555

Thesis Title	Inventory Management: A Case Study of an Electric Industry Company
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สรกฤตย์ เหล็กกล้า : การจัดการสินค้าคงคลัง: กรณีศึกษาอุตสาหกรรมเครื่องใช้ไฟฟ้า. (INVENTORY MANAGEMENT: A CASE STUDY OF AN ELECTRIC INDUSTRY COMPANY) อ.ที่ปรึกษาวิทยานิพนธ์หลัก : อ.ดร.โอฬาร กิตติธีรพรชัย, 102 หน้า.

สินค้าคงคลังเป็นปัจจัยสำคัญต่อการประกอบธุรกิจอย่างสูง การมีสินค้าสำเร็จรูปพร้อมจำหน่ายส่งผลโดยตรงต่อความพึงพอใจของลูกค้า ทว่าการมีสินค้าคงคลังเป็นปริมาณมากส่งผลให้มีค่าใช้จ่ายต่างๆ เช่นค่าใช้จ่ายในการจัดซื้อ จัดเก็บ หรือค่าการเสียโอกาสจากเงินลงทุนที่นำมาจัดซื้อสินค้าคงคลังดังกล่าว ในหลักการๆ ผลิตแบบ Lean สินค้าคงคลังจัดว่าเป็นของเสีย (Waste) ชนิดหนึ่ง และการลดปริมาณสินค้าคงคลังทำให้ธุรกิจทำกำไรได้มากขึ้นเนื่องจากเงินทุนที่ต้องใช้ในการจัดการสินค้าคงคลังลดลง จึงมีความจำเป็นต้องหาสมดุลระหว่างความสามารถในการตอบสนองต่อความต้องการของลูกค้า และการลดปริมาณสินค้าคงหลังให้ต่ำที่สุดเพื่อผลประกอบการที่ดียิ่งขึ้น การศึกษานี้นำเสนอการแบ่งประเภทสินค้าคงคลังตามความสำคัญแบบ ABC (ABC Classification) เพื่อเฟ้นหาประเภทของสินค้าคงคลังที่สงผลกระทบสูงเพื่อนำหลักการบริหารสินค้าคงคลังตามขนาดรุ่นของพัสดุคงคลัง (Lot Sizing) ชนิดต่างๆ มาปรับปรุง

การวัดปริมาณสินค้าคงคลังที่ธุรกิจในกรณีศึกษาใช้เป็นจำนวนสินค้าคงคลังตามวัน (Inventory Turnover Days) ซึ่งมีเป้าหมายที่เท่ากับหรือน้อยกว่า 10 วัน การแบ่งประเภทสินค้าคงคลังตามความสำคัญแบบ ABC และการจำแนกเพิ่มเติมส่งผลให้มีประเภทสินค้าที่จะทำการศึกษาเพิ่มเติม 12 ชนิด จากสินค้าตู้เย็น 3 รุ่น การเปรียบเทียบผลวิทยาการศึกษาสำนึก (Heuristic) 5 ชนิด ในหลักการบริหารสินค้าคงคลังตามขนาดรุ่นของพัสดุคงคลัง สามารถสรุปว่าวิธีการหาสมดุลในแต่ละช่วงเวลา (Part-Period Balancing) เป็นวิทยาการศึกษาสำนึก ที่ให้ผลดีที่สุด โดยมีสินค้าสองประเภทที่เข้าใกล้ถึงระยะ 3% ของค่าที่ดีที่สุดจากอัลกอริธึม Wagner-Whitin การนำวิธีการหาสมดุลในแต่ละช่วงเวลามาใช้กับสินค้าคงคลังทั้ง 12 ประเภทจากทั้งหมด 1,008 ประเภทสามารถลดจำนวนสินค้าคงคลังตามวันได้ถึง 0.5 วัน และเนื่องจากหลักการบริหารสินค้าคงคลังตามขนาดรุ่นของพัสดุคงคลังส่งผลให้ไม่มีสินค้าคงคลังเหลือหรือเหลือน้อย จึงกำหนดปริมาณสินค้าคงคลังสำรอง (Safety Stock) เพื่อป้องกันการขาดสินค้า

ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต ลายมือชื่อนิสิต
สาขาวิชา การจัดการทางวิศวกรรม ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก
ปีการศึกษา 2555

5271652421 : MAJOR ENGINEERING MANAGEMENT
KEYWORDS : INVENTORY MANAGEMENT / ABC CLASSIFICATION / LOT SIZING

SORAKRIT LEKKLAR : INVENTORY MANAGEMENT: A CASE STUDY OF AN ELECTRIC INDUSTRY COMPANY. ADVISOR : ORAN KITTITHREERAPRONCHAI, Ph.D., 102 pp.

One of the most important factors in business operations is inventory, especially Raw Material, as it protects against fluctuation in supply and realizes economy of scale for a company. Nevertheless, inventory is a costly asset. Reducing inventory levels allows a company to increase liquidity and to be more responsive to customer's demands. This case study proposes the use of ABC Classification to classify high-impact raw-material in an electronic industry company and the use of lot-sizing to improve the procurement process.

The inventory performance measure of the case study company is in Inventory Turnover Days where a target of no more than 10 days is set. ABC Classification and other prerequisites results in 12 items from 3 different refrigerator models on which further study is conducted. Comparing results from lot sizing heuristics showed that the Part-Period balancing heuristic performs best, resulting in a total cost difference of 12.09% from the optimum values obtained from Wagner-Whitin algorithm. The Part-Period Balancing heuristic also came as close to within 3% of the optimum values for two parts. Implementing the Part-Period Balancing heuristic to just the 12 selected items, out of 1,008 possible items resulted in a considerable Inventory Turnover Days reduction of 0.5 days. As Lot Sizing heuristics and algorithms leave little or no inventory at the end of each period, Safety Stock levels for the aforementioned items are established to guard against stock-outs.

Department : The Regional Centre for Manufacturing Systems Engineering Student's Signature ....
Field of Study : Engineering Management Advisor's Signature ....
Academic Year : 2012

ACKNOWLEDGEMENTS

The author would like to express his deepest gratitude to Dr. Oran Kittithreerapronchai, without whose advice, guidance, patience, and support, this thesis could not have been completed. The author would also like to sincerely thank members of the Thesis Examination Committee: Professor Sirichan Thongprasert, Ph.D. and Associate Professor Paveena Chaovalitwongse, Ph.D. for their invaluable guidance and suggestions.

The author would also like to extend his gratitude to Mr. Kompanat Pattamasoot and Ms. Naratip Ketsuwan of Refrigerator Division for their support before and throughout the course of this thesis.

Lastly, the author would like to give special thanks to friends and fellow Chula-Warwick classmates, who have learned and matured together, for their strength and support through friendship.

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CHAPTER I

INTRODUCTION

1.1 Introduction

One of the most important factors in business operations is inventory as it protects against fluctuation and enhances operational efficiency. Inventory comes in many forms. Inventory in the form of Raw Material or Work-in-Process (WIP) allows for uninterrupted production processes while readily available finished goods (FG) inventory creates customer satisfaction through high service levels. Nevertheless, inventories are costly assets and require capital to procure and maintain. Holding large quantities of inventory implies that a company has less liquidity for other business operations. Reducing inventory levels allows a company to increase liquidity and to be more responsive to customer’s demands.

In Just-In-Time (JIT) principle, for example, inventory is considered as a waste as no value-added activity is performed. As a result, JIT aims to reduce inventory to a bare minimum. Drawbacks of such extreme approach are that key suppliers must be located in proximity so that a continuous stream of goods/deliver can be achieved and the system is vulnerable to unforeseen disruption. For example, the aftermath of the 2011 Tōhoku earthquake and tsunami had crippled the Japanese auto industry for several months (Hagiwara et al., 2012).

Therefore, a company needs a suitable level of inventory, balancing between satisfying customer’s demands and maintaining production responsiveness, so that the company’s profit is maximized. That is, in turn, the objective of inventory management.

Company Background

The company in this case study, located on the outskirts of Bangkok, manufactures various electrical appliances for domestic sales and exports include inductive motors and household appliances such as refrigerators, microwave ovens, hot plates, dishwashers, fans, air purifiers, rice cookers, electric thermal pot, and water heaters (shower).

Figure 1.1 Consumer goods produced at case study factory

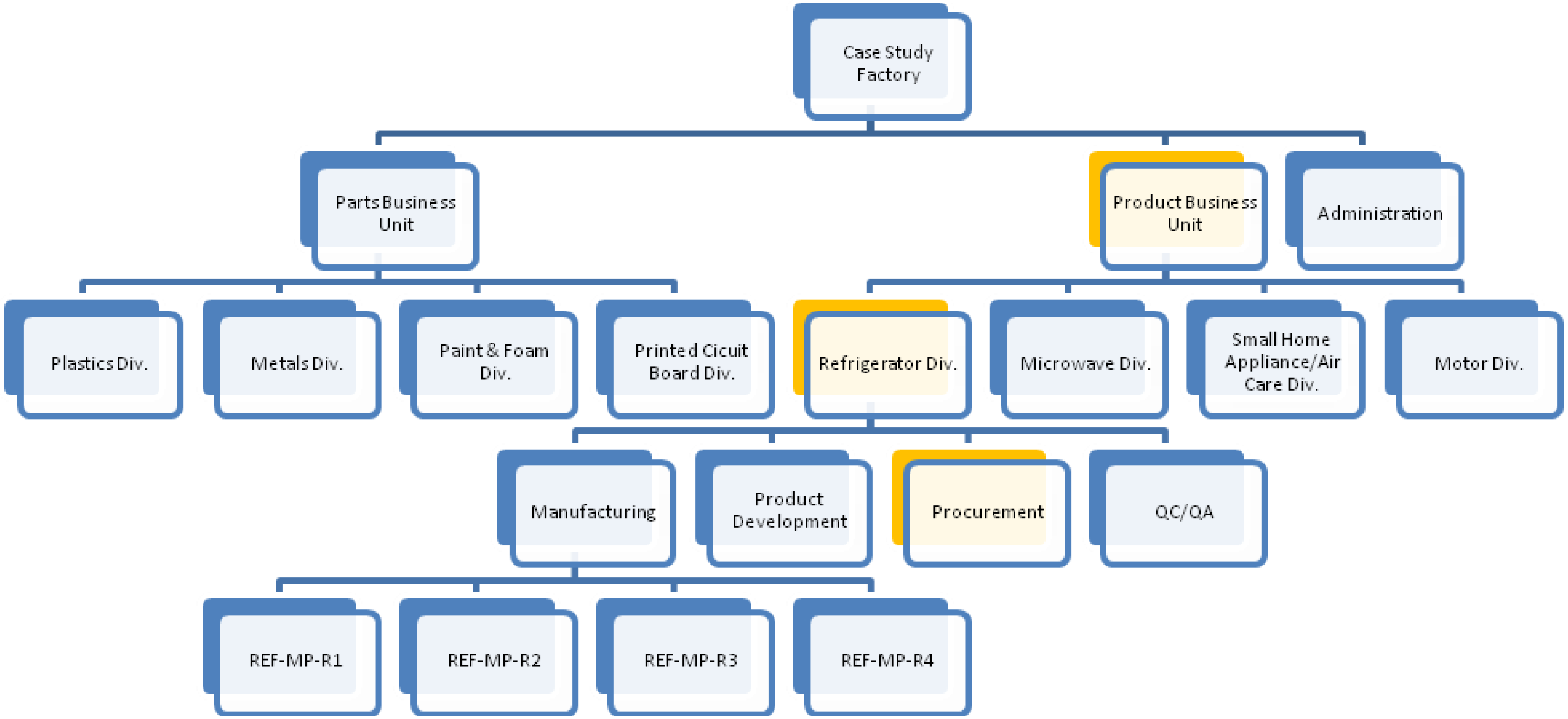


Figure 1.2 Case study factory organization chart

The case study company is organized into Parts Business Units, Product Business Units, and Administration. Administration, such as Accounting, Human Resources, and Engineering divisions plays supporting roles in assiting core manufacturing business units, particularly Parts Business Units and Product Business Units. Product Business Units are internal customers of Parts Business Units, such as Plastic and Metal Forming Division, whose main responsibility is to manfacture parts which will be used be the Product Business Unit for manufacture of finished goods.

Refrigerator Division

Figure 1.3 Products of REF. div.

This thesis focues on the case study factory's Refrigerator division (REF. div.), which generates the highest revenue in the company through manufacture of a monthly average of 33,286 refrigerators (February-August 2011). The manufacture of single door, direct-cool refrigerators are done consecutively by four production sections: REF-MP-R1, REF-MP-R2, REF-MP-R3, and REF-MP-R4.

- REF-MP-R1 is the metal processing section which transforms sheet metal into structural parts.
- REF-MP-R2 processes plastic sheets into the inner linings (cabinet and door) of refrigerators by vacuum forming and inserts them into the assembled refrigerator structure using components from REF-MP-R1.
- REF-MP-R3 or the Urethane section injects polyurethane foam, which serves as heat insulation and provides structural rigidity, into the cavity between the inner linings between the refrigerator structure and inner linings (both cabinet and door).
- REF-MP-R4 assembles the remaining parts as well as installing the compressor and charging it with refrigerant before performance and quality checks are performed. The refrigerators are then packed into finished goods.

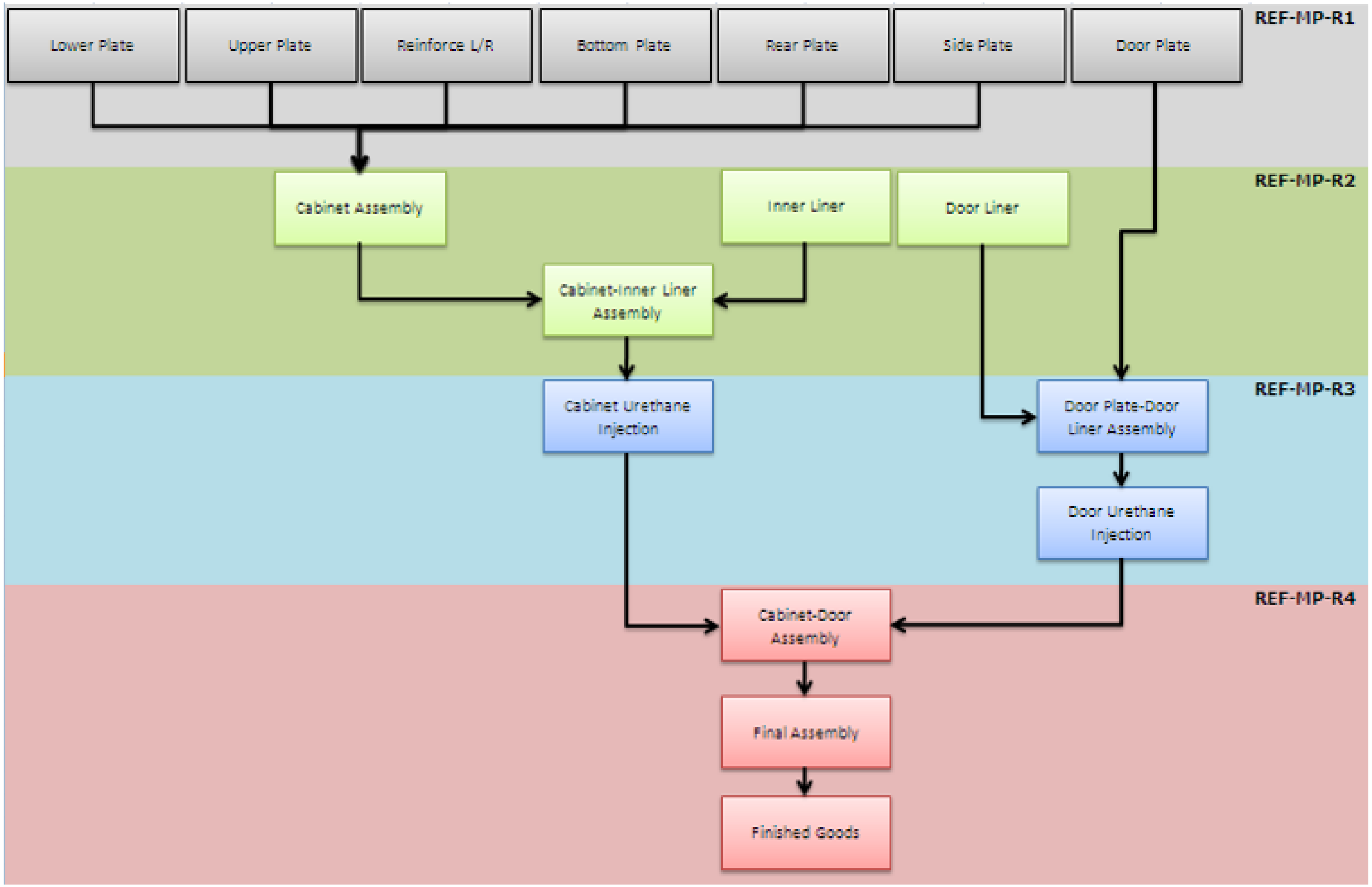


Figure 1.4 Manufacturing Activities Flow Chart

REF. div. Inventory Management Process

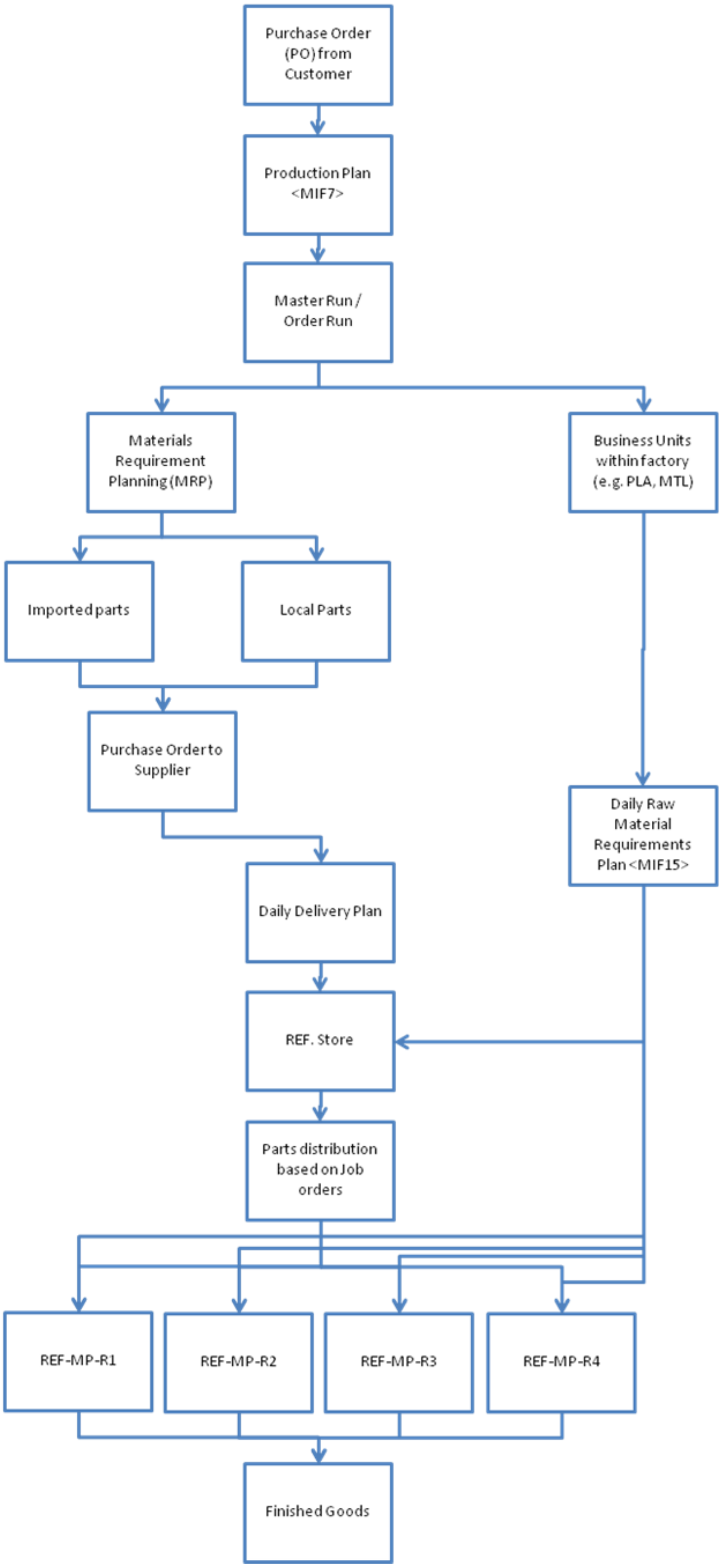


Figure 1.5 REF. div. Inventory Management Flow Chart

Purchase Order (PO) from Customers:

- The inventory management process starts with orders received from customers, both international and domestic. The main customer is a single domestic company which manages the brand's marketing and sales of all manufactured products sold domestically.
- The customers also gives forecasts up to 3 months into the future, although these are seldom accurate and are constantly revised.

Production Plan <MIF7>:

- These orders are then entered manually and developed into production plans by the production planners.

Master Run/Order Run:

- The production plans are entered into ORACLE which is the company's Enterprise Resource Planning (ERP) software.

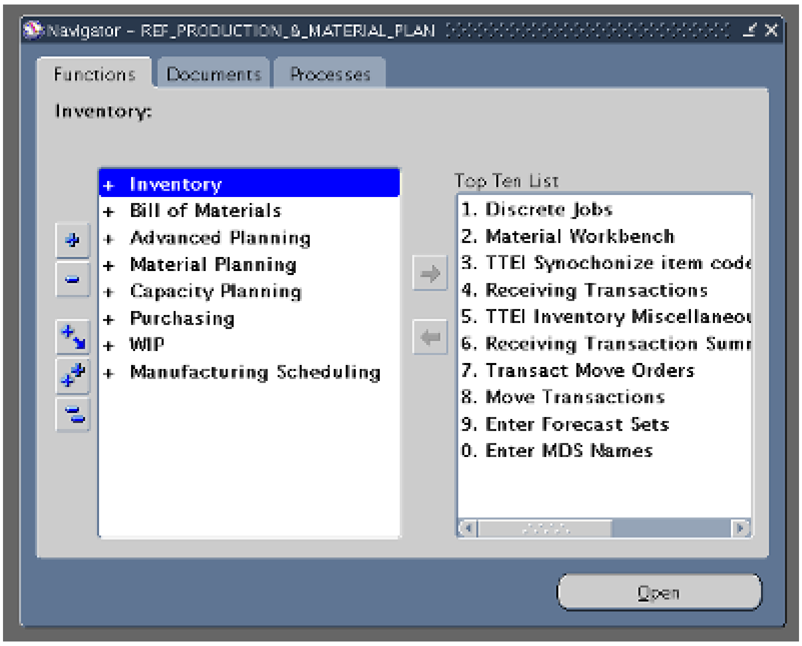


Figure 1.6 ORACLE ERP

Materials Requirement Planning (MRP):

- The Master Run/Order run results in the MRP—Material Resource Planning—for all the parts required in the manufacture of the ordered refrigerators for both REF. div. and other parts business units which supplies parts to REF. div.
- The division's procurement staff then issues purchase orders (PO) for imported and local parts.

Daily Delivery Plan:

- The suppliers are also notified of delivery plans on when delivery of ordered parts should be made through the division's Daily Delivery Plan as storage space is limited.

REF. STORE:

- The parts delivered are then kept at REF. div.'s Store which exists at two locations.
    - The first location handles large and heavy parts such as chemicals and sheet metal;
    - The second location which is close to the production lines of REF-MP-R2 and REF-MP-R4 handles smaller parts such as wire harnesses and plastic drain hoses.

Parts Distribution Based on Job Orders:

- Parts are issued from the Store to the various sections according to issued Jobs.
    - For example, if a Job is opened for 200 refrigerators of a certain model on a certain day, then 200 wire harnesses used for that model will be sent to the section that assembles the wire harness, which is REF-MP-R2 in this case, on that day.

Finished Goods:

- Only when the refrigerators have been fully assembled and packed can the issued Jobs be closed and transferred to the finished goods warehouse which is handled by a different company—Toshiba Logistics Thailand (TLGT).

1.2 Problem Statement

In the case study company, the key performance index (KPI) related to inventory is inventory turnover days, a ratio of total value of all inventories to the Sales Amount in the respective month. In the second half of 2010 fiscal year (October 2010 to March 2011) REF. div. currently has a high average monthly inventory turnover, ranging between 9 to 14 days. The six month average is 11 days; higher than the companywide objective of less than 10 days.

Quality Objective	Target	Number
Reduce Raw Material, Parts, Work-in-process, and Finished Goods Inventory	Inventory holding day	QMP/REF-11009
	Measure: Raw Material, Parts, Work-in-process, and Finished Goods inventory less than 10 inventory days in '11AB	

Figure 1.7 REF. div. Quality Objective

Inventory Turnover Days:

$$ITR = \left(\frac{RM + WIP + FG}{SaleAmount} \right) \times No.ofDays$$

The number of Inventory Turnover Days (ITR) in each month is calculated from the sum of monetary values of production inventory in all forms: Raw Material (RM), Work-in-Process (WIP), and Finished Goods (FG), divided by the Sales Amount then multiplied by the number of days in the respective month. An example calculation of ITR for March 2011 is shown as follows:

$$ITR_{March'11} = \left(\frac{19{,}602 + 6{,}184 + 8{,}875}{112{,}447} \right) \times 31 = 9.56 \approx 10$$

Section	Oct'10	Nov'10	Dec'10	Jan'11	Feb'11	Mar'11	Average
Raw Material	31,287	27,022	26,714	19,787	20,046	19,602	**24,076**
Work In Process	6,655	7,604	6,444	7,125	6,291	6,184	**6,717**
Finished Goods	9,317	9,363	15,413	11,796	6,011	8,875	**10,129**
Total Inventory	47,259	43,989	48,571	38,708	32,349	34,661	**40,923**
Sale amount	**124,037**	**120,161**	**109,980**	**104,902**	**105,269**	**112,447**	**112,799**
Inventory turnover (days)	**12**	**11**	**14**	**11**	**9**	**10**	**11**

Table 1.1 REF. div. Inventory turnover (days)

The six month average is 11 days. With raw material, work in process, and finished goods accounting for 58.8%, 16.4%, and 24.8% of total inventory respectively. Therefore, since the largest percentage of inventory is in Raw Material Inventory reducing this inventory would yield the highest benefits. The high amount of inventory is due to many factors such as:

High product variety, resulting in large number of Stock Keeping Units (SKU):

- 11 different models comprising of 92 variations (as of July 2011).
- A total of 1,008 active SKUs as of June, 2011.

Monthly demand fluctuation:

- Between January to June 2011, monthly production ranged from 27,661 sets/month in May to 37,351 sets/month in March (33,286 sets/month on average).

Inaccurate forecast:

- 1 month forecast accuracy for total refrigerator quantity can be as low as 85.69%.
- 1 month forecast of a specific model variation can be completely inaccurate, as sometimes orders for a specific variation are cancelled completely.

Multiple production plan revisions:

- Frequent order changes from customers (up to 10 revisions).
- Issuance of new production plan and Master/Order runs every time the order changes.

Coordination of imported and local parts:

- Imported parts tend to have longer lead times (up to 120 days from issue of PO) which often results in part shortages.
- Most local parts have short lead times, but because storage space is limited, some parts cannot be delivered all at once.

Inventory management policies are unclear:

- Managing inventory levels rely heavily on MRP from ORACLE
    - Often, orders are issued after MRP from Master/Order Run showed that there will not be enough of a certain part to meet forecasts.

- Parts shortage (e.g. imported compressor for HB refrigerator models)
- High stock levels (e.g. “PS” color door plates for B145 refrigerator models)

1.3 Objective

- To improve current Raw Material procurement processes thereby reducing inventory management costs and Inventory Turnover Days.

1.4 Scope

- ABC Classification
- Inventory management and parts procurement of SKU Group A: Long Lead Time
- Identification of Key Performance Index (KPI)
  - Inventory Turnover
- Establishment of Inventory related parameters
  - Holding Cost
  - Ordering Cost
  - Lead Time
  - Lot sizing
- Establishment of ordering policies and Safety Stock

1.5 Methodology

1. Literature review
2. Inventory management process and activities study
3. Study As-Is Process
4. Collect and Analyze Data
    a. ABC Analysis
    b. Classification
        i. Long LT
        ii. Short LT
        iii. By Model
5. Select Targeted RM and Propose Policy
    a. Establish parameters
        i. Ordering Costs
        ii. Holding Costs
    b. Cycle Inventory
        i. Production Plan
        ii. Inventory Levels
    c. Establish ordering policies
        i. Compare Heuristics
        ii. Choose best heuristic
    d. Lot Sizing
        i. Lot Size < MOQ
        ii. Lot Size > Current Lot Size
        iii. Overabundance of Inventory
    e. Policy Implementation
6. Summary
7. Thesis write up

Thesis Schedule

	2011				2012								
Items	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Literature review	■	■											
Propose Thesis	■												
Study As-Is Process		■	■										
Collect and Analyze data			■	■	■								
Select Targeted RM					■	■							
Test/Verify Selected Policy							■	■	■				
Summary										■	■	■	
Thesis write up												■	■

Figure 1.8 Gantt Chart

1.6 Expected Benefits

- Select suitable inventory control policies and parameters
- Reduced inventory costs
- Improved customer service levels through reduced stock-out

CHAPTER II

LITERATURE SURVEY AND THEORETICAL CONSIDERATION

2.1 ABC Classification

An organization may have thousands of inventory stock keeping units (SKU). To monitor the large multitude of inventory items, the traditional approach is to classify the inventory into different groups where different inventory control policies can then applied to each group. ABC analysis is a well known and practical classification based on the Pareto principle or the "80-20 Rule" which originated from Vilfredo Pareto's idea that 80 to 85% of Italy's wealth was held by only 15 to 20% of the country's population. Using this idea, inventory is classified into different levels, which in turn required different levels of attention.

However, the value ratio in ABC analysis is not fixed. Ng, W. L. (2005), for example, proposed that Group A is items that contributes about 70% of company's business but only taking up 10% of inventory, and requires the highest attention. Group B inventory items are those representing about 20% of company's business and taking up 20% of inventory. Group C items are those representing only 10% of company business but taking up 70% of inventory. While Flores and Whybark (1987), proposed different ratios for manufacturing and service firms as shown below:

Dollar-Usage Distribution

	Manufacturing Firm			Service Organization		
Dollar-Usage Category	No. of Items	% of Items	% of $ Usage	No. of Items	% of Items	% of $ Usage
A	15	11	84	22	20	72
B	25	15	15	33	30	22
C	88	74	1	55	50	6
Totals	128	100	100	110	100	100

Figure 2.1 ABC Dollar-Usage Distribution. Source: Flores and Whybark (1987)

This study focuses on Group A because of its greater impact on inventory turnover levels. Items which are classified as Group A items are those that have high Dollar-Usage or a high *'Dv'* value where *D* is the usage rate or demand, and *v* is the item value. These could be of two cases: the item has low sales but is high in value, or has high sales but is low in value. However, the items in the case of Group A, Long LT are of the first type as they are slow moving items making up only a small portion of total production, but are made into high-end refrigerator models.

Since the case study company currently has an ERP system in place, continuous review (review interval R=0) of inventory can be used as opposed to periodic review, which has greater exposure to variability. There are two general inventory control policies for continuous review. The first policy is the Order-point, Order-Quantity (s, Q) system where a fixed quantity Q is ordered when inventory level drops to s or lower. The second policy is Order-point, Order-up-to-level (s, S) system where the variable replenishment made when inventory level drops to s or lower is just enough to bring inventory level up to level S. Which policy to apply will depend on the nature of the individual items.

2.2 Lot Sizing

The Lot sizing problem is a form of production planning problem with setup—or in this case—ordering costs between production lots. Due to the existence of these ordering costs, it is often too costly to issue purchase orders for a given product in every production period. However, reducing the number of orders by ordering in large quantities at a time to satisfy future demands will result in high inventory holding costs. Therefore, the objective of Lot Sizing is to determine the periods where ordering should take place, and the quantities of the item to be ordered, in order to meet the demand while minimizing ordering and inventory holding costs. Many models have been proposed for solving lot sizing problems, but the most common model is the Economic Order Quantity (EOQ) model and heuristics such as the Least Period Cost (Silver-Meal), Periodic Order Quantity, Lot-for-Lot, Least Unit Cost, and Part-Period Balancing heuristics. A more complex approach which yields the optimal solution is the Wagner-Whitin algorithm.

2.2.1 Economic Order Quantity (EOQ)

Purchasing items is a key component of inventory management; if a company did not purchase items at the appropriate quantity, several problems may occur. Shortages might take place if there are not enough items to meet customers' requirements, or high inventory holding costs when there are excessive item quantities. Therefore, it is important for a company to determine the appropriate order quantity. The most simple and commonly used method is the economic order quantity (EOQ) model. It is a total cost optimization of annual holding and ordering costs. When the reorder point is reached, the economic order quantity is ordered when applicable. This method is simple but needs continuously monitoring when the inventory level meets reorder point. The basic EOQ formula is as follows:

$$Q = \sqrt{\frac{2C_p D}{C_H}}$$

Where:

Q	=	order quantity (units)
D	=	annual demand (units)
C_p	=	ordering cost (THB/order)
C_H	=	holding cost (THB/unit/year)

EOQ assumes a constant, deterministic demand rate and is applied when there is low demand variability so that the constant demand assumption is not moot. When demand rate varies with time, using the same replenishment (EOQ) quantity may not be a viable solution.

2.2.2 Wagner-Whitin Algorithm

One approach to solving the case such time-varying demand is to use an optimum solution to a mathematical model of the problem at hand such as the Wagner-Whitin algorithm. The algorithm is an example of dynamic programming which is a mathematical procedure for solving sequential decision problems (Silver et al., 1998). The algorithm's function is to minimize the total costs of ordering and holding inventory.

$$\text{Min. TRC} = \sum_{j=1}^{T} \left[A\delta(Q_i) + I_j vr \right]$$

Subject to

$$I_j = I_{j+1} + Q_i - D(j) \qquad j = 1, \ldots, \mathrm{T}$$

$$Q_j \geq 0 \qquad j = 1, \ldots, \mathrm{T}$$

$$I_j \geq 0 \qquad j = 1, \ldots, \mathrm{T}$$

Where $\delta(Q_i) = \begin{cases} 0 \text{ if } Q_j = 0 \\ 1 \text{ if } Q_j > 0 \end{cases}$

$D(j)$ = requirements in period *j*

I_j = ending inventory in period *j*

Q_j = replenishment quantity in period *j*

The optimum solution must also satisfy two properties: A replenishment can only occur when inventory level is equal to zero, and the upper limit to how far to include the demand requirements before period *j* is $D(j)$. However, this method is difficult to understand and implement and needs an ending point for the demand set which rarely exists in actuality as typical MRP operates on a rolling schedule with new demand continually added. Its application is usually limited to high value inventory (Group A) items as savings compared to other solutions may justify the complexity and effort in implementing this algorithm.

2.2.3 Least Period Cost (Silver-Meal) Heuristic

Creating and solving mathematical models to obtain an optimum solution is often too difficult for most people to implement. Different heuristics which also attempt to balance the costs involved are available and are less difficult to understand and implement. One such heuristic is the Least Period Cost or the Silver-

Meal heuristic. This heuristic aims to minimize the cost of ordering (*A*) and holding inventory per time period *T.*

$$\text{Total Relevant Costs} = \frac{A + \text{carrying costs}}{T}$$

If T = 1, there are no carrying costs as the order quantity is only enough to cover demand in period 1. If T = 2, carrying costs to carry demand in period 2 for one period is incurred. The heuristic calculates TRC for increasing period T until total relevant costs per period T start to increase and the number of period T before the increase is implemented and the cycle continues from the next period onwards.

2.2.4 Periodic Order Quantity (Fixed Period) Heuristic

While the EOQ approach was to order in fixed quantities, a slightly different approach for when there is greater demand variability is to express EOQ as a time supply per average demand.

$$T_{EOQ} = \frac{EOQ}{\overline{D}} = \sqrt{\frac{2A}{\overline{D}vr}}$$

A = Ordering Cost

v = Unit value

r = Holding cost as a percentage of Unit value

The resulting value is rounded to the nearest integer (except if the nearest integer is zero, then round up). The quantity ordered is enough to satisfy the integer number of periods from the calculation.

2.2.5 Lot-for-Lot (L4L) Heuristic

Lot-for-Lot is the simplest heuristic as it orders the exact quantity needed in each time period, hence inventory holding costs are zero as the ordered quantity is used up within the period. However, the drawback of this heuristic is the higher amount of ordering cost incurred compared to other heuristics as an order is placed for every period with non-zero demand.

2.2.6 Least Unit Cost (LUC) Heuristic

The Least Unit Cost heuristic is very similar to the Least Period Cost heuristic, except that the total relevant costs of holding and ordering inventory are divided by the number of items resulting in a total cost per unit. Calculation is done period-by-period as in LPC until the unit cost increases at which the period before the cost increase is used and the cycle repeats for the remaining periods.

$$\text{Total Relevant Costs} = \frac{A + \text{carrying costs}}{\textit{Units}}$$

2.2.7 Part-Period Balancing (PPB) Heuristic

The goal of the Part-Period Balancing heuristic is to choose the number of periods for which demand is covered by a single replenishment which results in a balance between inventory ordering and holding costs. The number of periods covered with total carrying cost closest to the ordering cost *A* is chosen, as an exact balance is rarely possible, and the cycle continues for the remaining periods.

2.3 Literature Survey

2.3.1 Supply Chain Management

Technological advances and increasing globalization have generated an ever increasingly competitive market place, forcing supply chains to continuously improve their efficiency in order to remain competitive. Numerous studies have been conducted into improving supply chain performances. Jammernegg and Reiner (2007) studied the use of coordinated application of inventory management and capacity management to improve the performance of supply chain processes. This application of capacity management is suitable for locations where there is a flexible workforce, more likely in countries where labor costs are low (low hiring and lay-off costs). This study addresses the trade-off in customer order decoupling point (CODP) which determines the inventory concentration between Made to Stock (MTS), Made to Order (MTO) and Assembly to Order (ATO). The study used process simulation to show that the coordinated application of methods from inventory management and capacity management results in reduced inventory carrying costs and improved delivery performance, and that a change from MTS to ATO can result in reduced total costs of roughly 11%.

The major impact of uncoordinated supply chain management is the bull-whip effect which could be minimized through availability of accurate demand information. Altug and Muharremoglu (2011) studied how advance supply information—forecasts from an upstream source regarding future capacity availability within a certain planning horizon—can be used when making replenishment decisions, and what is the value of such information sharing when compared to a fixed base-stock policy. The simulation study showed that state-dependent base-stock policies are optimal, and that advanced supply information is most beneficial when operating in environments where capacity is moderately variable and utilization is not too high or low.

For production and inventory management problems that involve multiple resource constraints, K.M. Bretthauer et al. (2006), presented a model which allows organizations to handle decision making involving multiple items such as determining order quantities, production batch sizes, number of production runs, or cycle times, as resource constraints such as raw material procurement, machine and work force capacity, become necessary to handle interaction among the multiple items. The variable versions of the resource constrained production and inventory management model is solved by the proposed algorithm. The continuous variable algorithm requires the solving of a series of box constrained nonlinear sub-problems and a series of nonlinear knapsack sub-problems, while the integer problem is solved with a branch and bound algorithm. Computational testing of the algorithms showed that they are effective for solving large-scale problems.

Schwartz and Rivera (2010) presented an approach for applying control-theoretic principles to tactical inventory management problem. The study uses internal model control (IMC) and model predictive control (MPC) to generate a series of increasingly sophisticated decision policies for inventory management. The proposed IMC policy was able to adjust factory starts in the presence of changes in inventory targets, forecasted customer demand shifts, and demand changes, while the MPC policy showed improved performance, greater flexibility, and higher functionality compared to an advanced order-up-to policy based on fundamental control engineering principles.

2.3.2 Inventory Classification

Due to the need to simplify the multitude of Stock Keeping Units into categories to form the basis for improvements, and also because the accuracy and effectiveness of such classifications greatly impacts the cost savings to be incurred, a variety of classification methods have been explored. W. L. Ng (2007), proposed a simple model for multiple criteria inventory classification. The model converts all inventory SKUs to a scalar score on which the MCIC based on ABC classification can be applied. If converted properly, the scores can be obtained on simple spreadsheet without a linear optimizer and can be applied by inventory managers with little or no background in optimization.

Another study on the multi-criteria inventory classification was made by J.-X. Chen (2011), which applies a peer-estimation approach for multi-criteria inventory classification (MCIC) to ABC inventory classification to address ABC classifications' limitation of being based on a single criterion (e.g. dollar value). The study proposed peer-estimation to all items in addition to the MCIC approach to determine two common sets of criteria weights from most favorable to least without any subjectivity where the two resulting performance scores in both criteria are aggregated by weight coefficients derived from the maximizing deviations method.

Other classification non-MCIC approaches have also been explored, such as a study by Ching-Wu Chu et al. (2008) which proposed a new inventory control approach based on ABC classification called ABC-Fuzzy Classification (ABC-FC) which can handle variables with either nominal or non-nominal attributes while also incorporating managers' judgment into the classification. This new control approach requires identification of the criticality function of inventory items: very critical, critical, and uncritical, based on their impact: very severe, severe, and not severe and their usage frequency before conducting ABC analysis and then fuzzy classification. Compared with actual data of Keelung port, the result from the proposed approach showed high accuracy.

After items have been classified, their inventory management and replenishment policies are then explored. Hautaniemi and Pirttilä (1999) studied the choice of replenishment policies in an MRP environment using a case study of an Assemble-to-order (ATO) company. Formulation of the replenishment policy begins with separation of items into three groups, beginning with low value (C-items), items which have a supply lead time shorter than the Final Assembly Schedule (FAS), and the remaining items are grouped by their demand pattern. The end result is five different item groups.

In Group I, C-items are those in which as little effort should be put in as possible due to their low value and high number of items, and the simple two-bin system is proposed. For Group II (items with supply LT shorter than FAS), conventional MRP system is proposed to maintain balance between high service level and a low inventory due to the criticality and higher item costs. The remaining items are grouped according to demand distribution: singular, lumpy, and continuous (Group III, IV, and V respectively). For Group III, volumes are either too low or demand for the item may fluctuate during supply LT making use of MRP difficult and ROP is proposed instead. Group IV is the most difficult to manage because the distribution of order quantity and interval between orders is not known, a solution may be to lengthen the delivery lead time of finished goods using items in Group IV to be as longer than the supply LT and move the item into Group II. For Group V, continuous demand, MRP can be used based on their sales forecasts.

To show which inventory management policies are best suited, tools such as Systems Simulation are often applied as in the study by Jiaravorapoj, Parthanadee, and Buddhakulsomsiri (2009) which improved on the inventory management system of a case-study distributor of herbal products. The products were first classified by ABC Classification, and then a simulation model was created to simulate the distributor's inventory management system. The four common inventory policies: (s,Q), (s,S), (R,S) and (R,s,S) were considered, taking into account order quantity values, review interval, reorder point and order-up-to-level, under 5 different customer service level (CSL) settings. Results showed that total inventory management costs were lowest when the CSL interval was set to 0.975-0.999 and total costs of groups A, B, and C were significantly lower when using (s,S) or (s,Q) policies, than when using the (R,S) and (R,s,S) policies at 95% confidence level.

2.3.3 Lot Sizing

A comprehensive review of the single item lot sizing problem or SILSP was presented by Brahimi et al. (2006). SILSP is a planning problem where there are varying demands for a single item over *t* periods. To solve the problem is to determine which periods to produce and in what quantities in order to satisfy demands while minimizing the total costs. The total cost of the basic problem comprises of unit production cost, setup cost, and inventory holding cost. Variations of the problem include capacitated, uncapacitated, discrete, multiple-level lot sizing problems.

Wagner and Whitin (1958) notices the limitations of the square-root equation used to find the economic order quantity (EOQ) which assumes constant demand, and developed their famed forward algorithm to address optimal lot size solutions using dynamic programming principles. The problem considered is the inconstant demand, no back-order, *n* period problem where demands in each period are known and uneven, and inventory costs in each period may be varied. The model allows optimal lot sizes for a single item to be determined while holding costs, ordering costs, and demand vary over time. The model's solution is usually the benchmark on which other lot-sizing methods or heuristics are compared.

A solution to the economic lot-sizing with backlogging problem was proposed by Van Vyve (2007), where in the single-item lot-sizing problem, there exists a demand for that item in *n* consecutive periods. Demand in period *t* may be met by production in period *t* or from ending inventory at the end of period $t-1$. If backlog is allowed as in this case, it may also be satisfied from backlog in period *t*. The costs for each production plan are separated between the production, holding, and backlogging cost in each period. The result of the study is an $O(n^3)$ algorithm.

The case where single-item is produced and shipped by an overseas export company is explored by Wakinaga and Sawaki (2008), where in their study, a dynamic lot size model is used to find an optimal production schedule subject to production and shipment constraints resulting in the minimum total cost over the finite planning horizon given deterministic demands which are satisfied by the dispatch of vehicles.

CHAPTER III

METHODOLOGY

3. Methodology

3.1 ABC Analysis with Multiple Criteria

As of June 2011, the company's REF. div. has 1,008 active stock keeping units (SKU) ranging from 0.02 THB/unit to 2,344.32 THB/unit. Large number of items and variation in their values hinder comprehensive study. We focus on a short list of high impact items which greatly affects KPI. Hence, ABC Classification is selected. If one performs ABC Analysis using 70%, 20%, and 10% as proposed by Ng, W. L. (2005) would result in large number of items in group A, as the item located at 70 percentile has an average ending monthly inventory of 62,192.92 THB or 0.33% of total inventory. Therefore, a ratio of 60%, 30%, and 10% for groups A, B, and C are selected instead. Group A, thus, consists of items having an average monthly inventory value of 100,000 THB.

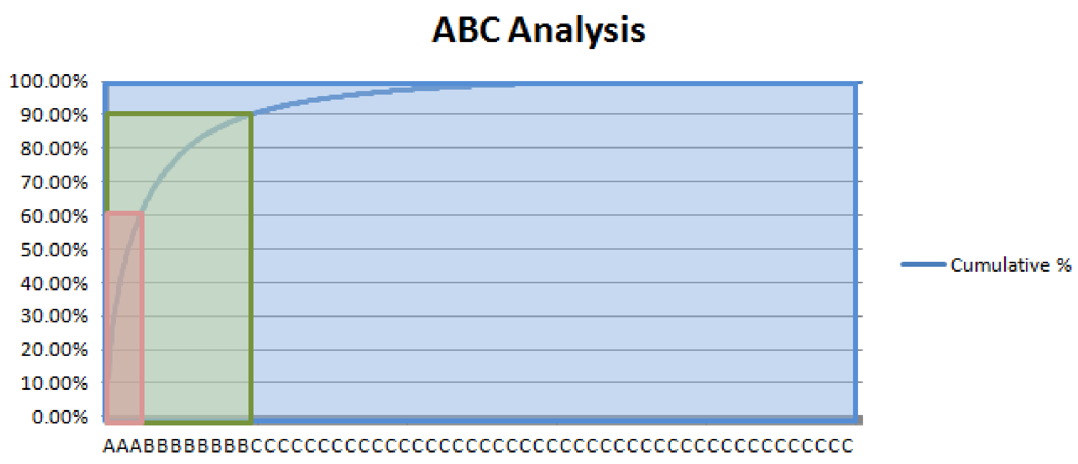


Figure 3.1 ABC Chart

Category	No. of Items	% of Items	THB Usage	% of THB Usage
A	43	4.27%	11,178,226.67	59.94%
B	147	14.58%	5,603,848.12	30.05%
C	818	81.15%	1,868,053.79	10.02%
Total	1,008	100%	18,650,128.59	100%

Table 3.1 ABC Classification

Group A can be divided further according to lead times (LT): Short and Long LT. In the company, REF. div. schedules production planning every month, and the main customer provides forecasting PSI (a rough plan) every two months. Therefore, it is natural to differentiate short and long lead time inventory using 30 days as the lead time.

At first glance, long lead time items are imported items which have long transportation time and may go through customs processes before being shipped to the case study company. Some of the items have short LT which makes them relatively easy to control, but are still situated in group A because of their high unit value and usage.

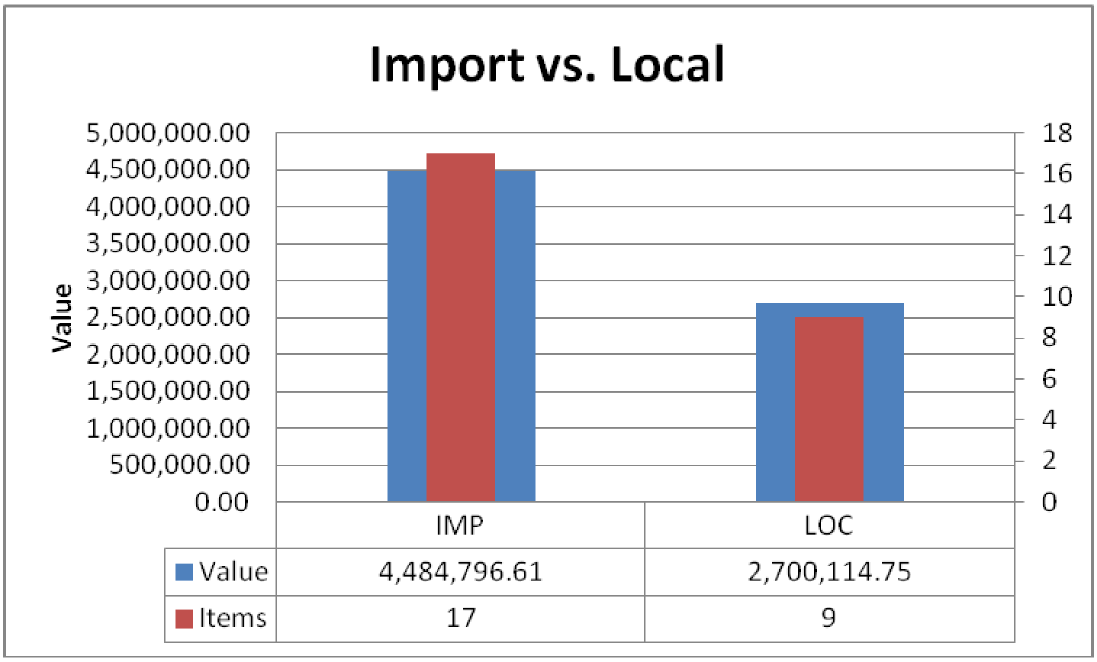


Figure 3.2 Imported vs. Locally Sourced Items

Despite having long lead times, some items should be excluded from the list as they are discontinued, such as copper tubes. In addition, door plate parts have also been omitted as their demand is dependent on the customer's preferences or marketing campaign at the time and has no seasonality or trend with some color items having a limited production run. Gaseous items such as HCFC-134A refrigerants have also been omitted, as the accuracy of their usage in Bill of Materials (BOM) is inexact, consisting of varying weight and allowances for different refrigerator sizes.

As a result, our list consists of 12 items, which are components of three distinct refrigerator models (Table 3.2). Four items—one of them being the most costly inventory item: Compressor DE33—are attributed to HB40 refrigerator model which has high usage of imported components and low production levels. Four items are from B175Z refrigerator model which is the highest production model from REF. div. These items have low unit cost, but high usage rate. The remaining four items are from wine cellar W80 model which has high use of imported parts, but very low production levels.

Item	Description	Unit Cost
RFBI09067680800	COMPRESSOR;DE33YD	2,344.32
RFBT09002850000	COMPREESOR WITH STANDARD ACCESSORIES NO.SB24	942.45
RFBB09003240000	COMPRESSOR WITH STANDARD ACCESSORIES FL0634-RD	1,050.18
RFBI09078970800	SWITCH	114.82
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	19.36
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	38.46
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	43.49
RFMI09007950600	LAMP SOCKET'06F	10.45
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	1,331.77
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30	950.37
RFBI09067840800	BALANCER (S)	16.70
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	49.76
WCBI00200590200	GLASS DOOR(383*685*21t)WIC-019A-AGB '02F	1,187.56
RFBI09070330800	SILENCER-A	14.70
RFNL00580421100	ZINC PLATE SGCC 882.4x564.4x0.25t(R.PL)170L '11F	48.47
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	131.25
RFNL00480421000	ZINC PLATE SGCC 734.9*564.4*0.25T(R.PL)140L	40.37
RFNL00680421000	ZINC PLATE SGCC 950.9*564.4*0.25T(R.PL)180L	52.23

(yellow)	B175Z
(green)	HB40
(blue)	W80

Table 3.2 Items under study

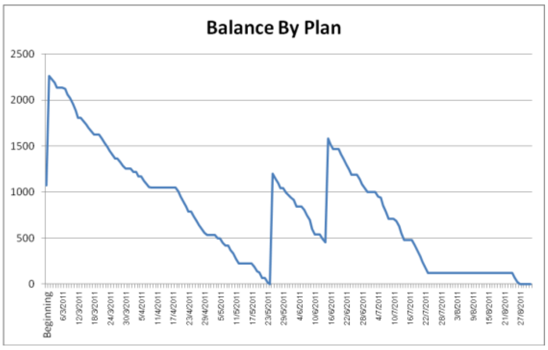
3.2 Inventory Level

3.2.1 Inventory Cycles

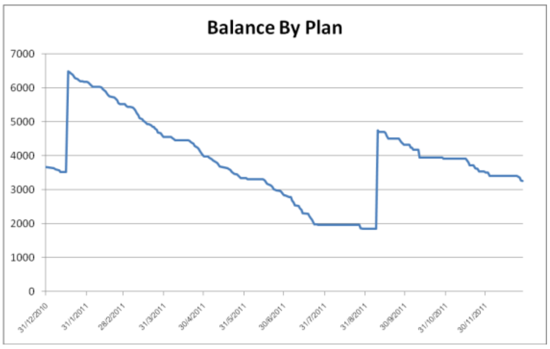
The inventory cycle and patterns for items pertaining to these models are different. Items for HB40 refrigerator and W80 wine cellar models are imported and have long lead times. They are ordered in large quantities although their usage rate is small; whereas, items for B175Z are ordered frequently in large quantities due to their short lead times and high usage rate.

3.2.1.1 HB40 Model Items

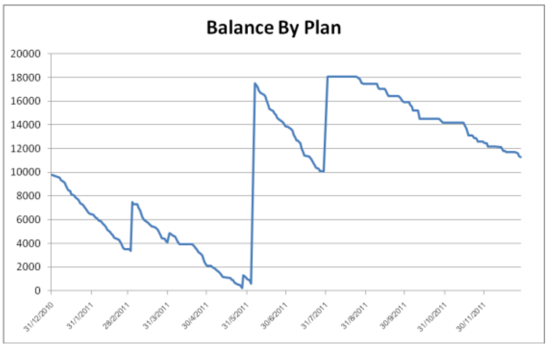
Two items showed fixed order quantities corresponding to minimum order quantities (MOQ). Historical data shows that managing inventories for these items have proven difficult with the occurrence of both stock-outs and high inventory levels for the same item. In the case of 'Compressor DE33,' initial inventory at the beginning of the year was high but gradually diminishes. However, inventory level reached zero before replenishments arrive. In the case of 'Switch,' replenishments arrived while inventory level is still moderate resulting in high average inventory level. For 'Balancer (S)' and 'Silencer-A,' a high single replenishment resulted in overstock of items. Inventory of 'Balancer (S)' and 'Silencer-A' are higher than other items because of their higher rate of usage. There are three 'Balancer (S)' and two 'Silencer-A' for every HB40 refrigerator.



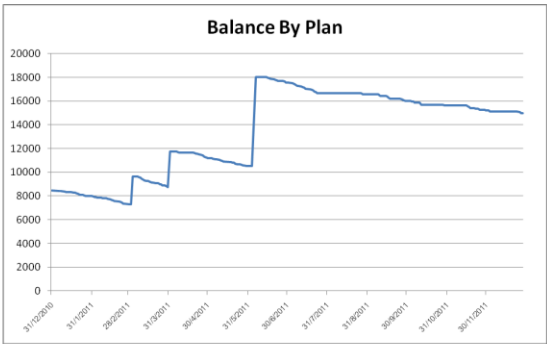
Compressor DE33



Switch



Balancer (S)

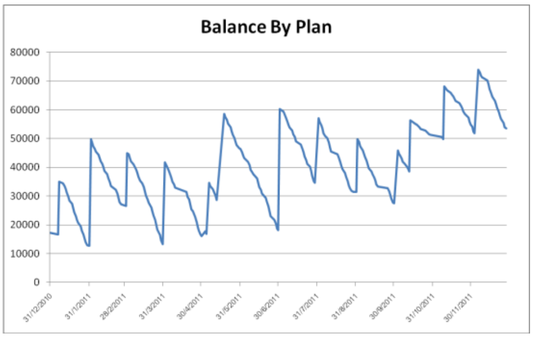


Silencer-A

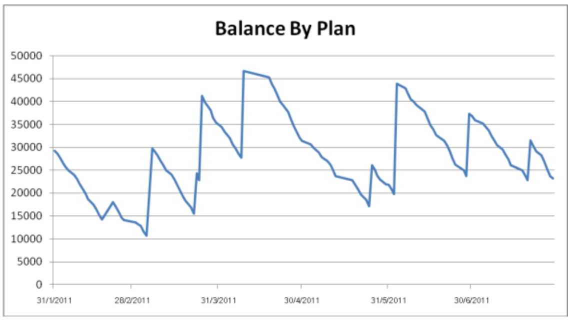
Figure 3.3 HB40 Items

3.2.1.2 B175Z Model Items

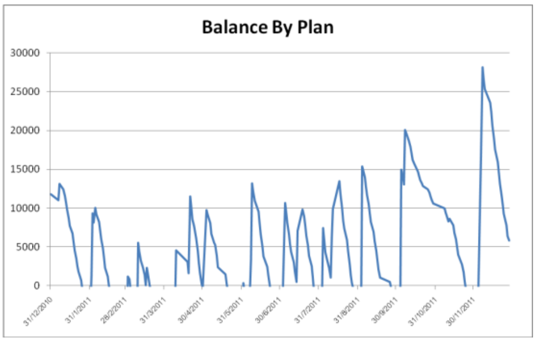
Items used in B175Z refrigerator models behave almost opposite to items used in HB40 models, because they are sourced domestically allowing for frequent ordering and replenishment and has high usage rates. However, there are instances of unusually high replenishment quantities and uncoordinated replenishment resulting in gradually increasing inventory levels for ‘Dryer Assy’ and ‘Lamp Socket.’ Meanwhile, inventory for ‘Bottom PLT’ when comparing production plan to initial inventory and replenishment often resulted in negative inventory. This is due to use of a similar item that is being phased out resulting in lower than anticipated replenishment. Actual inventory levels of ‘Bottom PLT’ in actuality should be similar to that of ‘Rear PLT 170L Curve’ which is procured from the same supplier.



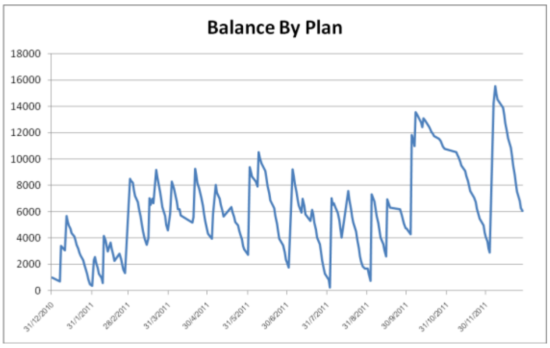
Dryer Assy



Lamp Socket



Bottom PLT

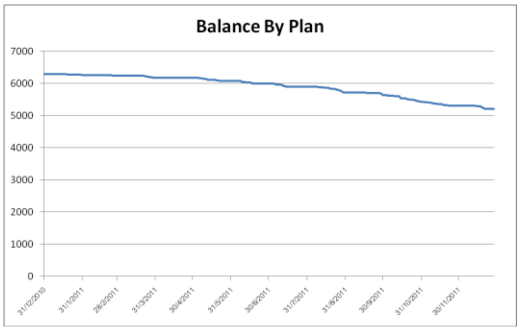


Rear PLT 170L Curve

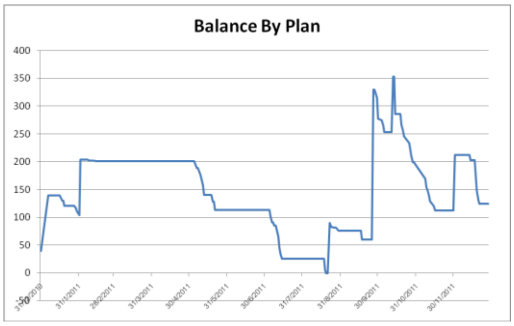
Figure 3.4 B175Z Items

3.2.1.3 W80 Model Items

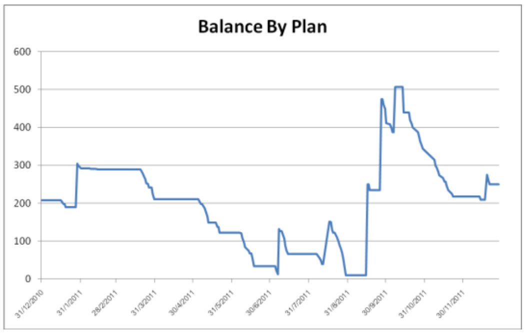
Wine Cellar W80 models use many imported parts but production quantity is very small compared to the other two models as it is rarely produced, when only in small batches when produced. Therefore, inventory level sometime remains unchanged for long periods of time, as in the case of ‘Glass Door W80’ and ‘Compressor SB30,’ during non-production periods. For this model, inventory level is highly sensitive to replenishment quantity as inventory level reduces very slowly afterwards. One extreme case is that of ‘Lower Hinge’ where 10,000 units were ordered in 2007, while annual demand in 2011 was only slightly over 1,000 units.



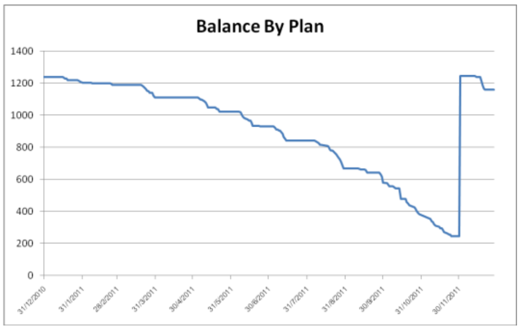
Lower Hinge



Glass Door W80



Compressor SB30



Drain Hose

Figure 3.5 W80 Items

3.3 Parameters

3.3.1 Ordering Cost

REF. div.’s inventory flow after an order run by ORACLE begins with analysis of MRP of related items by REF. div.’s planning staff. Parts which will or might experience shortage are those which will be ordered. The order quantity is based on the discretion of the planning staff based on her knowledge and experience or minimum order quantity. The information regarding parts to be ordered and their order quantity is then passed on to the staff from Purchasing division who oversees purchasing and procurement for REF. div. to issue the respective Purchase Orders (PO).

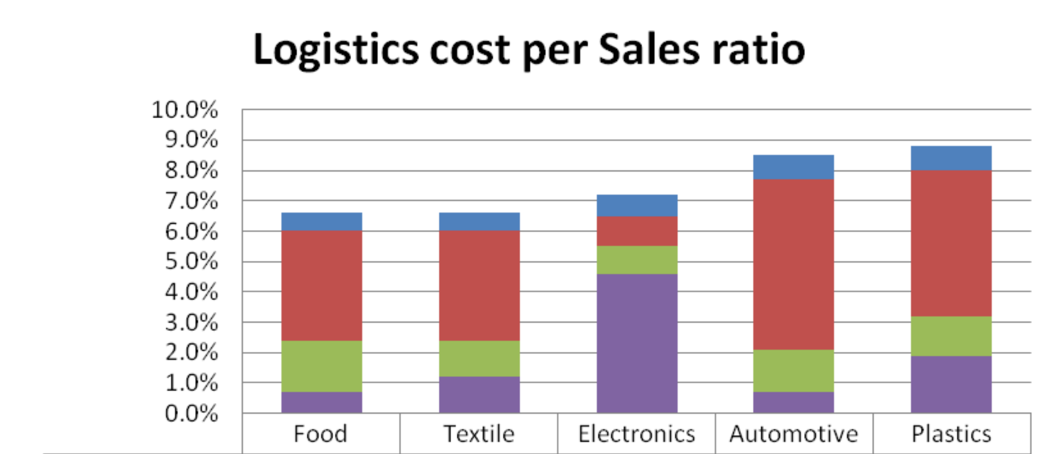
When parts arrive from suppliers, they are inspected by REF. div.’s incoming inspection (part of Quality Control section). The level of inspection varies from mere sampling to 100% inspection depending on the parts (complexity, importance, etc.) and suppliers (old or new). Parts which passed inspection are then taken to REF. Store for storage to await distribution.

The ordering and handling cost of each PO on the case study factory’s part is drawn from past data. Using historical data from 2010, a total of 3,069 Purchase Orders were issued. Therefore, the average cost is 1,008.80 THB/PO. Processing and handling costs such as telephone/fax and documentation was given by Purchasing division as 2.2%, resulting in a total average cost of associated with a single PO is 1,030.99 THB/PO.

Planning		
REF. Planning staff (1p):	30,000.00	THB/month
OT (2 hrs./day)	8,250.00	THB/month
Yearly bonus (3x)	7,500.00	THB/month
PUR. Staff (1p):	18,000.00	THB/month
OT (2 hrs./day)	4,950.00	THB/month
Yearly bonus (3x)	4,500.00	THB/month
	73,200.00	THB/month
Incoming inspection		
Incoming inspection QC (5p)	33,000.00	THB/month
OT (4 hrs./day)	24,750.00	THB/month
Yearly bonus (3x)	8,250.00	THB/month
	66,000.00	
Storage/Warehouse		
REF. Store General Worker (9p)	59,400.00	THB/month
OT (4 hrs./day)	44,550.00	THB/month
Yearly bonus (3x)	14,850.00	THB/month
	118,800.00	THB/month
Total cost/month	258,000.00	THB/month
TC	3,096,000.00	THB/yr.
		PO/yr.
# of PO	3,069.00	(2010)
Average	1,008.80	THB/PO
Processing cost	2.20%	
Ordering cost	**1030.99**	**THB/PO**

Figure 3.6 Purchasing Cost Calculation

Additionally, one of the main costs associated with inventory replenishment are transportation costs, especially in developing countries with limited infrastructure like Thailand where the cost of logistics (in 2008) can be as high as 18.6% of GDP (LSIC, 2010). However, each item's transportation and processing costs on behalf of the supplier is included and inseparable from the unit cost, but it has been calculated that in the Thai electrical appliance and electronics industry, the transportation and processing (administrative) cost per sales ratio is approximately 1.0% and 0.7% on average respectively.



	Food	Textile	Electronics	Automotive	Plastics
Administrative	0.6%	0.6%	0.7%	0.8%	0.8%
Transportation	3.6%	3.6%	1.0%	5.6%	4.8%
Warehousing	1.7%	1.2%	0.9%	1.4%	1.3%
Inventory	0.7%	1.2%	4.6%	0.7%	1.9%

Figure 3.7 Logistics cost per Sales ratio (LSIC, 2008)

Therefore, the estimated ordering or set up cost used is 1.7% of the average value of recorded past purchases and 1030.99 THB. Hence more expensive items or larger order quantities have higher ordering costs. The costs for each item are as follows:

Item	Description	Ordering Cost (THB)
RFBI09067680800	COMPRESSOR;DE33YD	91,201.82
RFBI09078970800	SWITCH	11,444.37
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	1,570.64
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	2,466.37
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	19,220.99
RFMI09007950600	LAMP SOCKET'06F	1,114.98
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	6,919.76
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30	3,546.73
RFBI09067840800	BALANCER (S)	4,091.81
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	2,516.25
RFBI09070330800	SILENCER-A	3,091.09
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	6,464.68

(yellow)	B175Z
(green)	HB40
(blue)	W80

Table 3.3 Item Ordering Cost

3.3.2 Holding Cost

REF. div. has three different storage areas for close proximity to where the parts are used. The main storage area is a large warehouse located furthest from the manufacturing area in a separate building and houses parts which are bulky and heavy parts such as carton boxes or compressors. The remaining warehouses are located close to the assembly lines, with one supplying smaller parts for REF-MP-R2 and REF-MP-R4, and the other supplying parts to one of REF. div.'s separate in-vehicle refrigerator section.

Due to the existence of multiple warehouses, different product sizes and varying storage locations, determining holding cost from the number of units flowing through the warehouse per year could prove inaccurate as a high value part would be given the same level of significance as a cheaper costing part.

Holding cost will instead be a percentage of the unit cost and therefore cost dependant. (Chopra and Meindl) Holding cost comprises of physical cost of capital (opportunity cost of alternative investment), cost of physically storing the inventory, obsolescence cost, and other related costs such as taxes and insurance. Holding cost is typically estimated to be "between 15% to 35% of unit value per year," Atkinson (2005).

Typically, at the company, when investing in new cost saving projects, a desired return on investment (ROI) should be less than 5 years or a Minimum Acceptable Rate of Return—MARR—of 20%. In this case, we use 20% of the unit value to be the unit holding cost per annum which is then divided by 256—the number of working days in a year—to get the holding cost per period of each item.

			20%, T=256
Item	**Description**	**Unit Cost**	**Holding Cost**
RFBI09067680800	COMPRESSOR;DE33YD	2,344.32	1.83
RFBI09078970800	SWITCH	114.82	0.09
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	19.36	0.02
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	38.46	0.03
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	43.49	0.03
RFMI09007950600	LAMP SOCKET'06F	10.45	0.01
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	1,331.77	1.04
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30	950.37	0.74
RFBI09067840800	BALANCER (S)	16.70	0.01
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	49.76	0.04
RFBI09070330800	SILENCER-A	14.70	0.01
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	131.25	0.10

(yellow)	B175Z
(green)	HB40
(blue)	W80

Table 3.4 Holding Cost per Period

3.3.3 Lead Time

The available standard lead time for each item from its supplier was proven to be inaccurate, with high probability of shipments arriving later than the projected date and lacked the variance or deviation necessary to find the range in which lead time can vary.

Item	L	σ_l	L_syst	Z	Prob. Over
COMPRESSOR;DE33YD	96.93	21.59	80	-0.78	78.36%
SWITCH	89.84	52.90	60	-0.56	71.37%
DRYER ASSY 10Gr(Non CFC)ID4.14'03F	41.25	22.49	75	1.50	6.67%
ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	68.25	29.94	45	-0.78	78.12%
LOWER HINGE(Wine Cel.)W80G(T)'02F	35.08	28.32	45	0.35	36.31%
LAMP SOCKET'06F	78.01	25.28	45	-1.31	90.42%
GLASS DOOR(383*685*21t)W80G(T)'02F	61.24	20.75	45	-0.78	78.30%
COMPRESSOR WITH STANDARD ACCESSORIES SB30	92.30	29.76	60	-1.09	86.11%
BALANCER (S)	74.86	29.88	75	0.00	49.82%
ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	68.25	29.94	45	-0.78	78.12%
GLASS DOOR(383*685*21t)WIC-019A-AGB '02F	53.83	22.57	45	-0.39	65.21%
SILENCER-A	87.32	31.22	75	-0.39	65.34%
DRAIN HOSE W80G(T)'02F 2F	82.31	31.88	45	-1.17	87.90%

Table 3.5 Standard vs. Actual LT and Probability

Therefore, the actual lead time and standard deviation from each item is recalculated using purchase history of the respective items and the standard deviation of each individual LT excluding outliers. There exist instances where LT is 0 days where the supplier is asked to ship items prior to issue of purchase orders.

LT (days) = Receipt Date – PO Issue Date

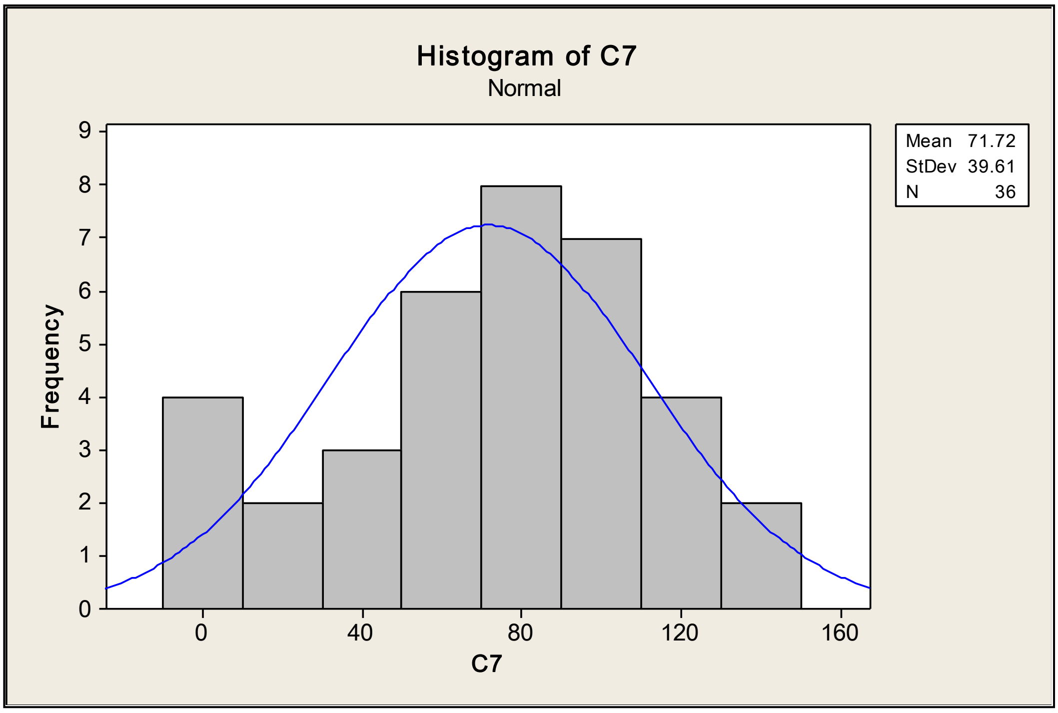


Figure 3.8 Example Histogram and Normal Probability Plot for Balancer (S)

3.3.4 Minimum Order Quantity (MOQ)

Much of the items in Group A which have long LT are due to the fact that these items are imported, with sea shipment being the most common and favored form of transportation as it provides the lowest cost to weight ratio compared to all other forms. Shipments of items by sea require them to be transported in containers either 20 or 40 feet long. For 'Compressor SB24,' 1,200 imported compressors in 8 pallets fit into a 40 feet container, an order quantity of less than 1,200 would result in a higher transportation costs per unit, so the Minimum Order Quantity—MOQ—for this item is 1,200 units.

3.4 Production Plan

A major problem for REF. div.'s inventory management is the multitude of production plan revisions with up to 13 revisions possible for a given month. The first revision is issued 3-4 weeks in advance and the last revision reflects actual production which took place within that month. Changes in production plan were made for the following reasons:

- Parts shortage—delay production, switch to produce other models.
- Manpower shortage—reduced production rate, stop production of non-core models.
- Customer requests—customer requests change in model or delivery date.

2011	**No. of revisions**
January	10
February	10
March	7
April	7
May	8
June	10
July	7
August	9
September	9
October	8
November	7
December	13

Table 3.6 Number of Production Plan Revisions

3.4.1 Production Plan 2011

Comparing production quantity between the first and last revisions of the three chosen models showed large discrepancies in production quantity. The actual production quantity can be up to 53.17% less than originally planned for HB40 models, or 12.12% more than originally planned in the case of W80 models.

Additionally, if actual production of a refrigerator model takes place on a day where no production was planned or if actual production exceeds the original planned quantity, the case study company is at risk of not having the necessary parts on hand. However, if no production of a refrigerator model took place on a day where production was planned, the case study company then incurs additional handling cost which is still more preferable than parts shortage. For models with low production quantities and where production does not take place every day like the HB40 and W80, unexpected demand—production not originally scheduled—accounts for 49.11% and 69.78% of total annual production respectively. The high production volume B175Z model on the other hand has an unexpected demand accounting for 18.85% of total annual production.

Model	**Last rev.**	**First rev.**	**% Diff.**	**Unexpected Demand**
HB40	3,421	5,240	-53.17%	49.11%
B175Z	103,679	95,689	7.71%	18.85%
W80	685	602	12.12%	69.78%

Table 3.7 First vs. Last Revisions

3.4.2 Safety Stock

Safety stock (SS), also known as buffer stock, is the average level of an inventory item just before replenishment of that item arrives. It provides a buffer against unusually large demand during the lead time from ordering to receiving of items. Calculation of Safety Stock takes into account the differences between actual and planned production for its establishment and is defined by Silver et al., 1998, as:

$$SS = k\sigma_L$$

Where

k = *safety factor*

σ_L = standard deviation of forecast errors of total demand over a period duration of *L*

Because safety stock is only useful when there is unexpected demand, the safety factor *k* is estimated as the average unexpected demand (total unexpected demand divided by number of occurrences). For example, production of HB40 refrigerator model in 2011 has a total of 61 unexpected demand occurrences totaling 1,680 sets. An unexpected demand occurrence is for 27.54 refrigerators on average or 0.81% of total annual production. Therefore, the safety factor for items pertaining to HB40 models is 1.0081. The standard deviation of forecast errors σ_L is estimated as:

$$\hat{\sigma}_L = \sqrt{L}\hat{\sigma}_1$$

Where

L = replenishment lead time (average actual lead time)

$\hat{\sigma}_1$ = estimate of the standard deviation of forecast errors over one basic period

The estimate of the standard deviation of forecast errors is estimated as:

$$\sigma_1 = \sqrt{trueMSE}$$

Where

trueMSE = true Mean-square-error in the forecast between the first and last revision

Item	MSE	σ_1	L	σ_L	Safety factor	Safety Stock
COMPRESSOR;DE33YD	924.16	30.40	96.93	299.30	1.0081	301.71
SWITCH	924.16	30.40	89.84	288.15	1.0081	290.47
DRYER ASSY 10Gr(Non CFC)ID4.14'03F	25,393.84	159.35	41.25	1,023.43	1.0013	1,024.77
ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	25,393.84	159.35	68.25	1,316.46	1.0013	1,318.17
LOWER HINGE(Wine Cel.)W80G(T)'02F	60.96	7.81	35.08	46.24	1.0152	46.95
LAMP SOCKET'06F	25,393.84	159.35	78.01	1,407.49	1.0013	1,409.32
GLASS DOOR(383*685*21t)W80G(T)'02F	60.96	7.81	61.24	61.10	1.0152	62.02
COMPRESSOR WITH STANDARD ACCESSORIES SB30	60.96	7.81	92.30	75.01	1.0152	76.15
BALANCER (S)	924.16	30.40	74.86	263.03	1.0081	265.15
ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	25,393.84	159.35	68.25	1,316.46	1.0013	1,318.17
SILENCER-A	924.16	30.40	87.32	284.07	1.0081	286.36
DRAIN HOSE W80G(T)'02F 2F	60.96	7.81	82.31	70.83	1.0152	71.91

(yellow)	B175Z
(green)	HB40
(blue)	W80

Table 3.8 Item Safety Stock

The safety stock level for items under study pertaining to the assembly of HB40 refrigerator model lasts approximately 6 days given the production capacity of 6 sets/hr. and a normal 8 hr. working day resulting in a demand of 48 HB40 refrigerators per day. Similarly—while low in quantity—safety stock levels of items pertaining to the low production W80 wine cellar models lasts 6 – 9 days given the low production capacity of 1 set/hr. However, while safety stock levels of items pertaining to B175Z models are higher, they are accountable for only approximately

2 – 3 days worth of supply which is due to these items being locally sourced and therefore having a shorter lead time.

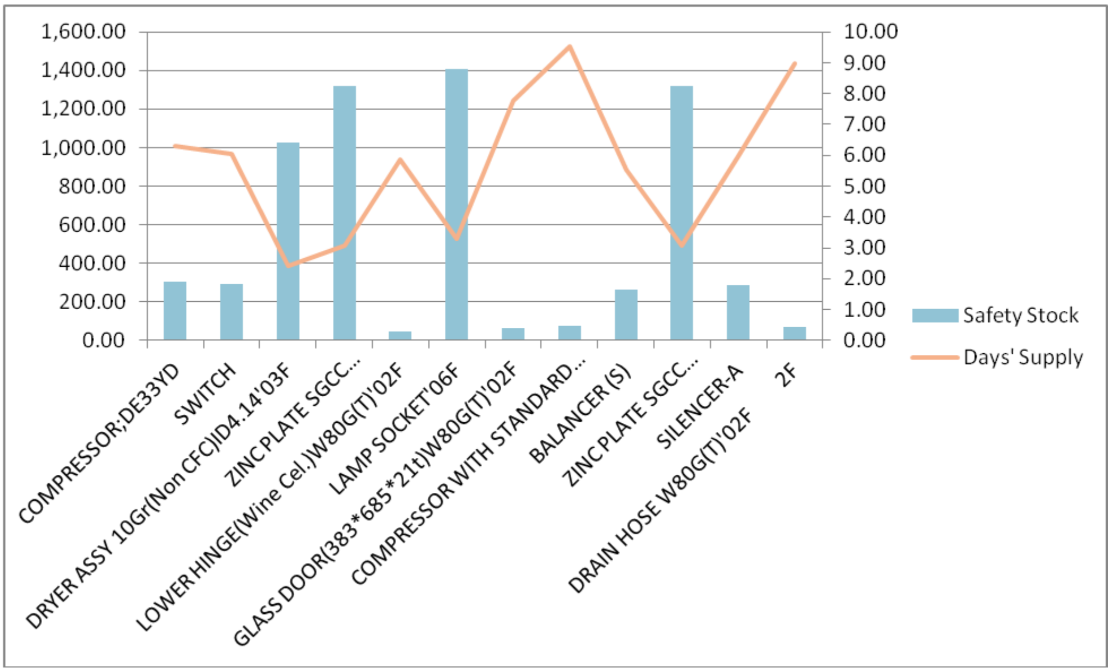


Figure 3.9 Safety Stock vs. Supply days

CHAPTER IV

LOT SIZING

4.1 Lot Sizing

Because of the small demand for some models and relatively high initial inventory, the demand period listing for each model is a compilation of production plans from January 2011 to June 2012 over a period of 1.5 years to allow enough time for multiple replenishments to take place. Additionally, the HB40 refrigerator model requires more than one unit of items under study and the demand period listing has been corrected as such. Specifically, one HB40 refrigerator requires 3 units of Balancer (S), and 2 units of Silencer-A.

To explore and compare results between each lot sizing technique, we input the related parameters: demand from production plan, ordering cost, holding cost, initial inventory into a model created using the R environment.

R is one of the most popular, open-sourced statistical computing environment, and has become a common statistical programming language of choice amongst academics and the private sectors. Being open-sourced, users around the world are able to contribute to existing programs through the Comprehensive R Archive Network (CRAN), one of which is used in this study is the SCperf package which contains different inventory models including the Wagner-Whitin algorithm.

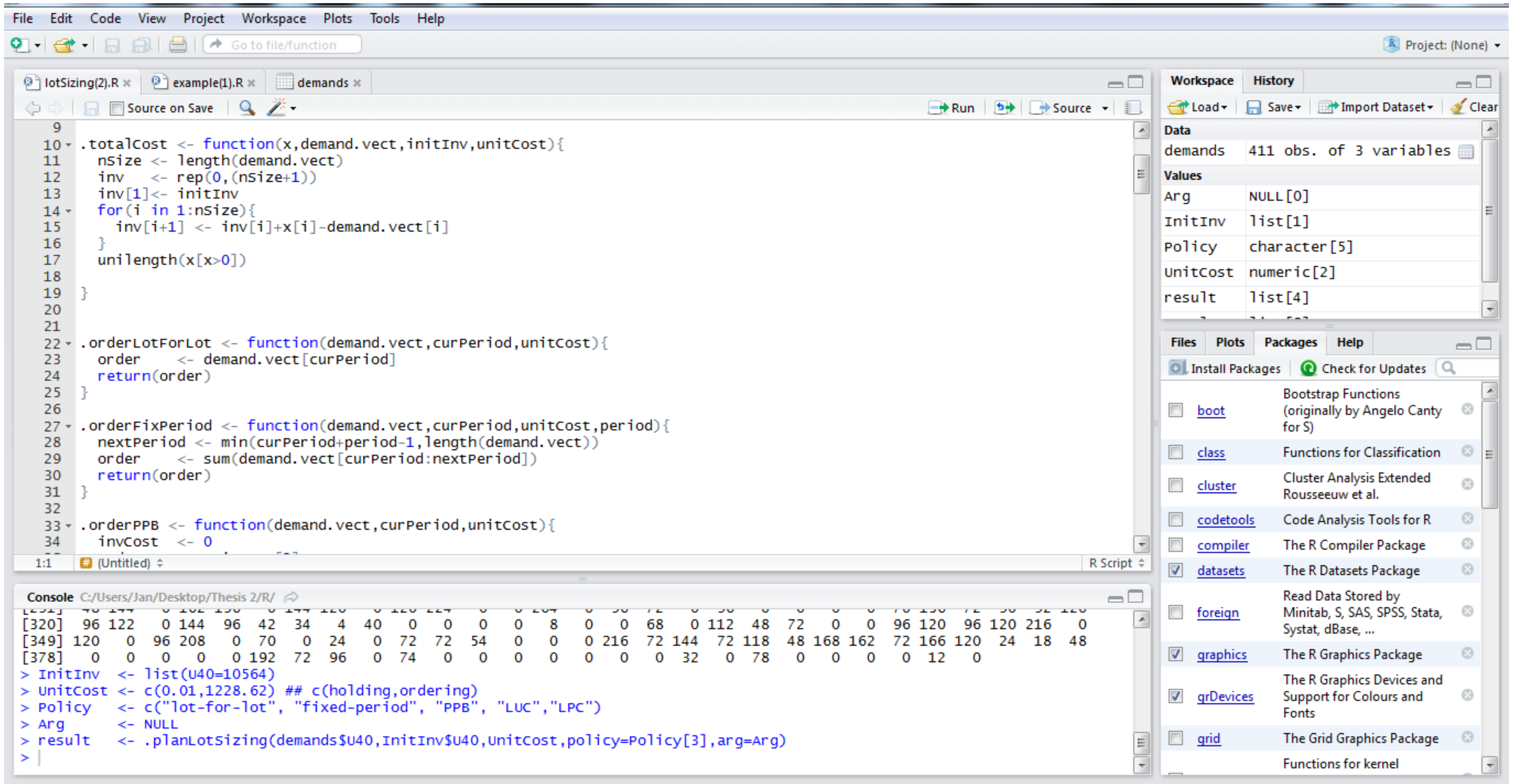


Figure 4.1 RStudio Console Capture

4.1.1 Least Period Cost

The Least Period Cost (LPC) or Silver-Meal heuristic minimizes the cost of ordering and holding inventory in each period with the demand in future periods being covered until the LPC increases. The result is are frequent, small quantity replenishments as the heuristic operates in an incremental manner and finds the local minimum instead of the global or true minimum.

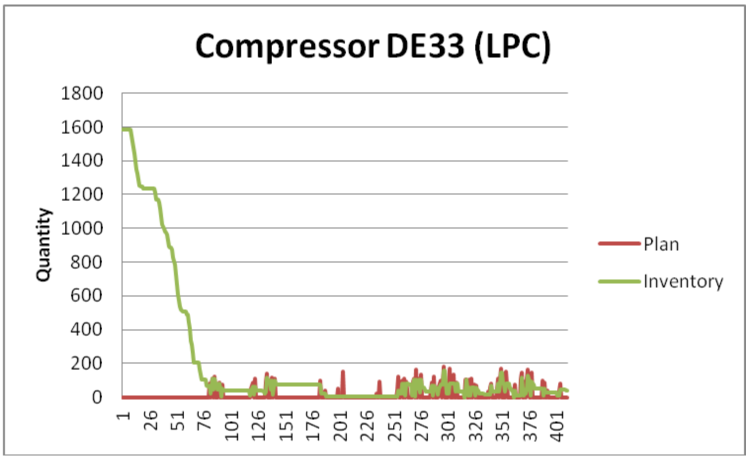


Figure 4.2 Compressor DE33 Inventory Level (LPC)

Item	Description	LPC
RFBI09067680800	COMPRESSOR;DE33YD	6,265,669.34
RFBI09078970800	SWITCH	540,899.94
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	252,059.54
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	398,076.16
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	72,098.04
RFMI09007950600	LAMP SOCKET'06F	181,587.05
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	289,393.76
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30	138,357.70
RFBI09067840800	BALANCER (S)	213,845.20
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	454,021.30
RFBI09070330800	SILENCER-A	138,060.33
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	32,484.10

B175Z
HB40
W80

Table 4.1 Total Cost (LPC)

4.1.2 Periodic Order Quantity

The Periodic Order Quantity (POQ) calculates how many periods in which to order for by dividing the Economic Order Quantity (EOQ) which assumes constant demand, by the average demand rate.

Item	d	POQ	POQ (rounded)
COMPRESSOR;DE33YD	31.03	56.65	57.00
SWITCH	25.06	100.91	101.00
DRYER ASSY 10Gr(Non CFC)ID4.14'03F	1,120.18	13.62	14.00
ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	1,131.77	12.04	12.00
LOWER HINGE(Wine Cel.)W80G(T)'02F	4.21	518.11	518.00
LAMP SOCKET'06F	993.38	16.58	17.00
GLASS DOOR(383*685*21t)W80G(T)'02F	2.68	70.51	71.00
COMPRESSOR WITH STANDARD ACCESSORIES SB30	4.05	48.56	49.00
BALANCER (S)	115.94	73.55	74.00
ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	442.91	17.10	17.00
SILENCER-A	25.06	146.57	147.00
DRAIN HOSE W80G(T)'02F 2F	4.21	172.96	173.00

Yellow	B175Z
Green	HB40
Blue	W80

Table 4.2 Periodic Order Intervals for Each Item

The result is an almost periodic replenishment. For example, for Compressor DE33 where the POQ is calculated to be 57 days, replenishment takes place on periods 81, 139, 200, 258, 316, 373, or 58.4 days apart on average. The order quantity for each replenishment is also greatly varied which indicates that demand is not constant.

Period	Order Qty	Interval
81	996	-
139	395	58
200	452	61
258	2050	58
316	1726	58
373	754	57

Table 4.3 Interval between Replenishment for Compressor DE33 (POQ)

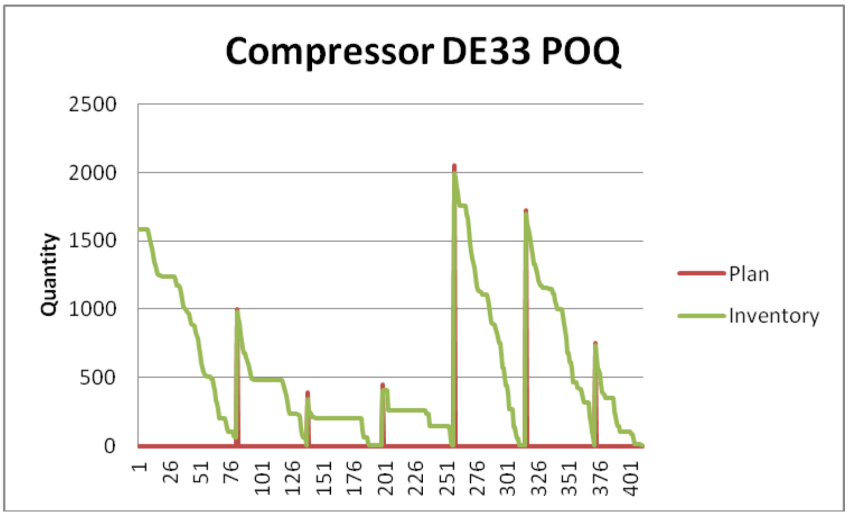


Figure 4.3 Compressor DE33 Inventory Level (POQ)

Item	Description	POQ
RFBI09067680800	COMPRESSOR;DE33YD	971,452.50
RFBI09078970800	SWITCH	74,980.29
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	63,547.82
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	103,739.35
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	72,098.04
RFMI09007950600	LAMP SOCKET'06F	36,742.62
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	71,306.64
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30	48,312.58
RFBI09067840800	BALANCER (S)	27,035.61
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	103,268.92
RFBI09070330800	SILENCER-A	19,661.84
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	32,484.10

(yellow)	B175Z
(green)	HB40
(blue)	W80

Table 4.4 Total Cost (POQ)

4.1.3 Lot-for-Lot

Lot-for-Lot (L4L) is the simplest and costliest heuristic as it orders the exact quantity needed for every time period in which there is demand. Initial inventory from the end of 2010 are used up before individual orders are triggered for every non-zero demand period to exactly meet the demand so that no inventory is carried over to the next period. Therefore, this heuristic result in the least inventory holding cost and the highest ordering costs.

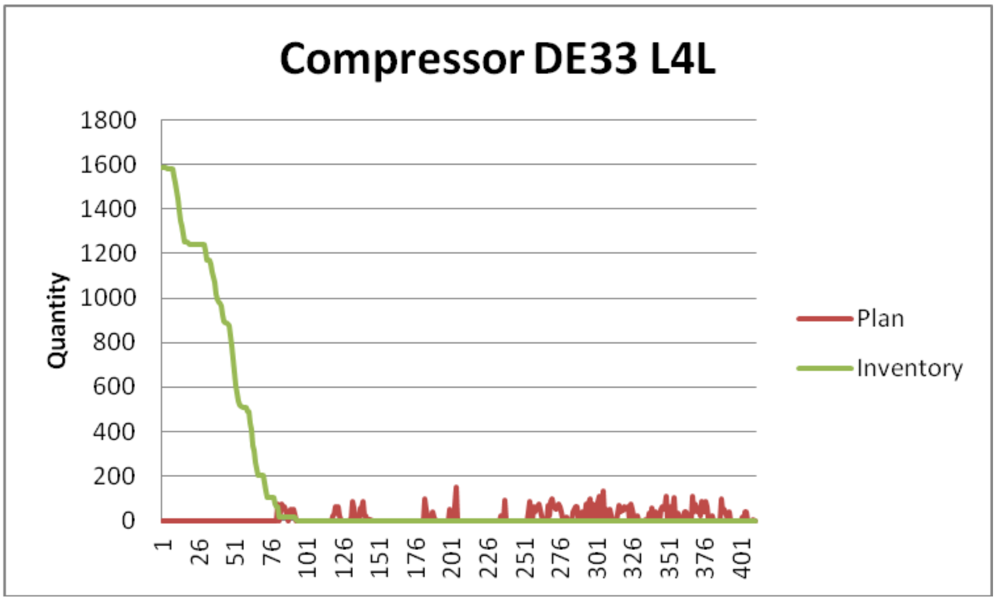


Figure 4.4 Compressor DE33 Inventory Level (L4L)

Item	Description	L4L
RFBI09067680800	COMPRESSOR;DE33YD	12,624,678.16
RFBI09078970800	SWITCH	1,032,334.47
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	549,417.62
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	887,200.35
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	72,098.04
RFMI09007950600	LAMP SOCKET'06F	887,200.35
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	602,791.84
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30	273,640.99
RFBI09067840800	BALANCER (S)	389,601.96
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	984,131.31
RFBI09070330800	SILENCER-A	249,209.57
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	32,484.10

(yellow)	B175Z
(green)	HB40
(blue)	W80

Table 4.5 Total Cost (L4L)

4.1.4 LUC

In each period, the Least Unit Cost heuristic takes the total relevant costs of holding and ordering inventory are divided by the number of items resulting in a total cost per unit. Calculation is carried out in a period until the unit cost increases at which the period before the cost increase is used and the cycle repeats for the remaining periods. The result is frequent orders in small quantities when demand is clustered, and large order quantities when demand is dispersed.

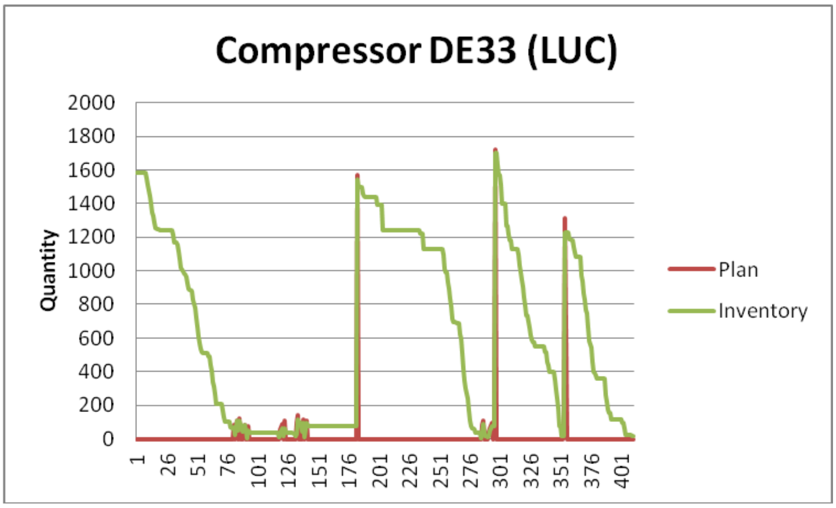


Figure 4.5 Compressor DE33 Inventory Level (LUC)

Item	Description	LUC
RFBI09067680800	COMPRESSOR;DE33YD	2,568,969.34
RFBI09078970800	SWITCH	72,385.32
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	59,790.60
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	87,681.23
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	72,098.04
RFMI09007950600	LAMP SOCKET'06F	87,681.23
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	62,086.00
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30	56,036.79
RFBI09067840800	BALANCER (S)	23,423.65
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	100,471.73
RFBI09070330800	SILENCER-A	20,830.74
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	32,484.10

(yellow)	B175Z
(green)	HB40
(blue)	W80

Table 4.6 Total Cost (LUC)

4.1.5 Part-Period Balancing

The Part-Period Balancing (PPB) heuristic chooses the number of periods for which demand is covered by the replenishment in that period which results in a balance between ordering and holding costs. The result are large replenishments placed at different intervals.

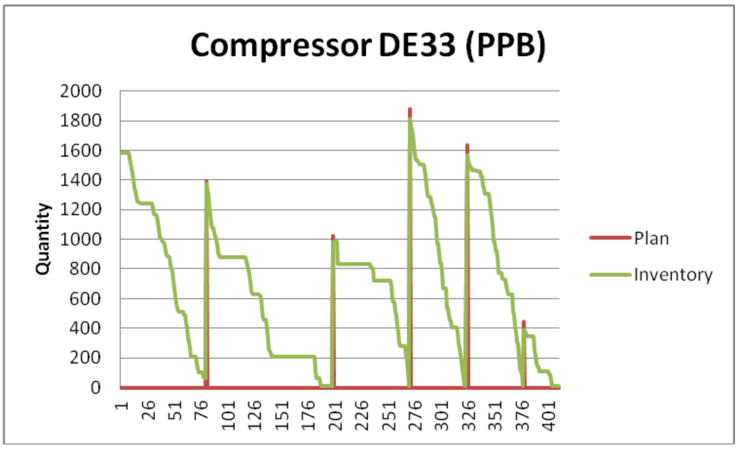


Figure 4.6 Compressor DE33 Inventory Level (PPB)

Item	Description	PPB
RFBI09067680800	COMPRESSOR;DE33YD	978,741.28
RFBI09078970800	SWITCH	73,836.30
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	58,985.12
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	86,229.91
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	72,098.04
RFMI09007950600	LAMP SOCKET'06F	86,229.91
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	65,066.64
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30	47,516.43
RFBI09067840800	BALANCER (S)	23,815.48
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	100,813.72
RFBI09070330800	SILENCER-A	20,830.74
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	32,484.10

(yellow)	B175Z
(green)	HB40
(blue)	W80

Table 4.7 Total Cost (PPB)

4.1.6 Wagner-Whitin

Results from the Wagner-Whitin algorithm are the benchmark for which to compare all other heuristics as it yields the lowest/optimum combination of ordering and holding costs. However, the Wagner-Whitin algorithm requires a high level of understanding and programming skills due to its complexity, and requires lengthy computation when applied to a large number of items. With a high number of SKU and need for an easy-to-use approach so as not to overburden the staff, heuristics which yield similar results such as Part-Period Balancing should be substituted.

In this particular study, there are exceptions for when the Wagner-Whitin does not perform better than other heuristics, which are in the cases of two parts: Lower Hinge and Drain Hose parts for W80 wine cellar models in which there is an overabundance of initial inventory as of December 28th, 2010 to last through June 30th, 2012, in which all heuristics and the Wagner-Whitin algorithm yields the same total cost equivalent to the holding cost as no ordering costs are incurred.

Description	L4L	POQ	PPB	LUC	LPC	WW
COMPRESSOR;DE33YD	12,624,678	971,453	978,741	2,568,969	6,265,669	844,240
SWITCH	1,032,334	74,980	73,836	72,385	540,900	71,622
DRYER ASSY 10Gr(Non CFC)ID4.14'03F	549,418	63,548	58,985	59,791	252,060	55,775
ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	887,200	103,739	86,230	87,681	398,076	82,094
LOWER HINGE(Wine Cel.)W80G(T)'02F	72,098	72,098	72,098	72,098	72,098	72,098
LAMP SOCKET'06F	404,302	36,743	33,059	33,519	181,587	31,384
GLASS DOOR(383*685*21t)W80	602,792	71,307	65,067	62,086	289,394	54,152
COMPRESSOR WITH STANDARD ACCESSORIES SB30	273,641	48,313	47,516	56,037	138,358	41,427
BALANCER (S)	389,602	27,036	23,815	23,424	213,845	23,149
ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	984,131	103,269	100,814	100,472	454,021	94,286
SILENCER-A	249,210	19,662	20,831	20,831	138,060	18,840
DRAIN HOSE W80G(T)'02F	32,484	32,484	32,484	32,484	32,484	32,484

Table 4.8 Total Costs (Ordering + Holding)

4.2 Results

The simplest Lot-for-Lot (L4L) heuristic is the least effective approach as ordering cost is incurred for every period in which there is positive demand regardless of how small the demand may be. The Least Period Cost (LPC) is the second least effective approach as orders are somewhat frequent with some of them fulfilling small demands as this approach returns the local minimum as periods go by which often results in small orders as stock out is not allowed.

Item	L4L	POQ	PPB	LUC	LPC
COMPRESSOR;DE33YD	1395%	15%	16%	204%	642%
SWITCH	1341%	5%	3%	1%	655%
DRYER ASSY 10Gr(Non CFC)ID4.14'03F	885%	14%	6%	7%	352%
ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	981%	26%	5%	7%	385%
LOWER HINGE(Wine Cel.)W80G(T)'02F	0%	0%	0%	0%	0%
LAMP SOCKET'06F	1188%	17%	5%	7%	479%
GLASS DOOR(383*685*21t)W80G(T)'02F	1013%	32%	20%	15%	434%
COMPRESSOR WITH STANDARD ACCESSORIES SB30	561%	17%	15%	35%	234%
BALANCER (S)	1583%	17%	3%	1%	824%
ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	944%	10%	7%	7%	382%
SILENCER-A	1223%	4%	11%	11%	633%
DRAIN HOSE W80G(T)'02F 2F	0%	0%	0%	0%	0%

B175Z
HB40
W80

Table 4.9 Percentage Difference from Wagner-Whitin

The least unit cost is effective for all items except Compressor DE33 for similar reasons to LPC of looking for the local minimum on a period-by-period basis and because the ordering cost for Compressor DE33 is the most expensive given its highest unit cost and import status, but this heuristic resulted in total costs within 1% of the optimum solution for two items: Switch and Balancer (S). The Periodic Order Quantity is generally effective for most items under study as they have rather constant monthly demand which conforms to normal distribution (Anderson-Darling, P-value = 0.05). Its effectiveness is hampered by its generalization that the items under study have constant demand which is only moderately true.

Therefore, the most effective heuristic is Part-Period-Balancing (PPB) which attempts to balance between ordering and holding costs resulting in the least overall difference of 12.09% from the optimum solution from the Wagner-Whitin algorithm.

	Total Cost	Difference
Wagner-Whitin	1,421,550.41	-
Part-Period Balancing	1,593,476.76	12.09%
Periodic Order Quantity	1,624,630.31	14.29%
Least Unit Cost	3,189,776.22	124.39%
Least Period Cost	8,976,552.46	531.46%
Lot-for-Lot	18,101,890.44	1173.39%

Table 4.10 Effectiveness of Each Heuristic

4.2.1 Sensitivity Analysis

The main uncertainty in the simulation model's output is likely each item's ordering costs as transportation costs, already combined into unit costs, allowed only the administrative portion of the ordering cost on the case study factory's part to be explored in detail. Therefore, other hidden costs such as the difference in ordering cost between local and imported items may be unaccounted for, which is why the ordering cost is subjected to change in sensitivity analysis.

Transportation costs for imported items are usually much higher than those of locally sourced items. For variation, we approximate transportation and administrative cost on behalf of the supplier to be 4%, or 2.35 times the original of 1.7%, on which the same 1,030.99 THB in-house processing cost is then added to. When subjected to 4% transportation and administrative costs, ordering cost increases ranged from 1.1 times to 2.34 times that when compared to those at 1.7%, with items that previously had high ordering costs registering the highest changes.

	1.70%	4%	
Item	**Ord. Cost**	**Ord. Cost**	**Diff. (x)**
COMPRESSOR;DE33YD	91,201.82	213,197.66	2.34
SWITCH	11,444.37	25,533.05	2.23
DRYER ASSY 10Gr(Non CFC)ID4.14'03F	1,570.64	2,300.76	1.46
ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	2,466.37	4,408.36	1.79
LOWER HINGE(Wine Cel.)W80G(T)'02F	19,220.99	43,830.99	2.28
LAMP SOCKET'06F	1,114.98	1,228.62	1.10
GLASS DOOR(383*685*21t)W80G(T)'02F	6,919.76	14,886.91	2.15
COMPRESSOR WITH STANDARD ACCESSORIES SB30	3,546.73	6,950.39	1.96
BALANCER (S)	4,091.81	8,232.91	2.01
ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	2,516.25	4,525.72	1.80
SILENCER-A	3,091.09	5,878.29	1.90
DRAIN HOSE W80G(T)'02F 2F	6,464.68	13,816.13	2.14

Table 4.11 Change in Ordering Costs

The higher the difference in total costs there is, the greater the reduction in number of replenishments throughout the 1.5 year period. For example, Compressor DE33 faces a total cost increase of 46.54% while the number of replenishment reduces from 5 to 3 or 40% when transportation and administrative costs increases from 1.7% to 4%. The reduction in number of replenishments while satisfying the same demand indicates a larger lot size.

Item	1.70% WW	4% WW	Diff.
COMPRESSOR;DE33YD	5	3	-40.00%
SWITCH	2	1	-50.00%
DRYER ASSY 10Gr(Non CFC)ID4.14'03F	17	12	-29.41%
ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	17	12	-29.41%
LOWER HINGE(Wine Cel.)W80G(T)'02F	0	0	0.00%
LAMP SOCKET'06F	13	12	-7.69%
GLASS DOOR(383*685*21t)W80G(T)'02F	5	3	-40.00%
COMPRESSOR WITH STANDARD ACCESSORIES SB30	4	4	0.00%
BALANCER (S)	2	1	-50.00%
ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	20	15	-25.00%
SILENCER-A	1	1	0.00%
DRAIN HOSE W80G(T)'02F 2F	0	0	0.00%

Table 4.12 Change in Number of Replenishments

However, when comparing the total costs of when transportation and administrative costs are at 1.7% to 4% using the Wagner-Whitin algorithm for optimal solution, the changes are noticeable smaller. The changes (excluding two items that do not have ordering costs) ranges from 4.61% for an item which has comparably lower ordering costs than others, to 57.85% for the Glass Door of Wine Cellar models which has low demand and small lot sizes.

Item	1.70% WW	4% WW	Diff.
COMPRESSOR;DE33YD	844,239.94	1,237,146.54	46.54%
SWITCH	71,622.03	87,473.66	22.13%
DRYER ASSY 10Gr(Non CFC)ID4.14'03F	55,774.84	65,921.78	18.19%
ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	82,093.70	107,478.12	30.92%
LOWER HINGE(Wine Cel.)W80G(T)'02F	72,098.04	72,098.04	0.00%
LAMP SOCKET'06F	31,384.16	32,830.67	4.61%
GLASS DOOR(383*685*21t)W80G(T)'02F	54,151.84	85,478.97	57.85%
COMPRESSOR WITH STANDARD ACCESSORIES SB30	41,427.06	55,041.70	32.86%
BALANCER (S)	23,148.97	29,001.46	25.28%
ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	94,285.88	128,920.00	36.73%
SILENCER-A	18,839.85	21,627.05	14.79%
DRAIN HOSE W80G(T)'02F 2F	32,484.10	32,484.10	0.00%

Table 4.13 Change in Total Costs

4.2.2 Lot Sizing Policy

For some items, the average of the suggested lot sizes from heuristics and the Wagner-Whitin algorithm resulted in lower order quantities than the current Minimum Order Quantity (MOQ). These items are Switch and Dryer Assy. These two items are not bulky, small in size, and are shipped in boxes, in which MOQ should be relatively easy to negotiate. Therefore, inventory management costs—more specifically, holding costs—can be saved by ordering more frequently in smaller lots without causing stock-out.

Two items—Lower Hinge and Drain Hose W80—could not be analyzed by the heuristics as their current quantity is far higher than annual usage and is overabundant. The overabundance of the Lower Hinge part is attributable to demand overestimation leading to the issuance of a single purchase order of 10,000 units in June of 2008 where of those quantities there remain 6,294 units and no purchase orders have been issued since. As for Drain Hose W80, its overabundance is caused by its high MOQ of 1,000 units as annual demand in 2011 was only 1,079 units. Repeated orders result in overly high inventory levels with the last receiving transaction (during the time of study) taking place in October 2010.

However, to calculate their appropriate lot size, the initial inventory is set to 0 and then analysis is conducted. For Lower Hinge, both Part-Period Balancing heuristic and the Wagner-Whitin algorithm resulted in a single order of lot size 1,030 units, which is lower than MOQ but should be negotiable as item size is small and delivered in boxes. For Drain Hose, both Part-Period Balancing heuristic and the Wagner-Whitin algorithm results in two separate orders, but both of which result in an average lot size of 515 units or roughly half of MOQ and should also be negotiable by changing the size of boxes in which to deliver concerned item.

Item	MOQ	Past (Mode)	POQ	PPB	LUC	LPC	WW
COMPRESSOR;DE33YD	600	600	1,062	1,275	247	96	1,283
SWITCH	3,000	3,000	2,145	2,139	2,139	98	2,152
DRYER ASSY 10Gr(Non CFC)ID4.14'03F	13,860	18,900	4,743	7,413	7,414	777	6,951
ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	1,000	9,000	4,000	7,751	7,297	792	7,289
LOWER HINGE(Wine Cel.)W80G(T)'02F	2,000	10,000	-	-	-	-	-
LAMP SOCKET'06F	2,000	20,000	5,692	8,944	8,347	785	9,644
GLASS DOOR(383*685*21t)W80G(T)'02F	100	100	198	198	198	24	196
COMPRESSOR WITH STANDARD ACCESSORIES SB30	120	120	138	165	165	25	205
BALANCER (S)	3,500	5,000	4,701	7,068	7,089	284	7,106
ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	1,000	3,000	5,615	6,742	6,419	760	6,725
SILENCER-A	300	3,500	3,722	3,782	3,782	183	7,560
DRAIN HOSE W80G(T)'02F 2F	1,000	1,000	-	-	-	-	-

B175Z
HB40
W80

Table 4.14 Average Lot Size from Heuristics and Algorithm

The remaining items which are used for the low production HB40 and W80 models, have suggested lot size from heuristics and the algorithm in excess of current ordering lot size. This means that order quantities are too small and not far apart enough. This may be due to the demand uncertainty and forecasting horizon of no more than 3 months, resulting in fear of ordering in excess which will result in high carrying costs.

For Compressor DE33 with MOQ and past orders equal to 600 units, compressors are shipped in 20 ft. containers. The suggested quantity from Part-Period Balancing and the Wagner-Whitin algorithm suggests a quantity close to double that of MOQ which suggests the use of a 40 ft. container to hold 1200 units. Similarly, Glass Door W80 with MOQ and past orders equal to 100 units are shipped in packs of 100. With suggested quantity from POQ, PPB, LUC, and Wagner-Whitin close to 200 units, the solution is to order two packs at a time to save on ordering costs.

For Bottom PLT, in which MOQ is 1000 units, and past orders equal to 9000 units. These steel sheets are packaged in packs of 250 units, so ordering either 7250 units—close to LUC and Wagner-Whitin—or 7750 units—close to PPB—are both viable solutions. Similarly, Rear PLT 170L Curve with MOQ is 1000 units, and past orders equal to 9000 units and packaged in packs of 250 units can be easily adjusted to 6750 or 6500 units depending on PPB and Wagner-Within or LUC is chosen.

Silencer-A and Balancer (S) are also small parts delivered in boxes in which additional quantity can be ordered without affecting ordering cost or transportation means. Furthermore, both of them are supplied by Heiwa Shoji Co., Ltd. which means further cost savings are possible by consolidating and ordering the two parts together to save ordering and transportation costs. However, Compressor SB30 are delivered in pallets of 120 units and shipped by air, the next increment would be 240 units which is somewhat close to the suggested lot size by Wagner-Within of 205 units, but nowhere near suggested lot size by other heuristics.

4.3 Inventory Turnover Days

Using available data from the company's accounting period 11A, and 2011 inventory data from January, February, and March 2011, it is seen that the total value of inventory items under study comprise 23.9% of all raw material value on average. Assuming that average Work In Process and Finished Goods inventory and Sales Amount values in the six months in accounting period 11A are constant, the total inventory value of the Raw Material Inventory must not exceed 20,753,667 THB for Inventory Turnover to be less than 10 days. Therefore, items in our study must not exceed 5,753,720 THB (23.9% of all Raw Material Inventory).

	Jan-11	Feb-11	Mar-11	Average
Value of items in study	4,284,338.82	5,058,611.91	4,862,699.87	4,735,216.87
Total Raw Mat'l	19,787,000	20,046,000	19,602,000	19,811,666.67
% of items in study	21.65%	25.24%	24.81%	23.90%

Table 4.15 Value Percentage of Items Under Study

*Values in 1,000 THB

Category	Oct'10	Nov'10	Dec'10	Jan'11	Feb'11	Mar'11	Avg.	Required
Items in Study (part of RM)	-	-	-	4,284	5,058	4,863	4,735	**5,754**
Raw Material	31,287	27,022	26,714	19,787	20,046	19,602	24,076	**20,754**
Work In Process	6,655	7,604	6,444	7,125	6,291	6,184	6,717	6,717
Finished Goods	9,317	9,363	15,413	11,796	6,011	8,875	10,129	10,129
Total Inventory	47,259	43,989	48,571	38,708	32,349	34,661	40,923	**37,600**
Sale amount	124,037	120,161	109,980	104,902	105,269	112,447	112,799	112,799
Inventory Turnover days	11.81	10.98	13.69	11.44	8.60	9.56	10.88	10.00

Table 4.16 Inventory Values

The average value of all other Raw Material is not a percentage and is estimated to be the difference between the total Raw Material value (24,076,000 THB) and the value of Items in Study (4,735,217 THB) or 19,340,783 THB.

Item	PPB	PRICE/PC	Value (THB)
COMPRESSOR;DE33YD	695	2,344.32	1,629,308.63
SWITCH	1,377	114.82	158,150.03
DRYER ASSY 10Gr(Non CFC)ID4.14'03F	4,119	19.36	79,718.40
ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	3,793	38.46	145,879.72
LOWER HINGE(Wine Cel.)W80G(T)'02F	5,847	43.39	253,734.93
LAMP SOCKET'06F	4,246	10.45	44,384.94
GLASS DOOR(383*685*21t)W80G(T)'02F	71	1,331.77	94,928.09
COMPRESSOR WITH STANDARD ACCESSORIES SB30C56GA00	98	950.37	93,064.58
BALANCER (S)	3,803	16.70	63,518.14
ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	3,071	49.76	152,817.44
SILENCER-A	3,564	14.70	52,396.66
DRAIN HOSE W80G(T)'02F 2F	790	131.25	103,737.64
			2,871,639.19

Yellow	B175Z
Green	HB40
Blue	W80

Table 4.17 Average Inventory Level from PPB and Corresponding Value

In the use of Part-Period Balancing (PPB)—the most effective heuristic—the average inventory level of items from dynamic modeling using RStudio and their corresponding values resulted in a total average inventory value of 2,871,639.19 THB. Therefore, the new total Raw Material Inventory value is equal to 22,212,412.32 THB, resulting in an Inventory Turnover of 10.39 days, a 0.49 inventory turnover day decrease from 10.88 days previously from implementation on just 12 items.

4.4 Unit Cost Change from Increase in Transportation Cost

We assume that the unit cost of each item is based on the shipping, handling, administrative, etc. costs to deliver at the Minimum Order Quantity (MOQ), and that MOQ is the base lot size. For example, the item Compressor DE33's MOQ is 600 units, therefore, lot sizes are in increments of 600 units (e.g. 1200 or 1800 units) also assuming the same mode of transportation. Therefore, in a worst-case scenario, the suggested lot size from Part-period Balancing (PPB) of 1,275 units has a remainder of 75 units which is to be packaged and transported by a third container so the ratio of change is approximated as 1800/1275 = 1.41 or a 41% increase in administrative and transportation costs which was previously estimated according to industry average at 1.7% of the unit cost resulting in a unit cost increase of 2.4% or 56.27 THB.

Item	MOQ	PPB	Unit Cost	PPB cost up (%)	PPB cost up (THB)	Unit Cost Increase
COMPRESSOR;DE33YD	600	1,275	2,344.32	41.20%	56.27	2.40%
SWITCH	3,000	2,139	114.82	40.25%	2.74	2.38%
DRYER ASSY 10Gr(Non CFC)ID4.14'03F	13,860	7,413	19.36	86.97%	0.62	3.18%
ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	1,000	7,751	38.46	3.22%	0.67	1.75%
LOWER HINGE(Wine Cel.)W80G(T)'02F	2,000	1,030	43.39	94.17%	1.43	3.30%
LAMP SOCKET'06F	2,000	8,944	10.45	11.80%	0.20	1.90%
GLASS DOOR(383*685*21t)W80G(T)'02F	100	198	1,331.77	0.81%	22.82	1.71%
COMPRESSOR WITH STANDARD ACCESSORIES SB30	120	165	950.37	45.63%	23.53	2.48%
BALANCER (S)	3,500	7,068	16.70	48.56%	0.42	2.53%
ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	1,000	6,742	49.76	3.83%	0.88	1.77%
SILENCER-A	300	3,782	14.70	3.12%	0.26	1.75%
DRAIN HOSE W80G(T)'02F 2F	1,000	515	131.25	94.17%	4.33	3.30%

B175Z
HB40
W80

Table 4.18 Unit Cost Increase

The raw material cost for HB40 refrigerator model should increase no more than 59.69 THB, B175Z model no more than 2.37 THB, and W80 wine cellar model no more than 52.11 THB. The unit cost increases can constitute an inventory value increase in excess of 160,000 THB (based on average inventory levels using PPB lot sizing) or 5.6% of previous total value of 2.8m THB.

As a whole, implementing Lot Sizing on the 12 selected items could increase the unit cost of each item anywhere between 1.75 to 3.3% in a worst-case scenario unless different means of packaging or transportation are implemented so that there are no remainders, or if the remainders are packaged and shipped differently, but the simplest solution is to round the lot size to the nearest possible increment.

Item	Description	PPB	Value Increase (THB)
RFBI09067680800	COMPRESSOR;DE33YD	695	39,109.54
RFBI09078970800	SWITCH	1,377	3,770.76
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	4,119	2,533.89
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	3,793	2,559.75
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	5,847	8,375.72
RFMI09007950600	LAMP SOCKET'06F	4,246	843.61
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	4,169	95,151.72
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30	98	2,304.03
RFBI09067840800	BALANCER (S)	3,803	1,604.13
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	3,071	2,697.31
RFBI09070330800	SILENCER-A	3,564	918.53
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	790	3,424.35
			163,293.34

(yellow)	B175Z
(green)	HB40
(blue)	W80

Table 4.19 Inventory Value Increase as a Result of Unit Cost

CHAPTER V

CONCLUSION AND DISCUSSION

5. Conclusion and Discussion

This study explored two methods: ABC Classification and Lot Sizing to identify high impact items and to reduce inventory level of raw material inventory for the Refrigerator Division of a case study electrical appliance manufacturing company. The study addresses the trade-off between reducing inventory turnover days while maintaining appropriate safety stock to prevent stock-outs. The implementation of Lot sizing in high impact items results in 0.5 inventory turnover days reduction.

5.1 Conclusion

5.1.1 Potential Savings

The best performing Part-Period Balancing lot sizing heuristic resulted in an average inventory value of the items under study at 2,871,639.19 THB, which when compared to the January to March 2011 average of 4,735,217 THB results in an inventory value savings of 1,863,577.68 THB.

The inventory level of two items under study—Lower Hinge and Drain Hose—are currently too high to benefit from Lot Sizing, thus incurring continually high holding costs. The quantity of these two items should be reduced possibly by redesigning other refrigerator models to use these parts, sell to other manufacturers which use similar parts, or declared as dead stock to reduce their inventory value.

5.1.2 Steps to Implement

Each stock keeping unit has varying impacts on raw material inventory value due to their difference in unit price and demand. However, these items have been grouped by this study into Groups A, B, and C in decreasing order of importance, and part of Group A mainly those with lead time longer than 30 days have already been explored.

Items to be explored next are the remaining items in Group A including those with shorter lead times as they are high impact items. Because Group B consists of 147 items accounting for 30% of total raw material inventory value, or 5.6 million THB, it is still a viable choice for partial Lot Sizing implementation. However, Group C with 818 items and accounting for 10% of raw material inventory value should not be implemented as the increased workload is unlikely to be manageable while resulting gains are much lower than the two previous groups.

The main issue of concern in implementing Lot Sizing is the future demand of items and their respective production plans. Since Lot Sizing requires that the production plan be known prior to calculation, production quantities planned for two future consecutive six-month accounting periods (such as should 12A and 12B) issued by Accounting Division and Top Management may be used for calculations in conjunction with historical data (as used in this study) to create rough production plans which could then be entered into the dynamic integer model for capacity planning.

The established safety stock level can also be entered into the case study company’s Oracle ERP system to warn production planners when breach of the safety stock level occurs when planning so that necessary actions can be taken to avoid stock-outs.

5.2 Discussion

Implementing Lot Sizing policies to raw material inventory has potential for high savings for the case study company as seen from the resulting reduction in raw material inventories value in excess of 1.8 million THB from application of Lot Sizing on 12 items. The decrease in inventory levels of the 12 items under study represents an inventory turnover day reduction of approximately 0.5 days or 5% of the target level of 10 days. It is therefore highly likely that the target inventory turnover level of 10 days can be achieved through implementation of Lot Sizing policies on additional items in Group A alone. Furthermore, by changing the lot sizes of items, there exist possibilities for consolidation of orders especially for multiple items from the same supplier to reduce transportation costs. For example, smaller purchases which were originally air freighted may be shipped by sea in conjunction with other items in a single container.

The established safety stock levels should also be implemented in conjunction with Lot Sizing as Lot Sizing policies alone leaves very little margins for error in case of unforeseen circumstances leading to unforeseen demand.

However, through sensitivity analysis, the transportation and administrative cost parameter has high impact on the results of lot sizing and its accuracy for each individual item should be explored in greater detail in further studies.

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Appendices

Appendix A

ABC Classification

Appendix A-1: Group A Items

Item Code	Item Description	Class	PRICE/PC	Avg. Q'ty	End Baht (Avg.)	% of Total	% of Total (Cum.)	Act. LT	Supplier	Category
RFBI09067680800	COMPRESSOR;DE33YD	IMP	2,344.32	922.42	2,162,440.54	11.59%	11.59%	97	TOSHIBA CARRIER CORPORATION	Long
RFBT09002850000	COMPREESOR WITH STANDARD ACCESSORIES NO.SB24C50GA00(MARIS)	LOC	942.45	1,242.50	1,170,994.13	6.28%	17.87%	100	PANASONIC INDUSTRIAL(THAILAND) LTD.	Long
RFBB09003240000	COMPRESSOR WITH STANDARD ACCESSORIES FL0634 -RD(Hitachi)	LOC	1,050.18	489.17	513,713.05	2.75%	20.63%	44	HITACHI COMPRESSOR (THAILAND) LTD.	Long
RFBI09078970800	SWITCH	IMP	114.82	3,943.75	452,834.58	2.43%	23.06%	90	TOSHIBA TRADING INCORPORATED	Long
RFNL00703110000	COMPRESSOR AZA1330YK-R(MOTOR59X)	LOC	835.79	457.25	382,164.98	2.05%	25.11%	30	KULTHORN KIRBY PUBLIC COMPANY LIMITED	Short
RFBI00680601PW1	DOOR PLATE PCM 1131.5*580.5*0.45t B183Z(PW) (B&W)'10F	IMP	140.18	2,246.25	314,888.63	1.69%	26.79%	62	DANA KOREA CO.,LTD.	Omit
RFMI005806004PS	DOOR PLATE PCM 1086.5*580.5*0.45t 170L(PS) (04SP116-PCM=#0624)'04F	IMP	146.28	2,038.58	298,204.85	1.60%	28.39%	62	DANA KOREA CO.,LTD.	Omit
RFNL00503070000	COMPRESSOR AZA1327YK-R	LOC	824.79	347.58	286,683.26	1.54%	29.93%	30	KULTHORN KIRBY PUBLIC COMPANY LIMITED	Short
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	IMP	19.36	14,806.92	286,598.38	1.54%	31.47%	84	Parker Hannifin Refrigeration and Air conditioning (WUXI)	Long
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	LOC	38.46	6,668.00	256,451.28	1.38%	32.84%	68	SEAH PRECISION METAL (THAILAND) CO.,LTD.	Long
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	IMP	43.39	5,833.25	253,122.33	1.36%	34.20%	70	ASIATEC CORPORATION	Long
RFNL01071840800	COPPER TUBE-1220T-0 OD4.76*0.5t	LOC	359.40	677.77	243,592.99	1.31%	35.50%	-	FURUKAWA METAL (THAILAND) PUBLIC CO.,LTD	Obsolete
RFBI00480601PW1	DOOR PLATE PCM 915.5*580.5*0.45t B143Z(PW) (B&W)'10F	IMP	113.42	2,100.00	238,185.02	1.28%	36.78%	62	DANA KOREA CO.,LTD.	Omit
RFBI00580601PW1	DOOR PLATE PCM 1086.5*580.5*0.45t B173Z(PW) (B&W)'10F	IMP	134.61	1,691.17	227,641.24	1.22%	38.00%	62	DANA KOREA CO.,LTD.	Omit
RFMI09007950600	LAMP SOCKET'06F	IMP	10.45	19,454.67	203,387.25	1.09%	39.09%	78	FUJISAWA DENKO CO.,LTD.	Long
RFBI09067780800	TERMINAL AS	IMP	114.25	1,704.25	194,704.70	1.04%	40.14%	25	FUJISAWA TRADING (SHANGHAI) CO.,LTD	Short
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	IMP	1,331.77	145.92	194,327.00	1.04%	41.18%	61	ASIATEC CORPORATION	Long
RFMI004806004PS	DOOR PLATE PCM 915.5*580.5*0.45t 140L(PS) (04SP116-PCM=#0624)'04F	IMP	123.27	1,535.33	189,255.84	1.01%	42.19%	62	DANA KOREA CO.,LTD.	Omit
RFBI005183608MG	DOOR PLATE PCM 0.45*648.3*1139.2 B191Z(PN) (Light Green Metalic)'08F	IMP	157.62	1,200.00	189,143.44	1.01%	43.21%	62	DANA KOREA CO.,LTD.	Omit
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30 C56GA00	LOC	950.37	197.00	187,222.89	1.00%	44.21%	100	PANASONIC INDUSTRIAL(THAILAND) LTD.	Long
RFNL09012530800	SILVER BRAZE SILVER 25%	LOC	9.30	19,931.55	185,363.42	0.99%	45.21%	50	SEAH PRECISION METAL (THAILAND) CO.,LTD.	Omit
RFMI00580601PP1	DOOR PLATE PCM 1086.5*580.5*0.45t B173Z(PP) (Lilac Pink)'10F	IMP	142.17	1,129.50	160,575.87	0.86%	46.07%	62	DANA KOREA CO.,LTD.	Omit
RFMI006806004PS	DOOR PLATE PCM 1131.5*580.5*0.45t 180L(PS) (04SP116-PCM=#0624)'04F	IMP	152.35	1,021.50	155,621.68	0.83%	46.90%	62	DANA KOREA CO.,LTD.	Omit
RFBI09067840800	BALANCER (S)	IMP	16.70	9,172.00	153,176.80	0.82%	47.72%	72	HEIWA SHOJI CO,LTD	Long

Appendix A-1: Group A Items (Continued)

Item Code	Item Description	Class	PRICE/PC	Avg. Q'ty	End Baht (Avg.)	% of Total	% of Total (Cum.)	Act. LT	Supplier	Category
RFMI004806010MB	DOOR PLATE PCM 915.5*580.5*0.45t B143Z(MB) (Blue Metalic)'10F	IMP	119.79	1,217.67	145,866.80	0.78%	48.50%	62	DANA KOREA CO.,LTD.	Omit
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	LOC	49.76	2,873.58	142,989.51	0.77%	49.27%	68	SEAH PRECISION METAL (THAILAND) CO.,LTD.	Long
RFMI00680601WH1	DOOR PLATE PCM 1131.5*580.5*0.45t 180L(WH1) (White Hairline with metallic-06C1)'11F	IMP	148.05	960.00	142,126.43	0.76%	50.03%	62	DANA KOREA CO.,LTD.	Omit
RFMI005806010MB	DOOR PLATE PCM 1086.5*580.5*0.45t B173Z(MB) (Blue Metalic)'10F	IMP	141.32	988.83	139,745.71	0.75%	50.78%	62	DANA KOREA CO.,LTD.	Omit
WCBI00200590200	GLASS DOOR(383*685*21t)WIC-019A-AGB '02F	IMP	1,187.56	115.00	136,569.74	0.73%	51.51%	61	ASIATEC CORPORATION	Long
RFBB00903260000	COMPRESSOR WITH STANDARD ACCESSORIES FL0739 -RE(Hitachi)	LOC	981.18	127.00	124,609.86	0.67%	52.18%	44	HITACHI COMPRESSOR (THAILAND) LTD.	Long
RFBI09070330800	SILENCER-A	IMP	14.70	8,358.42	122,878.10	0.66%	52.84%	82	HEIWA SHOJI CO,LTD	Long
RFMI00480601PP1	DOOR PLATE PCM 915.5*580.5*0.45t B143Z(PP) (Lilac Pink)'10F	IMP	119.79	1,007.58	120,700.48	0.65%	53.49%	62	DANA KOREA CO.,LTD.	Omit
RFNL09007290000	HCFC-134A (REF.CHARGE TYPE)	LOC	330.00	360.08	118,824.75	0.64%	54.13%	32	BRENNTAG INGREDIENTS (THAILAND) PUBLIC COMPANY LIMITED	Omit
RFNL00580421100	ZINC PLATE SGCC 882.4x564.4x0.25t(R.PL)170L '11F	LOC	48.47	2,395.83	116,126.04	0.62%	54.75%	68	SEAH PRECISION METAL (THAILAND) CO.,LTD.	Long
RFNL09003010000	COMPRESSOR AZA1320YK	LOC	796.79	141.75	112,944.98	0.61%	55.35%	30	KULTHORN KIRBY PUBLIC COMPANY LIMITED	Short
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	IMP	131.25	856.83	112,461.46	0.60%	55.96%	82	ASIATEC CORPORATION	Long
RFNL00480421000	ZINC PLATE SGCC 734.9*564.4*0.25T(R.PL)140L	LOC	40.37	2,744.75	110,805.56	0.59%	56.55%	62	SEAH PRECISION METAL (THAILAND) CO.,LTD.	Long
WCNL00200010200	ABS(Mat.)EX27N-037938RC W80G(T)'02F	LOC	155.00	708.33	109,791.67	0.59%	57.14%	62	SOJITZ (THAILAND) CO.,LTD.	Long
RFNL09011000600	PLUG WITH ELEC.WIRE(NEW มอก)SLIM&FAT '06F	LOC	24.30	4,434.67	107,762.40	0.58%	57.72%	31	CABLE CONNECTORS CO., LTD. / B.B.K. ELECTRIC CO., LTD.	Short
RFMI006806010MB	DOOR PLATE PCM 1131.5*580.5*0.45t B183Z(MB) (Blue Metalic)'10F	IMP	148.05	705.17	104,398.73	0.56%	58.28%	62	DANA KOREA CO.,LTD.	Omit
RFBI00680601XO1	DOOR PLATE VCM 1131.5*580.5*0.45t B183(XO) (Orange Pekoe)'10F	IMP	178.13	583.33	103,911.22	0.56%	58.84%	62	DANA KOREA CO.,LTD.	Omit
RFNL09003030000	COMPRESSOR AZA1320YK-R	LOC	814.79	126.33	102,935.14	0.55%	59.39%	30	KULTHORN KIRBY PUBLIC COMPANY LIMITED	Short
RFNL00680421000	ZINC PLATE SGCC 950.9*564.4*0.25T(R.PL)180L	LOC	52.23	1,962.17	102,483.97	0.55%	59.94%	68	SEAH PRECISION METAL (THAILAND) CO.,LTD.	Long

Appendix B

Demand

Appendix B-1: Demand Normality Test

Normality Test (Anderson-Darling, P-value = 0,05)

Item code	Item Description	weekly	monthly
RFBI09067680800	COMPRESSOR;DE33YD	0.005	0.63
RFBT09002850000	COMPREESOR WITH STANDARD ACCESSORIES NO.SB24	0.005	0.734
RFBB09003240000	COMPRESSOR WITH STANDARD ACCESSORIES FL0634	0.005	0.018
RFBI09078970800	SWITCH	0.049	0.755
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	0.149	0.167
RFBI09005330300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	0.017	0.558
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	0.137	0.528
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	0.005	0.151
RFMI09007950600	LAMP SOCKET'06F	0.328	0.327
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	0.005	0.095
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30	0.005	0.136
RFBI09067840800	BALANCER (S)	0.005	0.245
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	0.412	0.273
WCBI00200590200	GLASS DOOR(383*685*21t)WIC-019A-AGB '02F	0.005	0.005
RFBI09070330800	SILENCER-A	0.049	0.755
RFNL00580421100	ZINC PLATE SGCC 882.4x564.4x0.25t(R.PL)170L '11F	0.019	0.808
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	0.005	0.151
RFNL00480421000	ZINC PLATE SGCC 734.9*564.4*0.25T(R.PL)140L	0.450	0.433
RFNL00680421000	ZINC PLATE SGCC 950.9*564.4*0.25T(R.PL)180L	0.626	0.527
RFNL00480421100	ZINC PLATE SGCC 711.4x564.4x0.25t(R.PL)140L '11F	0.005	0.024
WCNI00200040200	ADJUSTABLE LEG(Wine Cel.)W80G'02F	0.005	0.151
WCBI00200360200	DOOR SWITCH W80G(T)'02F	0.005	0.136
WCBI00200400200	DRAIN EVAPORATOR PAN W80G(T)'02F	0.005	0.136
RFBI09013500000	SPECIAL SCREW(BSNI 4*12)(RoHS)	0.005	0.734
RFBI09070390800	DOOR SWITCH (ALPS SDKN)	0.008	0.789
RFBI09067770800	RELAY BAND	0.005	0.63
RFBI09068360800	SENSOR FIXER	0.005	0.63

Appendix B-2: B175Z Demand

Date	B175Z	Date	B175Z	Date	B175Z
2011-01-06	274	2011-03-02	16	2011-04-28	510
2011-01-07	310	2011-03-03	70	2011-04-29	592
2011-01-10	334	2011-03-04	593	2011-04-30	370
2011-01-11	416	2011-03-05	391	2011-05-03	411
2011-01-12	176	2011-03-07	477	2011-05-04	395
2011-01-13	283	2011-03-08	500	2011-05-06	501
2011-01-14	283	2011-03-09	571	2011-05-07	593
2011-01-15	317	2011-03-10	570	2011-05-09	471
2011-01-17	250	2011-03-11	511	2011-05-10	309
2011-01-18	299	2011-03-12	583	2011-05-11	95
2011-01-19	330	2011-03-14	482	2011-05-12	438
2011-01-20	296	2011-03-15	516	2011-05-18	251
2011-01-21	294	2011-03-16	460	2011-05-19	373
2011-01-22	231	2011-03-17	502	2011-05-20	73
2011-01-24	353	2011-03-18	522	2011-05-21	334
2011-01-25	364	2011-03-19	371	2011-05-23	291
2011-01-26	383	2011-03-21	551	2011-05-24	354
2011-01-27	333	2011-03-22	556	2011-05-25	285
2011-01-28	364	2011-03-23	487	2011-05-26	392
2011-01-29	349	2011-03-24	642	2011-05-27	487
2011-01-31	37	2011-03-25	579	2011-05-28	251
2011-02-01	271	2011-03-26	591	2011-05-30	271
2011-02-02	386	2011-03-28	655	2011-05-31	14
2011-02-03	443	2011-03-29	666	2011-06-01	346
2011-02-04	243	2011-03-30	438	2011-06-02	339
2011-02-05	378	2011-04-01	490	2011-06-03	379
2011-02-07	346	2011-04-02	549	2011-06-06	361
2011-02-08	369	2011-04-04	545	2011-06-07	382
2011-02-09	403	2011-04-05	583	2011-06-08	374
2011-02-10	367	2011-04-06	387	2011-06-09	337
2011-02-11	388	2011-04-07	595	2011-06-10	396
2011-02-12	423	2011-04-08	232	2011-06-13	582
2011-02-14	361	2011-04-09	346	2011-06-14	579
2011-02-15	458	2011-04-18	567	2011-06-15	553
2011-02-16	478	2011-04-19	564	2011-06-16	550
2011-02-17	433	2011-04-20	246	2011-06-17	551
2011-02-21	445	2011-04-21	495	2011-06-20	526
2011-02-22	396	2011-04-22	595	2011-06-21	436
2011-02-23	455	2011-04-23	375	2011-06-22	595
2011-02-24	370	2011-04-25	720	2011-06-23	568
2011-02-25	251	2011-04-26	635	2011-06-24	560
2011-03-01	0	2011-04-27	628	2011-06-27	498

Appendix B-2: B175Z Demand (Continued)

Date	B175Z	Date	B175Z	Date	B175Z
2011-06-28	565	2011-08-24	682	2011-10-20	198
2011-06-29	528	2011-08-25	622	2011-10-21	150
2011-06-30	156	2011-08-26	386	2011-10-25	200
2011-07-01	403	2011-08-27	360	2011-10-26	200
2011-07-04	277	2011-08-29	158	2011-10-27	200
2011-07-05	171	2011-08-30	0	2011-10-28	188
2011-07-06	476	2011-08-31	0	2011-10-29	75
2011-07-07	586	2011-09-01	444	2011-11-07	233
2011-07-08	542	2011-09-02	485	2011-11-08	206
2011-07-09	453	2011-09-03	507	2011-11-09	179
2011-07-11	584	2011-09-05	538	2011-11-10	342
2011-07-12	435	2011-09-06	558	2011-11-11	289
2011-07-13	549	2011-09-07	546	2011-11-14	304
2011-07-14	606	2011-09-08	495	2011-11-15	5
2011-07-18	527	2011-09-09	538	2011-11-16	345
2011-07-19	433	2011-09-10	546	2011-11-17	363
2011-07-20	477	2011-09-12	176	2011-11-18	320
2011-07-21	607	2011-09-13	298	2011-11-21	433
2011-07-22	580	2011-09-14	398	2011-11-22	244
2011-07-23	365	2011-09-15	234	2011-11-23	419
2011-07-25	522	2011-09-16	454	2011-11-24	328
2011-07-26	552	2011-09-17	220	2011-11-25	427
2011-07-27	647	2011-09-25	128	2011-11-28	536
2011-07-28	619	2011-09-26	397	2011-11-29	534
2011-07-29	297	2011-09-27	358	2011-11-30	333
2011-08-01	461	2011-09-28	355	2011-12-01	326
2011-08-02	592	2011-09-29	264	2011-12-02	577
2011-08-03	584	2011-09-30	10	2011-12-03	233
2011-08-04	526	2011-10-03	388	2011-12-06	466
2011-08-05	507	2011-10-04	463	2011-12-07	452
2011-08-06	238	2011-10-05	328	2011-12-08	609
2011-08-08	56	2011-10-06	146	2011-12-09	198
2011-08-09	586	2011-10-07	392	2011-12-13	374
2011-08-10	649	2011-10-08	228	2011-12-14	505
2011-08-11	617	2011-10-10	315	2011-12-15	646
2011-08-16	446	2011-10-11	281	2011-12-16	638
2011-08-17	377	2011-10-12	317	2011-12-17	514
2011-08-18	563	2011-10-13	349	2011-12-19	653
2011-08-19	578	2011-10-14	158	2011-12-20	355
2011-08-20	395	2011-10-17	362	2011-12-21	710
2011-08-22	400	2011-10-18	26	2011-12-22	747
2011-08-23	585	2011-10-19	86	2011-12-23	674

Appendix B-2: B175Z Demand (Continued)

Date	B175Z	Date	B175Z	Date	B175Z
2011-12-24	572	2012-02-16	292	2012-04-06	1
2011-12-26	727	2012-02-17	34	2012-04-07	4
2011-12-27	562	2012-02-18	1	2012-04-09	6
2011-12-28	212	2012-02-20	87	2012-04-10	1
2012-01-04	277	2012-02-21	182	2012-04-11	1
2012-01-05	375	2012-02-22	233	2012-04-12	122
2012-01-06	392	2012-02-23	258	2012-04-15	334
2012-01-07	36	2012-02-24	213	2012-04-16	386
2012-01-09	244	2012-02-25	200	2012-04-17	412
2012-01-10	490	2012-02-27	16	2012-04-18	299
2012-01-11	448	2012-02-28	0	2012-04-19	336
2012-01-12	168	2012-02-29	0	2012-04-20	309
2012-01-13	569	2012-03-01	224	2012-04-21	308
2012-01-14	564	2012-03-02	309	2012-04-23	159
2012-01-16	199	2012-03-03	192	2012-04-24	312
2012-01-17	392	2012-03-05	52	2012-04-25	210
2012-01-18	362	2012-03-06	6	2012-04-26	192
2012-01-19	265	2012-03-07	1	2012-04-27	203
2012-01-20	402	2012-03-08	3	2012-04-28	162
2012-01-21	422	2012-03-09	0	2012-04-29	133
2012-01-23	138	2012-03-10	9	2012-04-30	284
2012-01-24	133	2012-03-12	3	2012-05-02	57
2012-01-25	262	2012-03-13	0	2012-05-03	9
2012-01-26	476	2012-03-14	26	2012-05-04	2
2012-01-27	553	2012-03-15	198	2012-05-08	1
2012-01-28	296	2012-03-16	98	2012-05-09	4
2012-01-29	204	2012-03-17	342	2012-05-10	2
2012-01-30	410	2012-03-19	220	2012-05-11	1
2012-01-31	304	2012-03-20	4	2012-05-12	0
2012-02-01	389	2012-03-21	1	2012-05-14	0
2012-02-02	453	2012-03-22	0	2012-05-15	2
2012-02-03	292	2012-03-23	265	2012-05-16	0
2012-02-04	300	2012-03-24	318	2012-05-17	177
2012-02-06	355	2012-03-26	286	2012-05-18	14
2012-02-07	354	2012-03-27	451	2012-05-19	48
2012-02-08	230	2012-03-28	157	2012-05-21	344
2012-02-09	150	2012-03-29	11	2012-05-22	395
2012-02-10	274	2012-03-30	0	2012-05-23	429
2012-02-11	258	2012-04-02	126	2012-05-24	446
2012-02-13	296	2012-04-03	381	2012-05-25	119
2012-02-14	235	2012-04-04	87	2012-05-26	245
2012-02-15	315	2012-04-05	108	2012-05-28	348

Appendix B-2: B175Z Demand (Continued)

Date	B175Z
2012-05-29	378
2012-05-30	447
2012-05-31	312
2012-06-01	330
2012-06-02	10
2012-06-03	10
2012-06-04	5
2012-06-05	443
2012-06-06	380
2012-06-07	408
2012-06-08	441
2012-06-09	252
2012-06-10	214
2012-06-11	191
2012-06-12	9
2012-06-13	332
2012-06-14	477
2012-06-15	534
2012-06-16	36
2012-06-17	37
2012-06-18	212
2012-06-19	429
2012-06-20	385
2012-06-21	20
2012-06-22	4
2012-06-23	2
2012-06-24	31
2012-06-25	16
2012-06-26	30
2012-06-27	5
2012-06-28	444
2012-06-29	565
2012-06-30	197

Appendix B-3: HB40 Demand

Date	HB40	Date	HB40	Date	HB40
2011-01-06	0	2011-03-02	108	2011-04-28	180
2011-01-07	0	2011-03-03	105	2011-04-29	180
2011-01-10	0	2011-03-04	12	2011-04-30	78
2011-01-11	0	2011-03-05	0	2011-05-03	0
2011-01-12	3	2011-03-07	36	2011-05-04	108
2011-01-13	0	2011-03-08	144	2011-05-06	144
2011-01-14	0	2011-03-09	135	2011-05-07	96
2011-01-15	0	2011-03-10	180	2011-05-09	144
2011-01-17	105	2011-03-11	168	2011-05-10	75
2011-01-18	102	2011-03-12	180	2011-05-11	24
2011-01-19	102	2011-03-14	105	2011-05-12	15
2011-01-20	108	2011-03-15	108	2011-05-18	0
2011-01-21	144	2011-03-16	51	2011-05-19	0
2011-01-22	144	2011-03-17	18	2011-05-20	0
2011-01-24	72	2011-03-18	12	2011-05-21	0
2011-01-25	108	2011-03-19	0	2011-05-23	0
2011-01-26	102	2011-03-21	3	2011-05-24	0
2011-01-27	12	2011-03-22	51	2011-05-25	0
2011-01-28	12	2011-03-23	0	2011-05-26	0
2011-01-29	24	2011-03-24	156	2011-05-27	0
2011-01-31	0	2011-03-25	96	2011-05-28	0
2011-02-01	0	2011-03-26	213	2011-05-30	0
2011-02-02	0	2011-03-28	72	2011-05-31	0
2011-02-03	0	2011-03-29	144	2011-06-01	0
2011-02-04	0	2011-03-30	177	2011-06-02	0
2011-02-05	0	2011-04-01	0	2011-06-03	0
2011-02-07	0	2011-04-02	0	2011-06-06	0
2011-02-08	0	2011-04-04	0	2011-06-07	0
2011-02-09	0	2011-04-05	0	2011-06-08	0
2011-02-10	0	2011-04-06	117	2011-06-09	0
2011-02-11	75	2011-04-07	105	2011-06-10	0
2011-02-12	126	2011-04-08	81	2011-06-13	0
2011-02-14	0	2011-04-09	3	2011-06-14	0
2011-02-15	6	2011-04-18	0	2011-06-15	0
2011-02-16	48	2011-04-19	0	2011-06-16	72
2011-02-17	111	2011-04-20	0	2011-06-17	87
2011-02-21	144	2011-04-21	96	2011-06-20	180
2011-02-22	144	2011-04-22	30	2011-06-21	144
2011-02-23	69	2011-04-23	216	2011-06-22	180
2011-02-24	42	2011-04-25	144	2011-06-23	69
2011-02-25	24	2011-04-26	108	2011-06-24	18
2011-03-01	36	2011-04-27	216	2011-06-27	0

Appendix B-3: HB40 Demand (Continued)

Date	HB40	Date	HB40	Date	HB40
2011-06-28	0	2011-08-24	0	2011-10-20	0
2011-06-29	0	2011-08-25	0	2011-10-21	0
2011-06-30	0	2011-08-26	0	2011-10-25	0
2011-07-01	0	2011-08-27	0	2011-10-26	0
2011-07-04	18	2011-08-29	0	2011-10-27	0
2011-07-05	30	2011-08-30	0	2011-10-28	0
2011-07-06	249	2011-08-31	0	2011-10-29	0
2011-07-07	171	2011-09-01	0	2011-11-07	0
2011-07-08	42	2011-09-02	0	2011-11-08	0
2011-07-09	0	2011-09-03	0	2011-11-09	0
2011-07-11	0	2011-09-05	0	2011-11-10	0
2011-07-12	165	2011-09-06	0	2011-11-11	0
2011-07-13	177	2011-09-07	0	2011-11-14	0
2011-07-14	258	2011-09-08	0	2011-11-15	0
2011-07-18	72	2011-09-09	288	2011-11-16	0
2011-07-19	63	2011-09-10	150	2011-11-17	0
2011-07-20	3	2011-09-12	0	2011-11-18	0
2011-07-21	9	2011-09-13	0	2011-11-21	0
2011-07-22	3	2011-09-14	0	2011-11-22	0
2011-07-23	0	2011-09-15	108	2011-11-23	0
2011-07-25	0	2011-09-16	51	2011-11-24	0
2011-07-26	0	2011-09-17	3	2011-11-25	0
2011-07-27	0	2011-09-25	0	2011-11-28	0
2011-07-28	0	2011-09-26	0	2011-11-29	0
2011-07-29	0	2011-09-27	0	2011-11-30	66
2011-08-01	0	2011-09-28	0	2011-12-01	0
2011-08-02	0	2011-09-29	0	2011-12-02	0
2011-08-03	0	2011-09-30	0	2011-12-03	270
2011-08-04	0	2011-10-03	0	2011-12-06	0
2011-08-05	0	2011-10-04	0	2011-12-07	0
2011-08-06	0	2011-10-05	0	2011-12-08	0
2011-08-08	0	2011-10-06	147	2011-12-09	0
2011-08-09	0	2011-10-07	0	2011-12-13	0
2011-08-10	0	2011-10-08	0	2011-12-14	0
2011-08-11	0	2011-10-10	0	2011-12-15	0
2011-08-16	0	2011-10-11	453	2011-12-16	0
2011-08-17	0	2011-10-12	0	2011-12-17	0
2011-08-18	0	2011-10-13	0	2011-12-19	0
2011-08-19	0	2011-10-14	0	2011-12-20	0
2011-08-20	0	2011-10-17	0	2011-12-21	0
2011-08-22	0	2011-10-18	0	2011-12-22	0
2011-08-23	0	2011-10-19	0	2011-12-23	0

Appendix B-3: HB40 Demand (Continued)

Date	HB40	Date	HB40	Date	HB40
2011-12-24	0	2012-02-16	0	2012-04-06	0
2011-12-26	108	2012-02-17	243	2012-04-07	102
2011-12-27	252	2012-02-18	294	2012-04-09	0
2011-12-28	60	2012-02-20	0	2012-04-10	168
2012-01-04	0	2012-02-21	216	2012-04-11	72
2012-01-05	180	2012-02-22	180	2012-04-12	108
2012-01-06	108	2012-02-23	0	2012-04-15	0
2012-01-07	180	2012-02-24	180	2012-04-16	0
2012-01-09	144	2012-02-25	336	2012-04-17	0
2012-01-10	216	2012-02-27	0	2012-04-18	144
2012-01-11	60	2012-02-28	0	2012-04-19	180
2012-01-12	0	2012-02-29	396	2012-04-20	144
2012-01-13	12	2012-03-01	0	2012-04-21	180
2012-01-14	0	2012-03-02	144	2012-04-23	324
2012-01-16	0	2012-03-03	108	2012-04-24	0
2012-01-17	204	2012-03-05	0	2012-04-25	180
2012-01-18	72	2012-03-06	144	2012-04-26	0
2012-01-19	252	2012-03-07	0	2012-04-27	144
2012-01-20	285	2012-03-08	0	2012-04-28	312
2012-01-21	207	2012-03-09	0	2012-04-29	0
2012-01-23	144	2012-03-10	0	2012-04-30	0
2012-01-24	180	2012-03-12	105	2012-05-02	105
2012-01-25	216	2012-03-13	204	2012-05-03	0
2012-01-26	180	2012-03-14	108	2012-05-04	36
2012-01-27	108	2012-03-15	135	2012-05-08	0
2012-01-28	24	2012-03-16	138	2012-05-09	108
2012-01-29	0	2012-03-17	180	2012-05-10	108
2012-01-30	36	2012-03-19	144	2012-05-11	81
2012-01-31	42	2012-03-20	183	2012-05-12	0
2012-02-01	0	2012-03-21	0	2012-05-14	0
2012-02-02	0	2012-03-22	216	2012-05-15	0
2012-02-03	0	2012-03-23	144	2012-05-16	324
2012-02-04	108	2012-03-24	63	2012-05-17	108
2012-02-06	144	2012-03-26	51	2012-05-18	216
2012-02-07	180	2012-03-27	6	2012-05-19	108
2012-02-08	180	2012-03-28	60	2012-05-21	177
2012-02-09	36	2012-03-29	0	2012-05-22	72
2012-02-10	0	2012-03-30	0	2012-05-23	252
2012-02-11	15	2012-04-02	0	2012-05-24	243
2012-02-13	108	2012-04-03	0	2012-05-25	108
2012-02-14	72	2012-04-04	12	2012-05-26	249
2012-02-15	216	2012-04-05	0	2012-05-28	180

Appendix B-3: HB40 Demand (Continued)

Date	HB40
2012-05-29	36
2012-05-30	27
2012-05-31	72
2012-06-01	0
2012-06-02	0
2012-06-03	0
2012-06-04	0
2012-06-05	0
2012-06-06	0
2012-06-07	288
2012-06-08	108
2012-06-09	144
2012-06-10	72
2012-06-11	0
2012-06-12	111
2012-06-13	0
2012-06-14	0
2012-06-15	0
2012-06-16	0
2012-06-17	0
2012-06-18	0
2012-06-19	0
2012-06-20	0
2012-06-21	48
2012-06-22	0
2012-06-23	117
2012-06-24	117
2012-06-25	0
2012-06-26	0
2012-06-27	0
2012-06-28	0
2012-06-29	18
2012-06-30	0

Appendix B-4: W80 Demand

Date	W80	Date	W80	Date	W80
2011-01-06	0	2011-03-02	0	2011-04-28	0
2011-01-07	0	2011-03-03	0	2011-04-29	0
2011-01-10	0	2011-03-04	0	2011-04-30	0
2011-01-11	0	2011-03-05	0	2011-05-03	0
2011-01-12	0	2011-03-07	0	2011-05-04	0
2011-01-13	0	2011-03-08	0	2011-05-06	12
2011-01-14	0	2011-03-09	0	2011-05-07	0
2011-01-15	0	2011-03-10	0	2011-05-09	12
2011-01-17	9	2011-03-11	0	2011-05-10	8
2011-01-18	0	2011-03-12	0	2011-05-11	12
2011-01-19	9	2011-03-14	0	2011-05-12	17
2011-01-20	0	2011-03-15	0	2011-05-18	0
2011-01-21	0	2011-03-16	0	2011-05-19	12
2011-01-22	0	2011-03-17	0	2011-05-20	0
2011-01-24	0	2011-03-18	0	2011-05-21	15
2011-01-25	0	2011-03-19	0	2011-05-23	0
2011-01-26	0	2011-03-21	0	2011-05-24	0
2011-01-27	0	2011-03-22	0	2011-05-25	0
2011-01-28	4	2011-03-23	0	2011-05-26	0
2011-01-29	6	2011-03-24	0	2011-05-27	0
2011-01-31	7	2011-03-25	0	2011-05-28	0
2011-02-01	0	2011-03-26	0	2011-05-30	0
2011-02-02	0	2011-03-28	0	2011-05-31	0
2011-02-03	0	2011-03-29	0	2011-06-01	0
2011-02-04	0	2011-03-30	0	2011-06-02	0
2011-02-05	0	2011-04-01	0	2011-06-03	0
2011-02-07	0	2011-04-02	0	2011-06-06	0
2011-02-08	2	2011-04-04	0	2011-06-07	0
2011-02-09	0	2011-04-05	0	2011-06-08	0
2011-02-10	0	2011-04-06	0	2011-06-09	0
2011-02-11	0	2011-04-07	0	2011-06-10	0
2011-02-12	0	2011-04-08	0	2011-06-13	0
2011-02-14	1	2011-04-09	0	2011-06-14	0
2011-02-15	0	2011-04-18	0	2011-06-15	0
2011-02-16	0	2011-04-19	0	2011-06-16	0
2011-02-17	0	2011-04-20	0	2011-06-17	0
2011-02-21	0	2011-04-21	0	2011-06-20	0
2011-02-22	0	2011-04-22	0	2011-06-21	0
2011-02-23	0	2011-04-23	0	2011-06-22	0
2011-02-24	0	2011-04-25	0	2011-06-23	0
2011-02-25	0	2011-04-26	0	2011-06-24	0
2011-03-01	0	2011-04-27	0	2011-06-27	0

Appendix B-4: W80 Demand (Continued)

Date	W80	Date	W80	Date	W80
2011-06-28	0	2011-08-24	0	2011-10-20	10
2011-06-29	0	2011-08-25	1	2011-10-21	10
2011-06-30	0	2011-08-26	0	2011-10-25	12
2011-07-01	0	2011-08-27	0	2011-10-26	12
2011-07-04	0	2011-08-29	5	2011-10-27	12
2011-07-05	12	2011-08-30	0	2011-10-28	11
2011-07-06	10	2011-08-31	0	2011-10-29	0
2011-07-07	0	2011-09-01	0	2011-11-07	30
2011-07-08	6	2011-09-02	0	2011-11-08	15
2011-07-09	0	2011-09-03	0	2011-11-09	4
2011-07-11	19	2011-09-05	0	2011-11-10	11
2011-07-12	20	2011-09-06	0	2011-11-11	10
2011-07-13	11	2011-09-07	0	2011-11-14	8
2011-07-14	10	2011-09-08	0	2011-11-15	9
2011-07-18	0	2011-09-09	0	2011-11-16	0
2011-07-19	0	2011-09-10	0	2011-11-17	0
2011-07-20	0	2011-09-12	0	2011-11-18	0
2011-07-21	0	2011-09-13	0	2011-11-21	0
2011-07-22	0	2011-09-14	0	2011-11-22	0
2011-07-23	0	2011-09-15	0	2011-11-23	0
2011-07-25	0	2011-09-16	0	2011-11-24	0
2011-07-26	0	2011-09-17	16	2011-11-25	0
2011-07-27	0	2011-09-25	0	2011-11-28	0
2011-07-28	0	2011-09-26	0	2011-11-29	0
2011-07-29	0	2011-09-27	0	2011-11-30	0
2011-08-01	0	2011-09-28	6	2011-12-01	0
2011-08-02	0	2011-09-29	9	2011-12-02	0
2011-08-03	0	2011-09-30	38	2011-12-03	0
2011-08-04	0	2011-10-03	2	2011-12-06	0
2011-08-05	0	2011-10-04	10	2011-12-07	0
2011-08-06	0	2011-10-05	12	2011-12-08	0
2011-08-08	0	2011-10-06	0	2011-12-09	0
2011-08-09	0	2011-10-07	0	2011-12-13	0
2011-08-10	0	2011-10-08	0	2011-12-14	9
2011-08-11	0	2011-10-10	0	2011-12-15	0
2011-08-16	0	2011-10-11	0	2011-12-16	0
2011-08-17	0	2011-10-12	0	2011-12-17	0
2011-08-18	20	2011-10-13	0	2011-12-19	54
2011-08-19	6	2011-10-14	67	2011-12-20	17
2011-08-20	0	2011-10-17	0	2011-12-21	8
2011-08-22	9	2011-10-18	0	2011-12-22	0
2011-08-23	8	2011-10-19	20	2011-12-23	0

Appendix B-4: W80 Demand (Continued)

Date	W80	Date	W80	Date	W80
2011-12-24	0	2012-02-16	6	2012-04-06	0
2011-12-26	0	2012-02-17	0	2012-04-07	0
2011-12-27	0	2012-02-18	4	2012-04-09	0
2011-12-28	0	2012-02-20	13	2012-04-10	0
2012-01-04	0	2012-02-21	12	2012-04-11	0
2012-01-05	0	2012-02-22	8	2012-04-12	0
2012-01-06	0	2012-02-23	14	2012-04-15	0
2012-01-07	0	2012-02-24	2	2012-04-16	0
2012-01-09	0	2012-02-25	7	2012-04-17	0
2012-01-10	0	2012-02-27	1	2012-04-18	22
2012-01-11	0	2012-02-28	0	2012-04-19	0
2012-01-12	0	2012-02-29	0	2012-04-20	0
2012-01-13	0	2012-03-01	0	2012-04-21	0
2012-01-14	0	2012-03-02	0	2012-04-23	0
2012-01-16	0	2012-03-03	2	2012-04-24	0
2012-01-17	0	2012-03-05	1	2012-04-25	0
2012-01-18	0	2012-03-06	5	2012-04-26	0
2012-01-19	0	2012-03-07	8	2012-04-27	0
2012-01-20	0	2012-03-08	5	2012-04-28	0
2012-01-21	0	2012-03-09	2	2012-04-29	0
2012-01-23	0	2012-03-10	0	2012-04-30	0
2012-01-24	0	2012-03-12	0	2012-05-02	0
2012-01-25	0	2012-03-13	0	2012-05-03	0
2012-01-26	0	2012-03-14	0	2012-05-04	0
2012-01-27	0	2012-03-15	0	2012-05-08	0
2012-01-28	0	2012-03-16	0	2012-05-09	0
2012-01-29	0	2012-03-17	0	2012-05-10	0
2012-01-30	0	2012-03-19	2	2012-05-11	0
2012-01-31	0	2012-03-20	8	2012-05-12	0
2012-02-01	0	2012-03-21	15	2012-05-14	0
2012-02-02	0	2012-03-22	8	2012-05-15	0
2012-02-03	0	2012-03-23	9	2012-05-16	0
2012-02-04	0	2012-03-24	0	2012-05-17	0
2012-02-06	0	2012-03-26	1	2012-05-18	0
2012-02-07	0	2012-03-27	0	2012-05-19	7
2012-02-08	0	2012-03-28	0	2012-05-21	36
2012-02-09	0	2012-03-29	0	2012-05-22	13
2012-02-10	0	2012-03-30	0	2012-05-23	14
2012-02-11	0	2012-04-02	0	2012-05-24	12
2012-02-13	0	2012-04-03	0	2012-05-25	5
2012-02-14	7	2012-04-04	0	2012-05-26	1
2012-02-15	7	2012-04-05	0	2012-05-28	0

Appendix B-4: W80 Demand (Continued)

Date	W80
2012-05-29	0
2012-05-30	0
2012-05-31	0
2012-06-01	0
2012-06-02	0
2012-06-03	0
2012-06-04	0
2012-06-05	11
2012-06-06	7
2012-06-07	15
2012-06-08	11
2012-06-09	4
2012-06-10	0
2012-06-11	1
2012-06-12	14
2012-06-13	16
2012-06-14	1
2012-06-15	0
2012-06-16	0
2012-06-17	0
2012-06-18	0
2012-06-19	0
2012-06-20	0
2012-06-21	0
2012-06-22	7
2012-06-23	1
2012-06-24	0
2012-06-25	0
2012-06-26	0
2012-06-27	0
2012-06-28	0
2012-06-29	0
2012-06-30	0

Appendix C

Parameters

Appendix C-1: Lead Time and Standard Deviation Summary

Item	Supplier	L	σ_l
COMPRESSOR;DE33YD	TOSHIBA CARRIER CORPORATION	96.93	21.59
COMPREESOR WITH STANDARD ACCESSORIES NO.SB24	PANASONIC INDUSTRIAL(THAILAND) LTD.	102.62	42.73
COMPRESSOR WITH STANDARD ACCESSORIES FL0634	HITACHI COMPRESSOR (THAILAND) LTD.	43.68	27.01
SWITCH	TOSHIBA TRADING INCORPORATED	89.84	52.90
DRYER ASSY 10Gr(Non CFC)ID4.14'03F	Parker Hannifin Refrigeration and Air conditioning (WUXI)	41.25	22.49
DRYER ASSY 10Gr(Non CFC)ID4.14'03F	Parker Hannifin Refrigeration and Air conditioning (WUXI)	41.25	22.49
ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	SEAH PRECISION METAL (THAILAND) CO.,LTD.	68.25	29.94
LOWER HINGE(Wine Cel.)W80G(T)'02F	ASIATEC CORPORATION	35.08	28.32
LAMP SOCKET'06F	FUJISAWA DENKO CO.,LTD.	78.01	25.28
GLASS DOOR(383*685*21t)W80G(T)'02F	ASIATEC CORPORATION	61.24	20.75
COMPRESSOR WITH STANDARD ACCESSORIES SB30	PANASONIC INDUSTRIAL(THAILAND) LTD.	92.30	29.76
BALANCER (S)	HEIWA SHOJI CO,LTD	74.86	29.88
ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	SEAH PRECISION METAL (THAILAND) CO.,LTD.	68.25	29.94
GLASS DOOR(383*685*21t)WIC-019A-AGB '02F	ASIATEC CORPORATION	53.83	22.57
SILENCER-A	HEIWA SHOJI CO,LTD	87.32	31.22
ZINC PLATE SGCC 882.4x564.4x0.25t(R.PL)170L '11F	SEAH PRECISION METAL (THAILAND) CO.,LTD.	68.25	29.94
DRAIN HOSE W80G(T)'02F 2F	ASIATEC CORPORATION	82.31	31.88
ZINC PLATE SGCC 734.9*564.4*0.25T(R.PL)140L	SEAH PRECISION METAL (THAILAND) CO.,LTD.	68.25	29.94
ZINC PLATE SGCC 950.9*564.4*0.25T(R.PL)180L	SEAH PRECISION METAL (THAILAND) CO.,LTD.	68.25	29.94
ZINC PLATE SGCC 711.4x564.4x0.25t(R.PL)140L '11F	SEAH PRECISION METAL (THAILAND) CO.,LTD.	68.25	29.94
ADJUSTABLE LEG(Wine Cel.)W80G'02F	ASIATEC CORPORATION	77.50	31.66
DOOR SWITCH W80G(T)'02F	ASIATEC CORPORATION	69.87	20.15
DRAIN EVAPORATOR PAN W80G(T)'02F	ASIATEC CORPORATION	50.37	22.41
SPECIAL SCREW(BSNI 4*12)(RoHS)	ASIATEC CORPORATION	57.94	29.08
DOOR SWITCH (ALPS SDKN)	HEIWA SHOJI CO,LTD	101.52	25.85
RELAY BAND	HEIWA SHOJI CO,LTD	101.94	13.75
SENSOR FIXER	HEIWA SHOJI CO,LTD	82.61	30.66

Appendix C-2: Days' Supply of Safety Stock

Item	Description	Safety factor	Safety Stock	Days' Supply
RFBI09067680800	COMPRESSOR;DE33YD	1.0081	301.71	6.29
RFBI09078970800	SWITCH	1.0081	290.47	6.05
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	1.0013	1,024.77	2.40
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	1.0013	1,318.17	3.09
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	1.0152	46.95	5.87
RFMI09007950600	LAMP SOCKET'06F	1.0013	1,409.32	3.30
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	1.0152	62.02	7.75
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30C56GA00	1.0152	76.15	9.52
RFBI09067840800	BALANCER (S)	1.0081	265.15	5.52
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	1.0013	1,318.17	3.09
RFBI09070330800	SILENCER-A	1.0081	286.36	5.97
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	1.0152	71.91	8.99
	B175Z			
	HB40			
	W80			

Appendix D

Lot Sizing

Ending Onhand of REF

ITEM CODE	DESCRIPTION	DATE	QUANTITY	SUBINVENTORY
RFBI09067680800	COMPRESSOR;DE33YD	12/31/2010	1584	REF-STORE
RFBI09078970800	SWITCH	12/31/2010	3674	REF-STORE
RFBI09067840800	BALANCER (S)	12/31/2010	9774	REF-STORE
RFBI09070330800	SILENCER-A	12/31/2010	8478	REF-STORE
RFBI09070390800	DOOR SWITCH (ALPS SDKN)	12/31/2010	3310	REF-STORE
RFBI09067770800	RELAY BAND	12/31/2010	5103	REF-STORE
RFBI09068360800	SENSOR FIXER	12/31/2010	5885	REF-STORE
RFBT09002850000	COMPREESOR WITH STANDARD ACCESSORIES NO.SB24C50GA00(MARIS)	12/31/2010	2036	REF-STORE
RFBI09013500000	SPECIAL SCREW(BSNI 4*12)(RoHS)	12/31/2010	5911	REF-STORE
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	12/31/2010	6294	REF-STORE
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30C56GA00	12/31/2010	207	REF-STORE
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	12/31/2010	1237	REF-STORE
WCNI00200040200	ADJUSTABLE LEG(Wine Cel.)W80G'02F	12/31/2010	8383	REF-STORE
WCBI00200400200	DRAIN EVAPORATOR PAN W80G(T)'02F	12/31/2010	668	REF-STORE
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	12/31/2010	39	REF-STORE
WCBI00200360200	DOOR SWITCH W80G(T)'02F	12/31/2010	738	REF-STORE
WCBI00200590200	GLASS DOOR(383*685*21t)WIC-019A-AGB '02F	12/31/2010	128	REF-STORE
RFBB09003240000	COMPRESSOR WITH STANDARD ACCESSORIES FL0634-RD(Hitachi)	12/31/2010	74	REF-STORE
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	12/31/2010	11766	REF-STORE
RFMI09007950600	LAMP SOCKET'06F	12/31/2010	10564	REF-STORE
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	12/31/2010	1000	REF-STORE
RFNL00580421100	ZINC PLATE SGCC 882.4x564.4x0.25t(R.PL)170L '11F	12/31/2010	1000	REF-STORE
RFNL00480421000	ZINC PLATE SGCC 734.9*564.4*0.25T(R.PL)140L	12/31/2010	3000	REF-STORE
RFNL00680421000	ZINC PLATE SGCC 950.9*564.4*0.25T(R.PL)180L	12/31/2010	2000	REF-STORE
RFNL00480421100	ZINC PLATE SGCC 711.4x564.4x0.25t(R.PL)140L '11F	12/31/2010	1000	REF-STORE
RFBI09005330300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	12/31/2010	17181	REF-STORE

Appendix D-2: Average Order Quantity (1.7% vs. 4%)

		1.70%	4%		1.70%	4%	
Item	**Description**	**PPB**	**PPB**	**Diff.**	**WW**	**WW**	**Diff.**
RFBI09067680800	COMPRESSOR;DE33YD	1,274.80	2,136.00	67.56%	1,283.40	2,139.00	66.67%
RFBI09078970800	SWITCH	2,139.00	4,326.00	102.24%	2,151.50	4,303.00	100.00%
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	7,412.81	9,125.38	23.10%	6,951.29	9,847.67	41.67%
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	7,750.63	10,333.33	33.32%	7,288.88	10,325.92	41.67%
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	0.00	0.00	0.00%	0.00	0.00	0.00%
RFMI09007950600	LAMP SOCKET'06F	8,944.21	8,950.50	0.07%	9,644.23	10,447.92	8.33%
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	198.40	248.00	25.00%	196.20	327.00	66.67%
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30C56GA00	164.80	206.50	25.30%	204.75	204.75	0.00%
RFBI09067840800	BALANCER (S)	7,068.00	7,051.50	-0.23%	7,105.50	14,211.00	100.00%
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	6,742.00	8,989.33	33.33%	6,725.30	8,967.07	33.33%
RFBI09070330800	SILENCER-A	3,782.00	7,564.00	100.00%	7,560.00	7,560.00	0.00%
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	0.00	0.00	0.00%	0.00	0.00	0.00%
	B175Z						
	HB40						
	W80						

Appendix D-3: Holding Cost

Item	Description	L4L	POQ	PPB	LUC	LPC	WW
RFBI09067680800	COMPRESSOR;DE33YD	130,028.82	424,241.58	522,732.18	471,327.48	155,147.40	388,230.84
RFBI09078970800	SWITCH	36,674.28	52,091.55	50,947.56	49,496.58	37,347.66	48,733.29
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	9,117.46	24,281.82	33,854.88	34,660.36	11,751.62	29,073.96
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	6,706.26	27,281.88	46,767.99	45,752.94	10,856.07	40,165.41
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	72,098.04	72,098.04	72,098.04	72,098.04	72,098.04	72,098.04
RFMI09007950600	LAMP SOCKET'06F	1,794.25	12,213.06	17,449.28	16,793.98	3,190.25	16,889.42
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	772.72	36,707.84	30,467.84	27,487.20	5,683.60	19,553.04
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30C56GA00	14,729.70	27,032.20	29,782.78	38,303.14	17,768.88	27,240.14
RFBI09067840800	BALANCER (S)	9,063.63	14,760.18	15,631.86	15,240.03	9,254.70	14,965.35
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	277.56	42,878.92	50,488.72	47,630.48	6,128.80	43,960.88
RFBI09070330800	SILENCER-A	11,195.64	13,479.66	14,648.56	14,648.56	11,325.64	15,748.76
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	32,484.10	32,484.10	32,484.10	32,484.10	32,484.10	32,484.10
	B175Z						
	HB40						
	W80						

Appendix D-4: Ordering Cost

Item	Description	L4L	POQ	PPB	LUC	LPC	WW
RFBI09067680800	COMPRESSOR;DE33YD	12,494,649.34	547,210.92	456,009.10	2,097,641.86	6,110,521.94	456,009.10
RFBI09078970800	SWITCH	995,660.19	22,888.74	22,888.74	22,888.74	503,552.28	22,888.74
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	540,300.16	39,266.00	25,130.24	25,130.24	240,307.92	26,700.88
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	880,494.09	76,457.47	39,461.92	41,928.29	387,220.09	41,928.29
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	0.00	0.00	0.00	0.00	0.00	0.00
RFMI09007950600	LAMP SOCKET'06F	402,507.78	24,529.56	15,609.72	16,724.70	178,396.80	14,494.74
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	602,019.12	34,598.80	34,598.80	34,598.80	283,710.16	34,598.80
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30C56GA00	258,911.29	21,280.38	17,733.65	17,733.65	120,588.82	14,186.92
RFBI09067840800	BALANCER (S)	380,538.33	12,275.43	8,183.62	8,183.62	204,590.50	8,183.62
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	983,853.75	60,390.00	50,325.00	52,841.25	447,892.50	50,325.00
RFBI09070330800	SILENCER-A	238,013.93	6,182.18	6,182.18	6,182.18	126,734.69	3,091.09
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	0.00	0.00	0.00	0.00	0.00	0.00
	B175Z						
	HB40						
	W80						

Appendix D-5: Average Order Quantity (1.7% vs. 4%)

		1.70%	4%		1.70%	4%	
Item	**Description**	**PPB**	**PPB**	**Diff.**	**WW**	**WW**	**Diff.**
RFBI09067680800	COMPRESSOR;DE33YD	1,274.80	2,136.00	67.56%	1,283.40	2,139.00	66.67%
RFBI09078970800	SWITCH	2,139.00	4,326.00	102.24%	2,151.50	4,303.00	100.00%
RFMI09005340300	DRYER ASSY 10Gr(Non CFC)ID4.14'03F	7,412.81	9,125.38	23.10%	6,951.29	9,847.67	41.67%
RFNL09080401000	ZINC PLATE SGCC 661.9*561.8*0.25T(BT.PL)	7,750.63	10,333.33	33.32%	7,288.88	10,325.92	41.67%
WCNI00200910200	LOWER HINGE(Wine Cel.)W80G(T)'02F	0.00	0.00	0.00%	0.00	0.00	0.00%
RFMI09007950600	LAMP SOCKET'06F	8,944.21	8,950.50	0.07%	9,644.23	10,447.92	8.33%
WCBI00200570200	GLASS DOOR(383*685*21t)W80G(T)'02F	198.40	248.00	25.00%	196.20	327.00	66.67%
WCBT00200210000	COMPRESSOR WITH STANDARD ACCESSORIES SB30C56GA00	164.80	206.50	25.30%	204.75	204.75	0.00%
RFBI09067840800	BALANCER (S)	7,068.00	7,051.50	-0.23%	7,105.50	14,211.00	100.00%
RFNL00580421000	ZINC PLATE SGCC 905.9*564.4*0.25T(R.PL)170L	6,742.00	8,989.33	33.33%	6,725.30	8,967.07	33.33%
RFBI09070330800	SILENCER-A	3,782.00	7,564.00	100.00%	7,560.00	7,560.00	0.00%
WCNI00200410200	DRAIN HOSE W80G(T)'02F 2F	0.00	0.00	0.00%	0.00	0.00	0.00%
(yellow)	B175Z						
(green)	HB40						
(blue)	W80						

BIOGRAPHY

Mr. Sorakrit Lekklar was born in Bangkok, Thailand, on August 4th, 1986 to a family of diplomats. He finished grade school from International College Spain (ICS Madrid) before attending Ruamrudee International School (Graduating Class of 2004). He received his undergraduate study from Sirindhorn International Institute of Technology (SIIT), Thammasat University and graduated in the year 2008.

He then worked as Productivity Engineer at Thai Toshiba Electric Industries (Refrigerator Division) from April 2008 to September 2009, and then from March 2011 to April 2012, taking time off in between to enroll in courses for the dual-degree at The Regional Centre for Manufacturing Systems Engineering, Faculty of Engineering, Chulalongkorn University in conjunction with The Warwick Manufacturing Group, University of Warwick for the Master of Engineering in Engineering Management and Master of Science in Supply Chain & Logistics Management degrees.