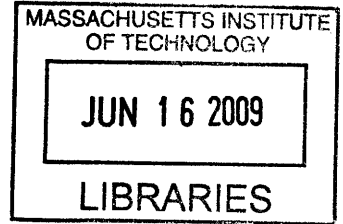


Development of International Supply Chain Strategies to Support Global Sourcing and Manufacturing

By

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B.S. in Mechanical and Aerospace Engineering, 2003
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Submitted to the MIT Sloan School of Management and the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for Degrees of

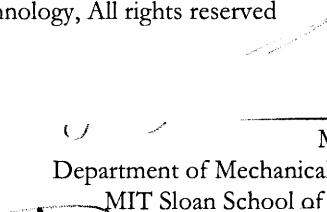
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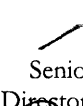
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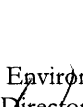
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Wondong Do

Submitted to the MIT Sloan School of Management and the Department of Mechanical Engineering on May 8th, 2009, in partial fulfillment of the requirements for the degrees of Master of Business Administration and Master of Science in Mechanical Engineering.

ABSTRACT

Globalization in sourcing and manufacturing is expected to offer several different kinds of benefits. Globalized companies can produce products at cheaper costs by accessing cheaper resources and they can be close to the local market, so that they can quickly react to the needs of local markets. However, there are risks involved in global expansion. Different countries have different cultures and environments. Political relationships between the countries and global economic challenges may also affect the reliability and the profitability of globalization. Globalization requires goods to travel longer, which in turn pushes up the logistics costs.

Among all the challenges, this thesis focuses on the supply chain challenges of globalization and develops the strategies to address those challenges. The thesis will provide framework to help to make international supply chain decisions. Based on this framework and the current Honeywell's environment, it will identify four different improvement opportunities and associated solutions. Each opportunity will be evaluated by appropriate models. The goal of identifying Honeywell's improvement opportunities and evaluating them is to present some structural results for each supply chain option: how the trade-offs of the option can be optimized and in each case, which option works best.

In the last part, the thesis will also discuss the implementation challenges. The organizational challenges will be analyzed by using the three lenses and the change management will be discussed. In addition to the organizational challenges, the communication challenges, which become more important in a global environment, will also be discussed. Although these are the challenges faced during the project at Honeywell, many companies that are trying to do global expansion experience same type of challenges. Thus, this discussion will help to address implementation issues that most companies face.

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1 Company Background

Honeywell (NYSE: HON) operates as a diversified cutting-edge technology and manufacturing company in four segments: Aerospace, Automation and Control Solutions, Specialty Materials, and Transportation Systems. Each segment has locations across the globe: Honeywell has 122000 employees in nearly 100 countries.

Honeywell Aerospace, based in Phoenix, delivers a diverse range of commercial and defense and space products, systems and services across the aerospace industry for aircraft manufacturers, and airlines, and general aviation, military, space and airport operations. From single-engine piston-powered airplanes to commercial applications to military and space vehicles applications, Honeywell's products and systems can be found on virtually every type of aerospace platform operating around the world today. Honeywell Aerospace is widely recognized as a key aerospace supplier that can deliver a broad range of aerospace solutions for the gate-to-gate needs of airframe manufacturers, commercial airlines, military and defense, business aviation and others in the aerospace industry. Honeywell Aerospace has sales of over \$11 billion and employs 40,000 people in 97 worldwide manufacturing and service sites. Honeywell Aerospace generates 35% of total corporate revenue and keeps growing and expanding its core products.¹

Aerospace Global Sourcing Group manages the supply base to be competitive for Honeywell Aerospace through world class supplier selection, consistent and predictable supplier performance; driving cost, delivery, quality and service superiority.

The Asia-Pacific (AP) region becomes more and more important in terms of not only its cheaper sourcing cost but also new business opportunity. Aerospace Global Sourcing Group is working on many transition projects to the AP region.

¹ Company information is excerpted from the company's website, www.honeywell.com. More information can be found in the website.

2 Project Orientation

2.1 Problem Overview

The trend of globalization in sourcing and manufacturing is prevailing across the world. Many multinational companies are seeking opportunities to manufacture offshore or outsource from the other countries. There are several different reasons why many companies are looking for global manufacturing opportunities. Cheaper production costs of the low cost countries have attracted the global manufacturing companies. Manufacturing offshore or outsourcing from the other countries would make it easier to enter the protected market. In the Aerospace industry, whose technology is not as open to other countries because of the security issues, the level of globalization has been relatively lower compared to the other industries such as commercial electronics industry. However, the need for globalization of the aerospace industry is rapidly growing. Honeywell Aerospace is one of the aerospace companies that is exploring opportunities to make and buy from the world. It has especially been growing its manufacturing footprint in the Asia Pacific (AP) region recently. Due to the regulations in the aerospace industry, however, Honeywell's OEM sites and vendors in China are not producing final products to serve the local market. Instead, they are producing the intermediate parts that will be shipped to the US where final assembly will take place. Also the OEM sites and vendors in China can't source the raw materials in China or from the countries nearby. Due to the government regulations regarding the source of raw materials, Honeywell buys the materials in the US and ships them to China. Figure 1 shows Honeywell's China supply chain.

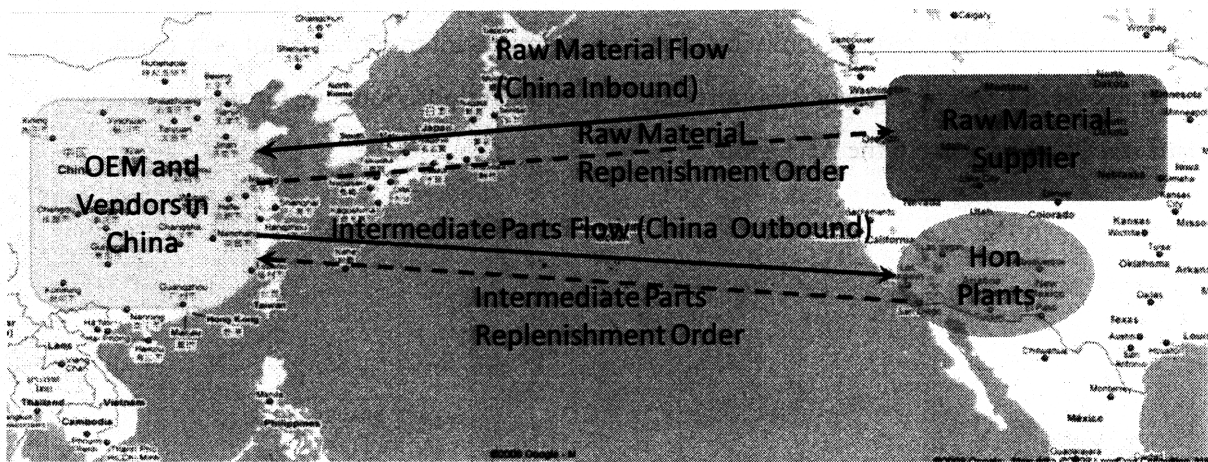


Figure 1 Overview of the Honeywell's China Supply Chain

The biggest challenges in managing global manufacturing are, as we can guess from Figure 1, high transportation costs and difficulty in communication with remote sites. In case of Honeywell, these issues are even more important because there are two directions of trans-pacific transportation and order (information) flow in the supply chain. Although there are more advanced transportation and information technology that can potentially resolve those issues, the company needs a strategy that will address how to use the technologies in a cost effective and reliable manner. Honeywell needs to develop an AP supply chain strategy to make it cheaper and reliable, so that they can materialize its plan to grow OEM and vendor footprints 45% every year successfully.

2.2 Project Objective

The project is focused on developing international supply chain strategies because supply chain costs (transportation and inventory costs) are a big portion of the costs associated with the Honeywell's AP sourcing and manufacturing. However, the project is not limited to the case of Honeywell but is aimed at developing generalized global supply chain strategies and models based on the specific examples of Honeywell. There are four primary objectives set by the project team.

- Since Honeywell Aerospace has recently started a manufacturing transition to the AP region, there has been lack of standard guidance that can be used when to establish a new supply chain network associated with expansion to a new international region. The first goal of the project is to provide a general framework for the company for setting up a new supply chain network by addressing different interests and concerns of the logistics and operations team members.
- With the general framework established, Honeywell's status quo AP supply chain network will be evaluated and improvement opportunities will be identified. The second goal of the project is to assess different improvement opportunities with relevant models. The opportunities will not only bring short-term savings but also make supply chain network more reliable for future growth.
- Performing assessment of the different improvement opportunities of Honeywell will offer chances to do case studies for the general framework. The third primary goal of the project is to better understand general structure of the trade-offs of the different supply chain options through Honeywell case studies.

- Once the best opportunities are selected, the opportunities will be transferred to relevant stakeholders. The project team and stakeholders will prepare for implementation of the solutions. The fourth goal of the project is to address change management issues such as organizational challenges and communication issues for seamless implementation.

3 Globalization and Global Logistics Literature Review

Several articles helped to understand the challenges of globalization and the strategic importance of global logistics prior to developing international supply chain strategy to support global sourcing and manufacturing. Rosenfield (Rosenfield Donald, 1996) pointed that global manufacturing presents a series of challenging management problems that are similar, but also very different from, traditional operations management problems in logistics and manufacturing. Similar to traditional manufacturing, there are traditional trade-offs among transportation and manufacturing cost and service. There is also a range of other issues such as taxes and duties, local presence, and local content restrictions, and most importantly, exchange rate uncertainty. Fawcett (Fawcett Stanley, 1990) focused more on the logistics challenges and the importance of logistics in global manufacturing throughout his research. Fawcett examined the emphasis placed on logistics issues by 228 firms in the decision to establish foreign production operations in Mexico's maquiladora industry. Following this finding, Fawcett (Fawcett Stanley, 1992) identified logistics' role in global manufacturing in his subsequent article. He especially emphasized that logistics provides a fundamental mechanism for managing the increase environmental uncertainty of global manufacturing. According to Fawcett, effective use of logistics strengthen the firm's ability to respond not only to lead time uncertainty in longer international supply lines but also to other types of uncertainty, such as currency valuation and political instability. This is because if a company both produces and markets in a variety of countries, and has established an effective and reliable logistics system, management increases flexibility in deciding how to match supply and demand to overcome unfavorable fluctuations in exchange rate and short-run political risks and labor disputes. Fawcett also listed the techniques and practices that can be used to make more flexible international logistics less vulnerable to uncertainty. See the following list.

- Buying and shipping sourced items in container lot sizes on a periodic or systematic schedule.

- Greater use of air freight for regular shipments.
- Increased use of intermodal transportation including sea-air and double stack.
- Developing partnership relationships with providers of transportation services.
- Developing partnership relationships with domestic and foreign suppliers of sources components.
- Reliance on third-party transportation companies.
- Use of local third-party warehousing to buffer global and JIT purchasing.
- Use of advanced information systems including EDI to track and/or expedite shipments.
- Pre-clearance through customs.

Shapiro (Shapiro Roy, 1984) pointed that companies can use logistics system to gain competitive advantage. For the companies focusing on product innovation, faster and flexible distribution system is required. For the companies who want to compete on costs, they need to align their logistics strategy with their operational policy to make cheaper supply chain. As companies become more global, the role of logistics in enhancing those competitive advantages becomes more significant.

4 Methodology

The project methodology followed by five steps approach: 1. Data gathering and problem definition, 2. Improvement opportunity identification, 3. Analysis of the improvement opportunities, 4. Implementation preparation, 5. Implementation.

- 1) Data gathering and Problem definition: This step gathers data required to understand the status quo of the Honeywell's AP logistics network as well as its general logistics practices. Gathered data includes the origin and destination pairs, annual shipping volume, shipping frequency, spend on the logistics, customs clearance practice, freight forwarders being used, and ordering policy of each site. At the same time, during the step 1, a general framework to help to make logistics decisions is developed through the interest and concerns of the different groups and teams. This decision framework will be discussed in the Chapter 5 of the thesis.
- 2) Improvement opportunity identification: The hypothetical options that can address the issues defined through the step 1 are identified in the step 2. The general decision framework developed in the step 1 can help to come up with the hypothetical options and to figure out the trade-offs of each option. Chapter 5 contains the issues and improvement opportunities identified.
- 3) Analysis of the improvement opportunities: In the step 3, the opportunities identified in the step 2 are analyzed in both of quantitative and qualitative ways. In the quantitative analysis, trade-offs of each option are optimized by relevant modeling and calculations, which in turn shows the best possible savings of the option. In the thesis, the actual Honeywell's figures are not used. But those used in this thesis are the figures that represent the current Honeywell's situation and also well represent how different factors affect the optimization of trade-offs. The opportunities will be assessed by qualitative analysis as well. The analysis will be discussed from the Chapter 6 through the Chapter 9 in the thesis.
- 4) Implementation preparation: In order to get the best option implemented smoothly, preparation should be performed. First, the project team finds the stakeholders who should be involved in the implementation process and explains rationale behind the options. Connecting the stakeholders each other is also important. Documents are created to

communicate the improvement plan effectively with different stakeholders. In the thesis, the organizational analysis and challenges in communication with stakeholders in the other country will be discussed in Chapter 10.

- 5) Implementation: With a proper implementation plan, the chosen options are implemented. The project team is in charge of facilitating the implementation.

5 General Decision Framework for a New Supply Chain Network Establishment

5.1 Overview of Supply Chain Costs (Total Landed Costs)

Supply chain costs (total landed costs) defined as the major cost factors associated procuring, moving and storing materials between suppliers' sites and the company's manufacturing sites. (Feller Brian, 2008, pp. 15) Those major costs are mainly purchasing costs and logistics costs. Logistics costs can be broken down into transportation, inventory, and other costs. Transportation costs include fixed, variable, and fuel surcharges and inventory costs include cycle stock, pipeline inventory, and safety stock holding costs. In the other cost category, there are customs brokerage fees, duties, and taxes. Figure 2 presents the cost breakdown. To minimize the logistics costs, two decision points need to be optimized: one is logistics decisions and the other is ordering and inventory decisions. See Figure 3 to understand the dynamics between logistics decisions, ordering decisions, and required data to calculate the associate costs of decisions. This diagram is the basis of the cost optimization calculations performed throughout this thesis.

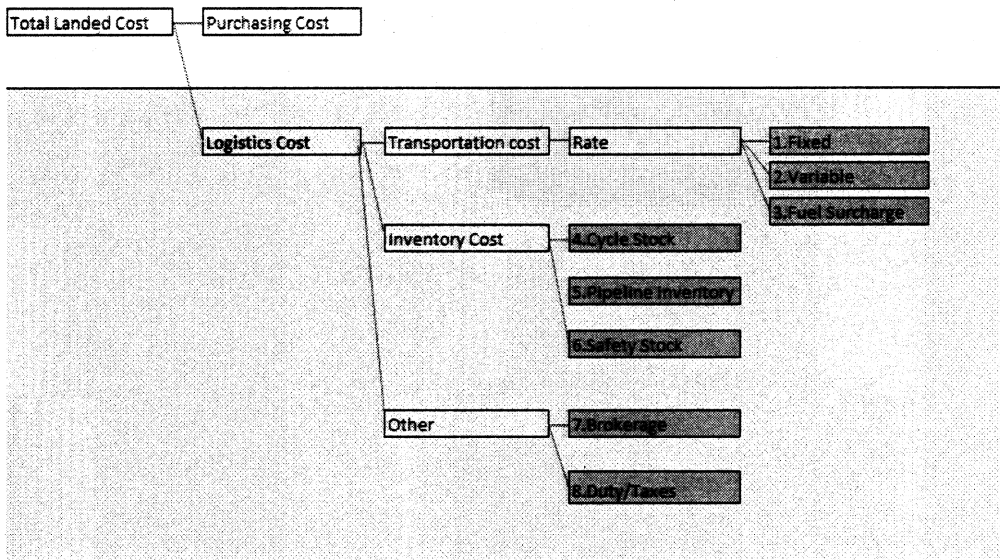


Figure 2 Supply Chain Costs (Total Landed Costs) Breakdown

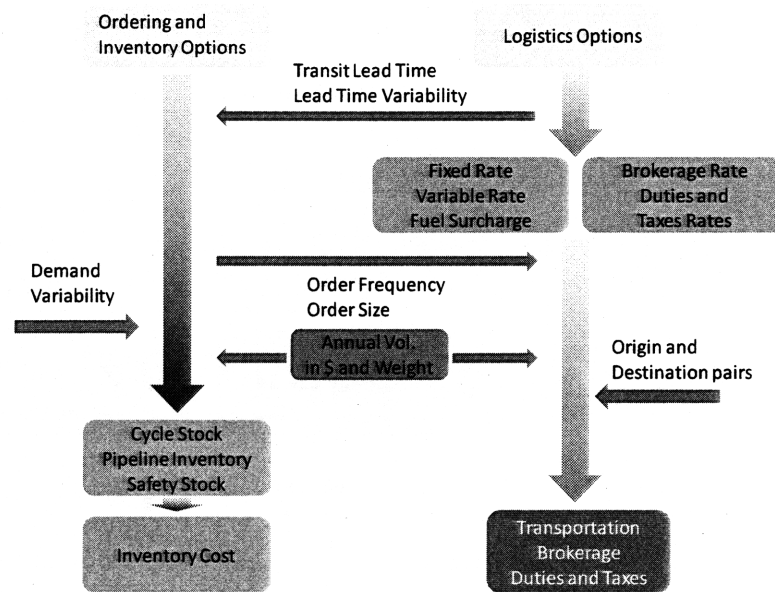


Figure 3 Diagram for Dynamics of Logistics Costs

5.2 General Supply Chain Decision Framework

As noted in Chapter 2, the project started with gathering relative decision points to provide a generalized decision framework that guides decision making in establishing a new supply chain and logistics network. The framework shows detailed description of the decisions and associated trade-offs that logistics managers need to consider. By interviewing people at site, different concerns were gathered and those concerns were converted to the general decision points. For the logistics options, Fawcett's 10 techniques (Fawcett Stanley, 1992) introduced in the Chapter 3 helped to group the different options. Figure 4 and Figure 5 present ordering and inventory decision framework and logistics decision framework respectively.

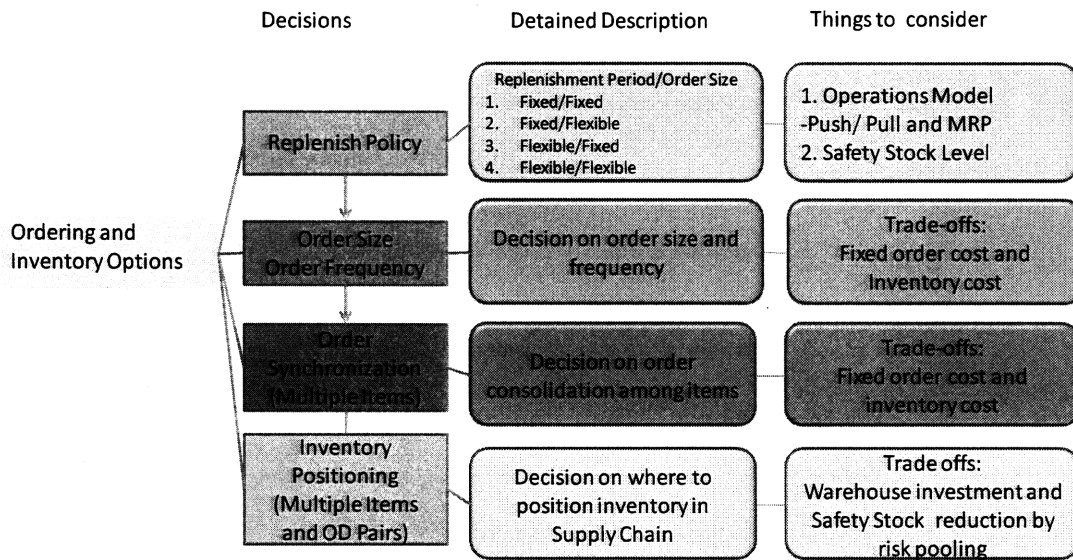


Figure 4 Ordering and Inventory Decisions Framework

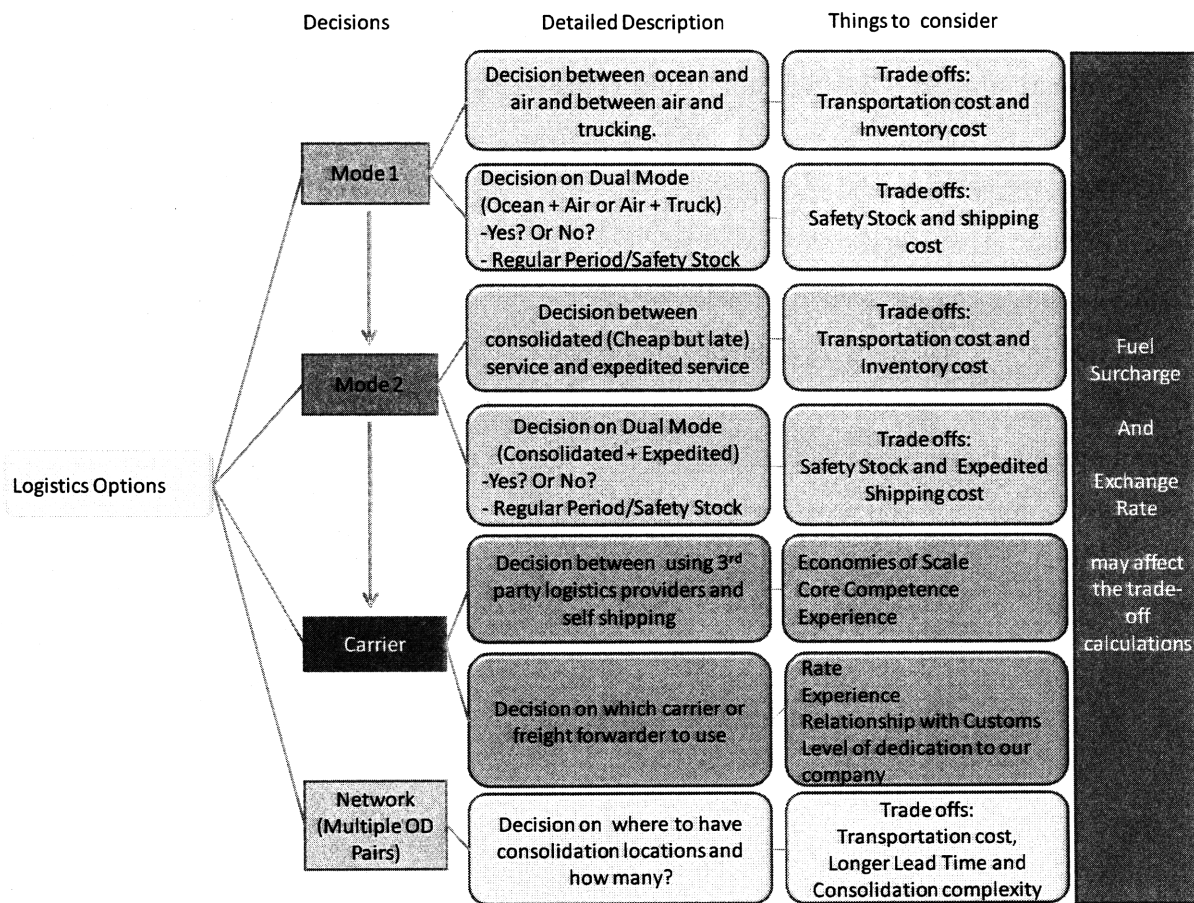


Figure 5 Logistics Decisions Framework

5.3 Issues in Honeywell's AP Supply Chain Network and Chapter Introduction

Analysis of Honeywell's current AP logistics practices identifies several issues. These include the following: 1. Shipment (order) frequency from each origin is high due to high mix of goods, 2, only air shipping mode has been used, 3, there are more than 50 origins spread around the US with low volume shipment, and 4, the percentage of expedited shipments is high due to lack of guidance.

To address these issues, the project team developed hypotheses that can improve Honeywell's current Asia Pacific logistics performance. The hypotheses associated with each issue follow. Issue 1 can be resolved by making a proper order size and consolidating orders. By consolidating orders, for example one order per week for each supplier, the fixed order cost will be saved while the inventory will increase due to the early orders placed to meet the once a week regular order day. Chapter 6 shows the detailed calculation and optimization model for the order consolidation. Issue 2 suggests exploring ocean shipping and Chapter 7 analyzes ocean shipping. Chapter 7 also provides the ocean and air dual mode calculations. Issue 3 implies the opportunity of optimizing network by having consolidation locations rather than shipping directly from point to point. Chapter 8 explains trade-offs of the network optimization and emphasizes the importance of collaboration with 3rd party logistics providers in international logistics. Issue 4 tells that a guideline is needed in deciding when to use consolidated service and expedited service. Chapter 8 provides the guideline for the decision on when to use consolidated service and expedited service. Chapter 9 explores the possibility to buy materials from the US supplier's warehouses in China. Chapter 9 also contains a study on Chinese import duties. Chapter 10 covers the organization and communication related challenges that the project team faced over the course of the project. It analyzes the challenges using three lenses: statistical, cultural and political.

6 Opportunity 1 - Order Synchronization and Shipment Consolidation over Time

6.1 Overview of ABC Approach and EOQ calculation

Honeywell categorizes its materials into three different groups, based on the percentage of the annual purchasing value of a specific material out of total annual material costs. (ABC approach²) Each category follows different replenishment plans. The materials in the group A have shorter replenishment times than the materials in the group C have. Honeywell tries to optimize the order size by having three groups instead of doing Economic Order Quantity (EOQ) calculations³ for each material.

Both the ABC approach and EOQ calculation aim at optimizing the trade-offs between fixed ordering costs and storage costs. Fixed transportation costs can be considered as one of the fixed ordering costs if transportation is paid by a buyer and inventory holding costs can be an example of the storage costs. As the order size increases, the fixed transportation costs that the company has to pay will decrease. But the inventory holding costs will go up because the average inventory level goes up. An optimal order quantity will balance the fixed ordering costs with storage costs.

6.2 Multiple Items from One Supplier

If a material vendor supplies more than one item, different approach is needed. Honeywell's ABC approach and EOQ calculation addresses how to find the optimal order quantity of each individual material. But there is another optimization opportunity between order synchronization and the inventory costs if a vendor supplies more than one item. Assume that one of Honeywell's material vendors supplies material M and F, both of which fall in the group A. The MRP system notifies material planners that one week amount of material M should be ordered today and one week amount of material F should be ordered tomorrow. Ordering one week amount of the material M today will optimize the trade-offs between the fixed ordering costs and the storage costs if the material vendor supplies only the material M to Honeywell. However, since the material vendor supplies two materials to Honeywell, we can save another fixed ordering cost and packaging cost by

² This is one of the practical ways to reduce inventory. (Simchi-Levi, Kaminsky, Simchi-Levi, Third Edition, pp. 55-56)

³ The classing economic lot size model, introduced by Ford W. Harris in 1915, is a simple model that illustrates the trade-offs between ordering and storage costs. (Simchi-Levi, Kaminsky, Simchi-Levi, Third Edition, pp. 33-35)

consolidating two orders for the material M and F. If the material planner decides to order the material F together with the material M today, the fixed ordering costs will be half while the inventory holding costs will increase but only marginally because Honeywell will carry more inventory of the material F by one day.

Honeywell's order frequency for some of the raw material vendors is very high. If the order timings for different materials from one material vendor are perfectly synchronized, the shortest order interval will be same as the order interval of the class A materials.⁴ Figure 6 shows that the order intervals for 84% of the orders from Dec. 07 to May 08 are less than 7 days. These highly frequent orders are being placed because the orders for different materials are not synchronized but placed whenever MRP system directs to place an order based on the ABC classification. Although the material M and material F's order intervals are one week⁵, the order interval that the vendor sees is shorter than one week because orders for different materials are not synchronized.

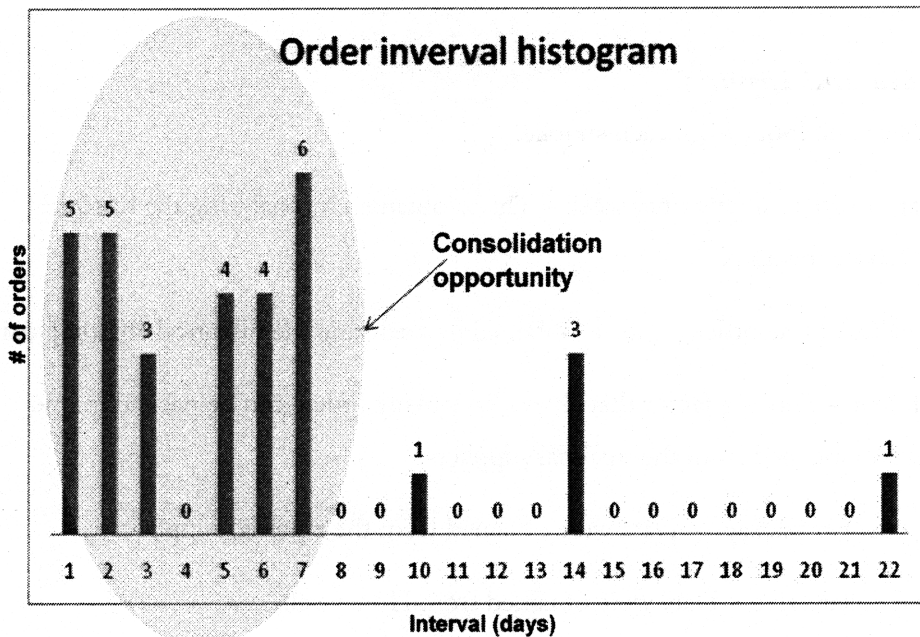


Figure 6 Order Interval Histogram for an Anonymous Material Vendor (Data gathered from Dec. 07 to Mar. 08)

⁴ This is based on the assumption that replenishment period for the group A materials whose order quantity is one week amount is roughly one week. If they order one week amount of a group A material, they don't need to place another order until a week after, if demand uncertainty is not too high.

⁵ Assuming that the order quantity for the class A materials is one week amount.

6.3 Optimization Model

In order to optimize the trade-offs of the order synchronization, the fixed ordering costs and increase in the inventory carrying costs caused by early orders should be calculated. One of the big complaints from some of the material vendors was about complicated and highly frequent packaging. Since aerospace parts has to use the materials in high quality, material packaging instruction requires for shippers to meet high standard of packaging, which in turn requires more expensive packaging. Since Honeywell has to pay the packaging costs, it can be thought as the fixed ordering costs with the assumption that packaging costs for a consolidated shipment is same as that of an individual package. (In reality, it is not the same so a factor that shows how many orders can be packed in one package was used in calculation.) Honeywell seems to have a significant cost saving opportunity in packaging. The following model explains how much Honeywell can save the packaging costs by consolidating orders over time and how much the inventory carrying costs increase as a result of the order consolidation.

6.3.1 Required Data and Input

These are the required data and input from each supplier.

- Average number of orders shipped per week – This is obtained by analyzing the historical shipping data. Denote this as N .
- Average dollar value of one order – This is obtained by analyzing the historical shipping data.
- Consolidation factor – This is a factor that shows how many orders can be packed in one package. Data were obtained from the material suppliers.
- Unit Packaging cost per package – Data were obtained from the material suppliers.
- Annual purchase dollar value – Data were obtained from Honeywell.

6.3.2 Decision Variable

- Consolidation period – If the consolidation period is one week, a buyer will place an order once a week. In reality, buyers will be able to see the material needs for next one week from now in the MRP system and place an order for those materials now.

6.3.3 Calculation

There are two different parts in the cost calculation: Packaging cost and inventory carrying cost calculation.

6.3.3.1 Packaging cost

Currently, one order is packed in one package without consolidation so the number of packages is equal to the number of orders.

- Current annual spend on packaging
= $52 \times N \times \text{Unit Packaging Cost}$, where N is the average number of orders shipped per week.

Consolidation can reduce the number of packages.

- The number of orders shipped per consolidation period
= $N \times \text{consolidation period as number of weeks}$
- The number of packages per consolidation period
= $\frac{\text{The number of orders shipped per consolidation period}}{\text{Consolidation factor}}$, This always should be rounded up.
- The new annual spending on packaging
= The number of packages per consolidation period $\times \frac{52}{\text{Consolidation period}}$ \times unit packaging cost

6.3.3.2 Inventory carrying cost ⁶

By the order synchronization, some of the orders will be placed earlier than before but the interval between orders is same as before. Therefore, there will be an increase in cycle stock because of early orders, but there will be no change in the pipeline inventory. Also the calculation assumed that safety stock will not be adjusted for the early orders.

Assuming that the orders are uniformly distributed over time, average cycle stock increase can be calculated as follows.

⁶ Anupindi, Chopral, Deshmukh, Mieghem Van, Zemel, *Managing Business Process Flows: Principles of Operations Management*, Second Edition, pp. 141-143

- Cycle stock before consolidation =
Annual purchase dollar value $\times \frac{1}{N \times 52 \times 2}$
- Cycle stock after consolidation =
Annual purchase dollar value $\times \frac{\text{Consolidation period as numer of weeks}}{52 \times 2}$
- Cycle stock increase = Cycle stock after consolidation - Cycle stock before consolidation
= $\frac{\text{Annual purchase dollar value}}{52 \times 2} \times \left(\text{Consolidation period as number of weeks} - \frac{1}{N} \right)$
Cycle stock carrying cost increase = Cycle stock increase \times Annual Cost of Capital

6.3.4 Result and analysis

Figure 8 is a snapshot of the excel spread sheet for the optimization model. The figures in this section are not real data. As the consolidation period increases, the fixed ordering cost savings tend to increase until consolidation can't reduce the number of packages any more. This is when the the number of packages during the consolidation period becomes larger than the consolidation factor. If the packaging cost is a perfectly fixed cost, however, which means the consolidation factor is infinite, the packaging cost will continuously decrease as the consolidation period increases. In contrast, the inventory carrying cost increases as the consolidation period increases. See Figure 7 to see these trends.

There are other factors that affect the total possible savings.

- The number of orders – More frequent orders indicates better chance to save the fixed ordering costs.
- Consolidation factor – Greater consolidation factor indicates more opportunity to reduce the number of packages by consolidation.
- The unit packaging cost (fixed ordering cost) – Higher unit packaging cost results in greater savings.
- The total annual purchase value – Higher annual purchase value will result in higher inventory carrying cost.

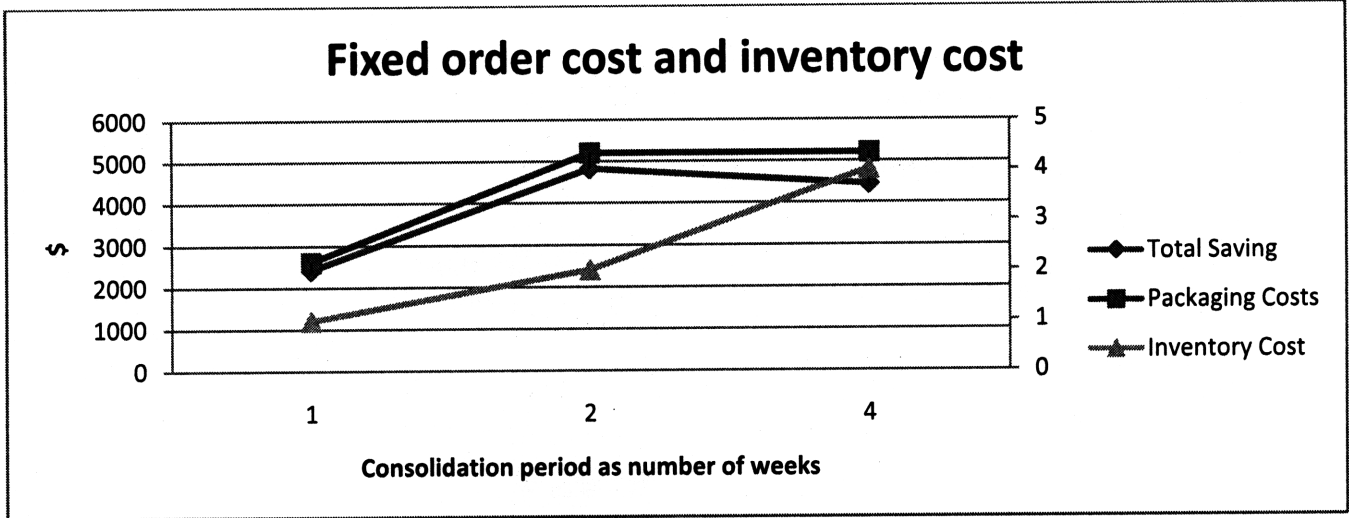


Figure 7 Fixed order cost and Inventory cost Vs. Consolidation period

Effect of order consolidation

Fixed Order Cost Saving (Packaging cost)

Input

# of current annual packages	78 Packages
Consolidation period (Decision Variable)	1 wk(s)

New Packaging Cost

The number of orders per consolidation period	1.5 orders
New # of annual packages	52 Packages

Current package cost spending	\$ 7,800.0
New package cost spending	\$ 5,200.0

Annual SAVING	\$ 2,600.0
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Inventory Carrying Cost Increase

Input

Cost of Capital	10% % / year
Annual purchase	\$ 200,000.0 \$ / year

Calculation

Inventory Increase (Cycle stock only)	641.03 \$
---------------------------------------	-----------

Annual Inventory holding cost increase	\$ 64.1 \$
---	-------------------

NET IMPACT	\$ 2,535.9 Gain
-------------------	------------------------

Figure 8 Trade-off between Fixed order cost and Inventory cost

Table 1. Facts from historical shipment data

Item	Value	Unit
Packaging cost per package	\$ 100.0	\$
Consolidation factor*	5	# of orders in one package
Total # of annual orders	78	Orders
# of orders per week	1.5	Orders

Table 1 Inputs for the Optimization Model

In case of Honeywell, the order synchronization turned out to save not as much as expected because the number of annual packages was not big.

7 Opportunity 2 - Ocean Shipping and Ocean and Air Dual mode

7.1 Ocean Shipping

7.1.1 Overview

If only air shipping has been used for trans-pacific shipments, ocean shipping could be an option that can reduce transportation costs. Honeywell Aerospace has used only air shipping for its trans-pacific shipments. To accurately estimate the amount of savings that ocean shipping can generate, we have to understand quantitative trade-offs between transportation costs and inventory costs.

Ocean shipping is generally cheaper than air shipping, but the lead time of ocean shipping is longer and more volatile than that of air shipping. This implies that supply chain with ocean shipping is not flexible enough to react to demand fluctuations quickly. In order to cover the longer shipping lead time of ocean shipping, which in turn results in higher possibility of stock-out, we have to increase safety stock. Pipeline inventory will be increased as a result of the longer shipping lead time as well. In other words, longer shipping lead time results in inventory holding cost increase. Only in the case that the transportation cost savings made by ocean shipping exceeds the inventory holding cost increase, ocean shipping can be used.

7.1.2 Ocean vs. Air comparison

As mentioned above, in order to make a choice between air and ocean shipping, both of inventory and shipping cost calculations for each of ocean and air shipping are necessary. Before setting up an excel spread sheet to perform the calculations, we need to understand how shipping frequency affects inventory level and transportation costs. As shipping frequency decreases, the transportation cost becomes less expensive because of economies of scale of ocean shipping. But the safety stock will increase as a result of less frequent shipping. In contrast, if we ships more frequently, safety stock will decrease, which reduces the inventory carrying costs. We can optimize the trade-offs between the transportation costs and inventory costs by changing the ocean shipping frequency.

7.1.3 Ocean shipping Optimization Model

7.1.3.1 Required data, units and notations

Data	Unit	Notation
Daily average demand of item i (weight)	Kg	μ_i
Daily demand variability of item i (weight)	Kg	σ_i
Shipping Lead Time	Day	L
Air Shipping Lead Time	Day	L1
Ocean Shipping Lead Time	Day	L2
Fixed Cost of Air and Ocean shipping	\$ per shipment	No notation
Variable Cost of Air and Ocean Shipping	\$/Kg	
z Value Associated with Desired Service Level	N/A	z
Weight to Value Conversion Ratio of item i	\$/Kg	α_i

Table 2 Required Data, their Units and Notations for Ocean Shipping
Note: The same notations are used throughout this Chapter.

7.1.3.2 Decision variable

- Ocean shipping frequency –Shipping frequency is a decision variable. Before comparing the ocean shipping costs to air shipping costs, we need to find an ocean shipping frequency that optimizes the trade-off between the ocean shipping transportation cost and safety stock holding cost. The ocean shipping frequency is denoted as f and ocean shipping interval is denoted as R . If review period for each item from its ABC classification is shorter than R , those items have to sit in the port until next container departs. Therefore, review period is typically a multiple of R depending on its ABC classification.

Ocean Shipping Interval	Day	R
Ocean Shipping Frequency	1/Day	$f = 1/R$

Table 3 Decision Variable of the Ocean Shipping Optimization Model

With the required data and ocean shipping frequency, inventory level and its associated carrying cost as well as the ocean shipping cost can be calculated.

pipeline inventory is the inventory that is in transit and safety stock is a stock that's set aside to cover demand variability during the period from when an order is placed until the next order arrives (L+R). Therefore, total average inventory at a given moment is:

- Average Inventory = Cycle Stock + Pipeline inventory + Safety Stock

$$\frac{\mu_i R}{2} + \mu_i \times R \times \frac{L}{R} + z \times \sigma_i \times \sqrt{L + R} \quad ^9$$

Therefore, Total average inventory across the items is:

- Total Average Inventory Level = $\sum_i \left(\frac{\mu_i R}{2} + \mu_i \times L + z \sigma_i \sqrt{L + R} \right)$

In the formula above, R is the decision variable. As shipping frequency goes up, R decreases because R is equal to $\frac{1}{f}$. We can find from the formula the fact that the total average inventory level goes up as R goes up.

Now, we can calculate the inventory carrying cost associated the inventory level. The weight to value conversion ratio (α_i) will convert the inventory level in weight to dollar value. Honeywell uses 10% as firm's annualized cost of capital. Therefore, the annual inventory carrying cost is 10% of the total average inventory value.

- Total Inventory Carrying Cost =

$$\sum_i \left(10\% \times \alpha_i \times \frac{\mu_i R}{2} + \mu_i L + z \sigma_i \sqrt{L + R} \right)$$

If there is enough information, other inventory costs such as warehouse cost and obsolesce cost need to be taken into account.

7.1.3.4.2 Shipping Cost (Transportation cost) Calculation

To calculate shipping (transportation) cost, we need to look at the shipping cost structure. Below is an example of the shipping cost structure provided from one of the ocean freight forwarders. This is the cost for the route from the US West coast to Shanghai, China.

⁹ *Designing and Managing the Supply Chain*, Simchi-Levi, Kaminsky, Simchi-Levi, Third Edition, pp. 46.

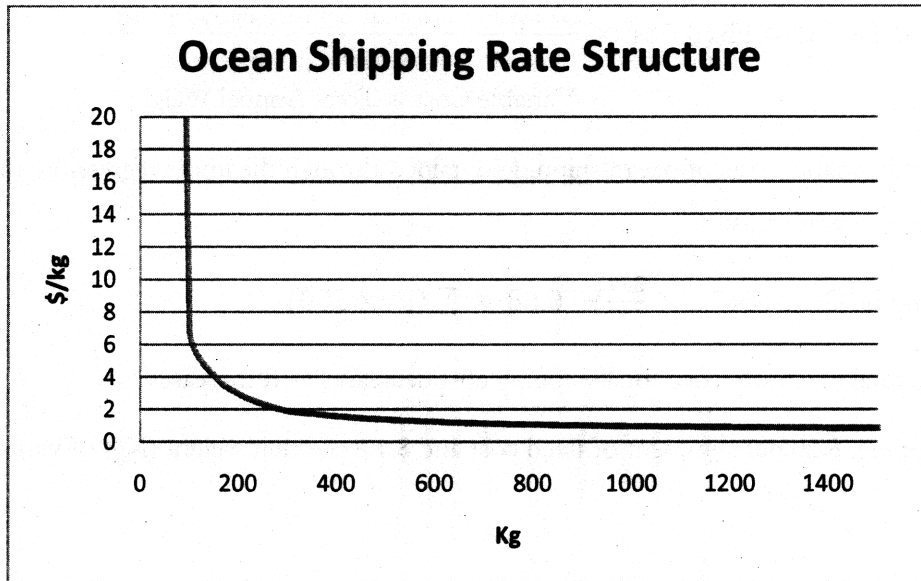


Figure 10 Ocean Shipping Rate Structure (from an anonymous ocean freight forwarder)

As shown in Figure 10, ocean shipping requires a high fixed cost which indicates the fact that if R becomes higher, so that the volume per shipment becomes greater, the total shipping cost becomes cheaper. This cost structure also implies that the more annual shipping volume, the cheaper to use the ocean shipping. By performing a linear regression of the cost against the shipping weight, the fixed cost and variable cost can be obtained. Figure 11 illustrates the regression result.

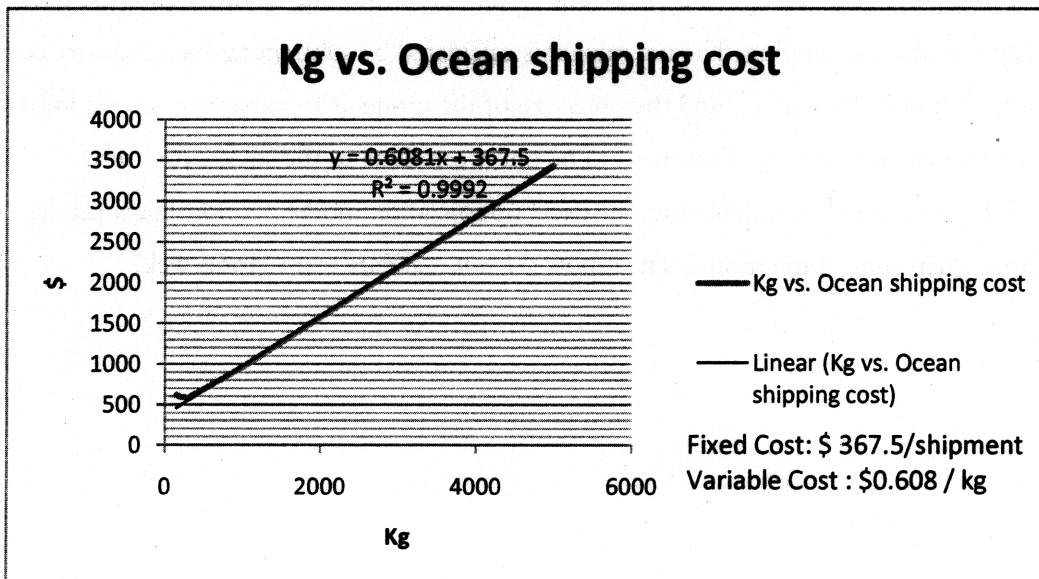


Figure 11 Fixed and Variable costs Calculation

- Total Shipping Cost = Fixed Cost $\times \frac{\text{The number of annual business operating day}}{R}$
+ Variable Cost \times Total Annual Weight

Using the fixed and variable costs of ocean shipping obtained through the linear regression, the total shipping cost can be rewritten as:

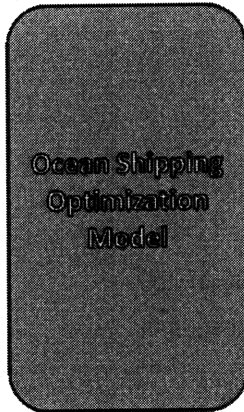
$$\text{Total Shipping Cost} = 367.5 \times \frac{350}{R} + 0.68 \times \sum_i(\mu_i \times 350)$$

In contrast to the total inventory cost, total shipping cost decreases as R increases.

In case of air shipping, \$ 20 per shipment of fixed cost and \$ 1.8 per unit weight (Kg) of variable cost were used.

7.1.3.5 Excel Model Development

The excel optimization model has four different parts: Input, Decision Variable(s), Result, and Calculation. The inputs are described in the beginning of this section. See Table 2. The decision variable (ocean shipping interval, R) is set as an integer variable. In reality, the shortest ocean shipping interval is half of a week. Therefore, if R is one, that corresponds to half of a week. The actual ocean shipping interval can be calculated by multiplying R by half of a week. A bound constraint for the R was imposed because R should be larger than 0 but lower than 104, which is the total number of weeks per year multiplied by two. The result part shows the net impact of the ocean shipping compared to the air shipping. The net impact is calculated by subtracting the inventory cost increase from the shipping cost savings and the objective of the model is to maximize the net impact. The shipping interval for air shipping is assumed to be one week. Due to the square root term (safety stock) of the inventory cost calculation, the excel optimization model is a non-linear model. See Figure 12 for a snap shot of the model. The inputs are not real data from Honeywell.



Inputs

Category	Description	Value	Unit
Daily Demand	Mean	500	Kg
	Variability (sigma)	100	Kg
Transit Lead Time	Ocean Lead Time	25	Days
	Air Lead Time	2	Days
Shipping Rates	Fixed Ocean Shipping Rate	386	\$ per shipment
	Variable Ocean Shipping Rate	0.2	\$/kg
	Fixed Air Shipping Rate	20	\$ per shipment
	Variable Air Shipping Rate	1.8	\$/kg
Others	Desired Service Level	95%	%
	Weight to Value conversion ratio	50	\$/Kg
	Z level	1.644854	
	Cost of Capital	10%	%/yr

Decision Variable(s)

Description	Value	Unit
Ocean Review Period (R)	3	0.5 wks

Result

NET IMPACT	\$	48,739.31	GAIN
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Figure 12 Snap Shot of the Ocean Shipping Optimization Model

7.1.3.6 Result and Analysis

The optimization model estimated that the net impact of changing from air shipping to ocean shipping is \$ 48,739 of annual savings when the mean and variability of the demand is 500 Kg and 100 Kg respectively. The optimized review period (=R) is three, which means one and a half week.

The optimization model also can tell us what other factors can affect the net impact and how much. The mean and variability of demand, the transit lead time and shipping rate differences between ocean and air shipping and the weight to value conversion ratio are those factors. Sensitivity analysis can show that the demand mean and the net impact of ocean shipping have a positive relationship, whereas the variability and the net impact have a negative relationship. Both of the mean and the variability have negative relationship with R. What is useful to the logistics manager and production planners is at what weight to value conversion ratio ocean shipping becomes cheaper for a given the mean and variability of demand. With the optimization model, the break-even weight to value conversion ratio at a given demand mean and variability can be found. The author calls this break-even weight to value ratios as weight to value frontier. Figure 13 shows the example of the weight to value frontier. Upper left side of the frontier is the region where air shipping is cheaper and right bottom side of the frontier is the region where ocean shipping is cheaper.

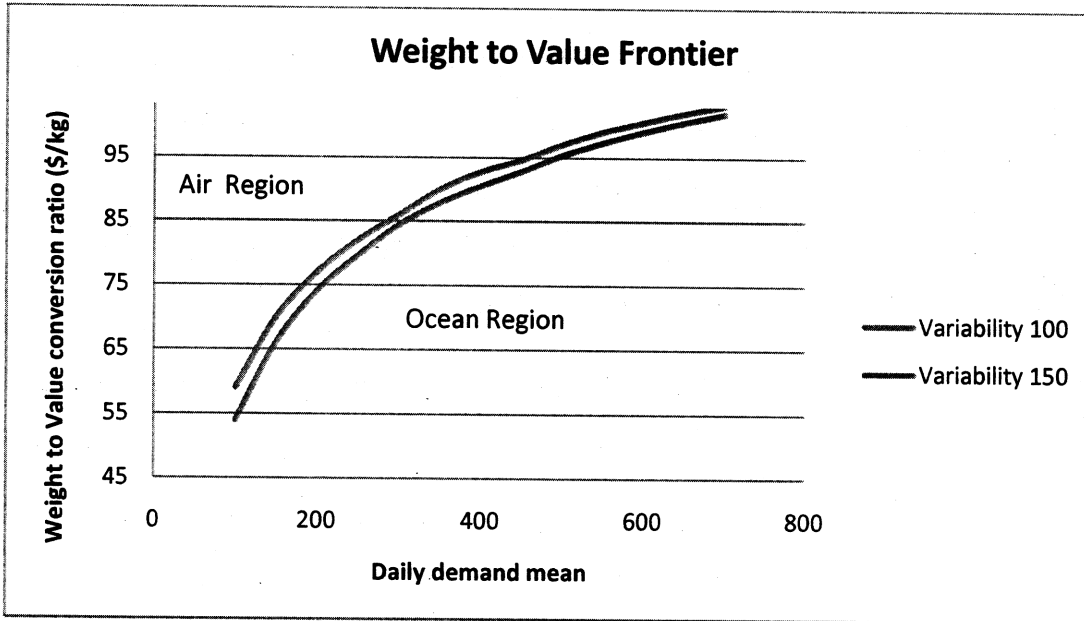


Figure 13 Example of Weight to Value Frontier

7.1.3.7 Model Extension for Multiple items

The excel model developed in the previous section can be extended to be used in a case of multiple items by defining two different weighted averages of weight to value conversion ratio.

In case of one item, the excel model calculate the inventory carrying cost as follows:

$$\text{COC} \times \alpha_i \times \left\{ \mu_i \left(\frac{R}{2} + L \right) + z\sigma_i \sqrt{L + R} \right\}$$

If there are two items, the total inventory carrying cost for two items should be calculated as:

$$\text{COC} \times \left\{ \alpha_1 \times \left(\mu_1 \left(\frac{R}{2} + L \right) + z\sigma_1 \sqrt{L + R} \right) + \alpha_2 \times \left(\mu_2 \left(\frac{R}{2} + L \right) + z\sigma_2 \sqrt{L + R} \right) \right\}$$

For notations, please refer to Table 2 in Section 7.1.3.1.

This expression can be rewritten as

$$\text{COC} \times \left\{ (\alpha_1 \mu_1 + \alpha_2 \mu_2) \left(\frac{R}{2} + L \right) + (\alpha_1 \sigma_1 + \alpha_2 \sigma_2) (z\sqrt{L + R}) \right\}$$

Define $\mu_{1,2}$ as $\mu_1 + \mu_2$ and $\sigma_{1,2}$ as $\sqrt{\sigma_1^2 + \sigma_2^2 + \text{COV}(1,2)}$.¹⁰

Also Define γ as $\frac{\alpha_1\mu_1 + \alpha_2\mu_2}{\mu_{1,2}}$ and define θ as $\frac{\alpha_1\sigma_1 + \alpha_2\sigma_2}{\sigma_{1,2}}$

Using γ and θ , the total inventory carrying cost for two items can be rewritten as,

$$\text{COC} \times \left\{ \gamma \times \mu_{1,2} \left(\frac{R}{2} + L \right) + \theta \times \left(z\sigma_{1,2}\sqrt{L + R} \right) \right\}$$

For m items, $\gamma = \frac{\alpha_1\mu_1 + \alpha_2\mu_2 + \dots + \alpha_m\mu_m}{\mu_{1,2,\dots,m}}$ and $\theta = \frac{\alpha_1\sigma_1 + \alpha_2\sigma_2 + \dots + \alpha_m\sigma_m}{\sigma_{1,2,\dots,m}}$, where $\mu_{1,2,\dots,m}$ is the mean of the sum of demands of m items and $\sigma_{1,2,\dots,m}$ is the standard deviation of the sum of demands of m items.

Therefore, the excel model can be used for the multiple items with the mean weighted average of the weight to value conversion ratio (γ) and standard deviation weighted average of the weight to value conversion ratio (θ). The inputs (mean and standard deviation) of the model in this case are the mean and standard deviation of the sum of demands of multiple items.

The shipping cost calculation for one item can return the shipping cost for multiple items, if the entered mean is the mean of the sum of demands.

¹⁰ $\mu_{1,2}$ and $\sigma_{1,2}$ are mean and standard deviation of the sum of two independent random variables respectively.

7.2 Dual shipping mode- Combination of Air and Ocean

7.2.1 Overview

One of the main factors that made ocean shipping look less attractive is increased safety stock due to longer transit lead time of ocean shipping. If we can reduce safety stock, ocean shipping will look more attractive. One of the ways to reduce safety stock is to use dual shipping mode, which means a combination of the longer transit lead time shipping (ocean) and shorter transit lead time (air) shipping.

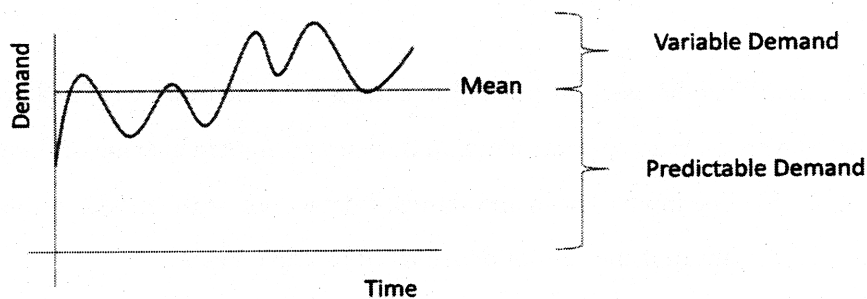


Figure 14 Demand Variability (Feller Brian, 2008)

As shown in Figure 14 above, demand can be divided into two different parts: variable demand and predictable demand. In case of the single ocean mode as provided in the previous section, the variable demand is covered by safety stock. In the dual mode, however, instead of having safety stock to handle the variable demand, we can use air shipping to meet the variable demand. There is obviously a trade-off between air shipping cost increase and safety stock carrying cost decrease in the dual mode. Following optimization model shows details of the trade-off.

7.2.2 Dual Mode Optimization Model

7.2.2.1 Required data and Input

- Mean and variability of demand in weight
- Fixed and variable cost of ocean shipping and air shipping
- Ocean shipping and air Shipping lead time
- Desired Service Level

- Weight to Value Conversion ratio

Please see Table 2 for the notations. The notations defined in Table 2 will be used throughout this chapter.

7.2.2.2 *Decision Variables and the Objective of the Model*

There are two decision variables in this model: Review period R and Safety Stock SS. The objective of the model is to optimize the trade-off between air shipping cost increase and safety stock carrying cost decrease by searching for the best review period R and Safety Stock SS combination. The model is designed to maximize the net impact of the dual mode compared to the single ocean shipping mode.

7.2.2.3 *Calculation*

The dual mode reduces the safety stock carrying cost, while it requires additional air shipping cost. The cycle stock, pipeline inventory and ocean shipping cost for the dual mode and the single ocean mode are also different. Therefore, the net impact of dual mode, that is, the savings from the dual mode compared to the single ocean mode is:

- Savings from safety stock reduction – Additional air shipping costs
 + Cycle stock decrease + Ocean shipping cost decrease + Pipeline inventory decrease

The hardest part is the additional air shipping cost calculation. In order to calculate that, there are two values that need to be calculated first:

- We need the probability that stock-out can happen during one cycle, so that the air shipping will be used. This probability is a function of safety stock level that we carry. Denote this probability as $P(T)$.
- We also need the average volume of air shipping. This is the average weight per air shipping if air shipping is used during the cycle.

7.2.2.3.1 *Probability of air shipping per cycle, $P(T)$*

First of all, we need to understand the relationship between the amount of safety stock and the probability of stock-out. A period between when the regular order arrives and L1 (air shipping lead

time) days before the next regular order arrives is denoted as the Period A. During the Period A, once the remaining stock on hand hits air shipping threshold, $\mu_i L1 + z\sigma_i \sqrt{L1}$, materials should be ordered using air shipping. $z\sigma_i \sqrt{L1}$ is the minimal safety stock we should carry to cover demand volatility during the air shipping lead time $L1$. With the minimal safety stock of $z\sigma_i \sqrt{L1}$, the average stock when the new order arrives at the D point in Figure 15 is $\mu_i R + z\sigma_i \sqrt{L1}$. Thus, if the demand during the Period A exceeds $\mu_i R - \mu_i L1$, the remaining stock on hand hits the threshold level, $\mu_i L1 + z\sigma_i \sqrt{L1}$, so a replenishment order should be placed with air shipping. This is denoted as CASE 1. If we have additional safety stock above the minimal safety stock, $z\sigma_i \sqrt{L1}$, let's say we have $z\sigma_i \sqrt{L1} + \beta$ for safety stock, the average stock at the point D is $\mu_i R + z\sigma_i \sqrt{L1} + \beta$. Thus, we can wait until the demand during the Period A reaches $\mu_i R - \mu_i L1 + \beta$. This is denoted as CASE 2.

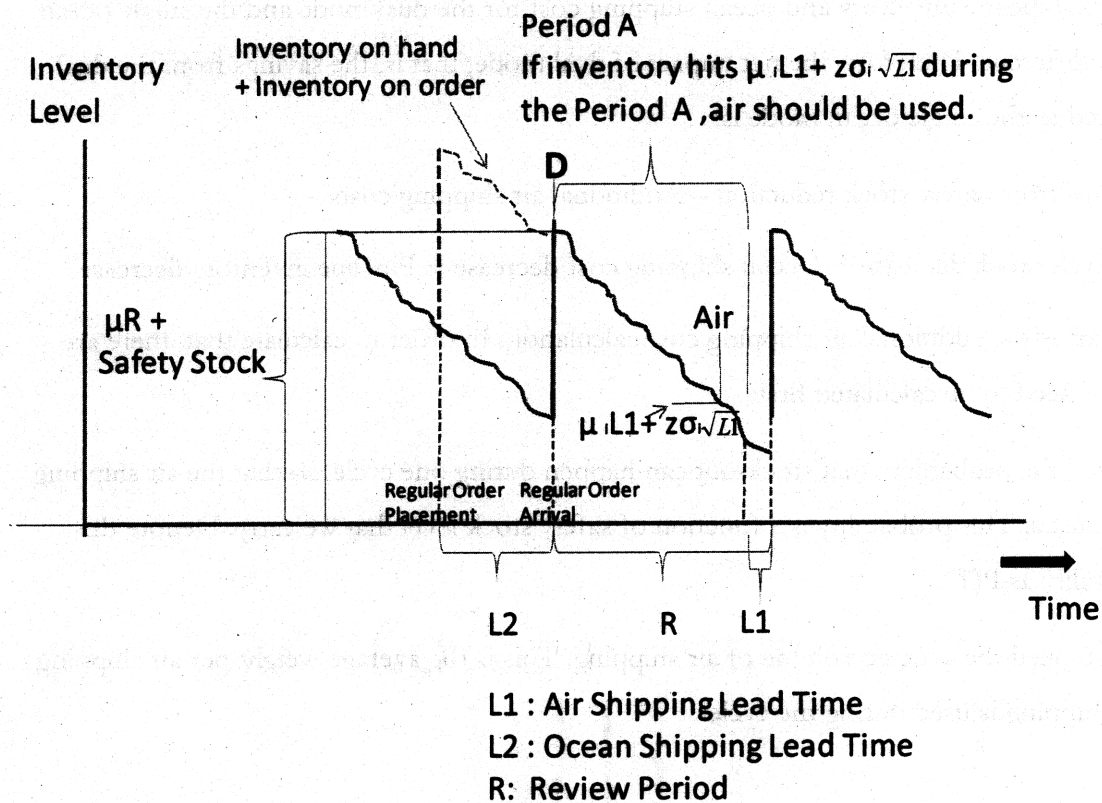


Figure 15 Dual mode

Assuming that daily demands are independent, the mean for the accumulated demand during the Period A is $\mu_i(R - L1)$ and standard deviation is $\sigma_i\sqrt{R - L1}$.¹¹ Assuming the demand distribution follows normal distribution, the demand distribution during the Period A is shown at Figure 16 and Figure 17.

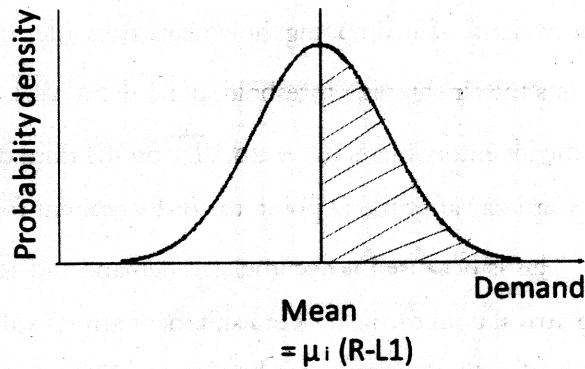


Figure 16 Probability Density Function for the CASE 1

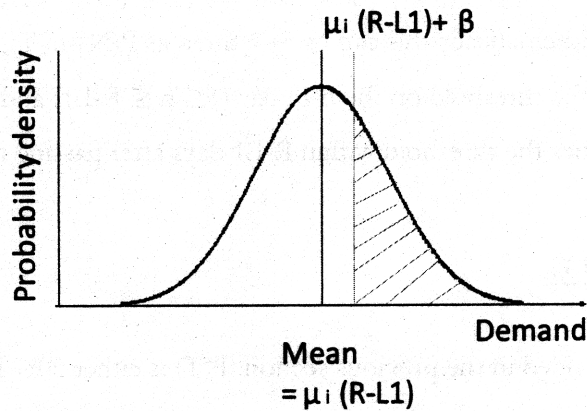


Figure 17 Probability Density Function for CASE 2

¹¹ $\mu_i(R - L1)$ and $\sigma_i\sqrt{R - L1}$ are mean and standard deviation of the sum of $R-L1$ independent random variables respectively who follow the same normal probability distribution with a mean of μ_i and a standard deviation of σ_i .

The probability to use air shipping during a cycle in the CASE 1 is same as the probability that the demand during the Period A exceeds $\mu_i(R - L1)$, which is the shaded area in Figure 16. The figure shows the probability for the CASE 1 is 50 %. However, for the probability to use air shipping during a cycle in the CASE 2 is same as the probability that the demand during the Period A exceeds $\mu_i(R - L1) + \beta$, which is less than 50%.

7.2.2.3.2 Average Amount (weight) of Air Shipping per Cycle

To calculate the average amount (weight) of air shipping, how many days after the D point (the order arrival day) the inventory hits the air shipping threshold, $\mu_i L1 + z\sigma_i\sqrt{L1}$, needs to be calculated first. For example, if the inventory hits $\mu_i L1 + z\sigma_i\sqrt{L1}$ on the third day after the D point, so that air shipping used on the third day after the D point, the order amount for the air shipping is $\mu_i(R-L1-3) + z\sigma_i\sqrt{R - L1 - 3}$. This is because the accumulated demand and safety stock to cover the period from the air shipping arrival until the next ocean shipment arrives will be ordered using air. In general, if the inventory hits the threshold on n-th day after the D point, the amount of air order on the n-th day should be $\mu_i(R-L1-n) + z\sigma_i\sqrt{R - L1 - n}$.

For the average weight of air shipment calculation, a conditional probability that the inventory hits the threshold on the n-th day after passing the D point given that the air shipping is used during that cycle should also be found. Mathematically this can be re-written as $P(N=n | T)$, where $N=n$ is an event when the inventory hits the threshold on the n-th day ($1 \leq n \leq R-L1$) and T represents an event when the inventory reaches the threshold within $R-L1$ days after passing the D point so that air shipping is used.

$$P(N=n | T) = \frac{P(N=n \text{ and } T)}{P(T)}$$

The calculation for $P(T)$ is provided in the previous section. $P(T)$ is either 50% in the CASE 1 or less than 50% in the CASE 2 depending on the safety stock level being carried. Since event $N=n$ is a part of the event T , $P(N=n \text{ and } T) = P(N=n)$. Therefore,

$$P(N=n | T) = \frac{P(N=n \text{ and } T)}{P(T)} = \frac{P(N=n)}{P(T)}$$

Because $P(N=n)$ means the probability that the inventory on hand reaches the threshold on the n-th day for the first time, $P(N=n)$ is, in others words, $P(N \neq 1 \text{ and } N \neq 2, \dots N \neq n - 1, \text{ and } N = n)$.

The event $N \neq 2$ is a part of the event $N \neq 1$ and similarly, the event $N \neq n - 1$ is a part of the event $N \neq n - 2$. Therefore,

$$P(N \neq 1 \text{ and } N \neq 2, \dots N \neq n - 1, \text{ and } N = n) = P(N \neq n - 1 \text{ and } N = n)$$

According to the fourth law of probability¹²,

$$P(N \neq n - 1 \text{ and } N = n) = P(N \neq n - 1) \times P(N = n | N \neq n - 1)$$

$P(N \neq n - 1)$ can be rewritten as

$P(N \neq n - 1) = \int_{x=0}^{\mu_i(R-L1)} \text{PDF}(x)_{n-1} dx$, where $\text{PDF}(x)_{n-1}$ is a probability density function of the accumulated demand for $n-1$ days. Assuming demand is normally distributed and daily demands are independent each other, $\text{PDF}(X)_{n-1}$ is a normal distribution function with a mean of $\mu_i(n-1)$ and a standard deviation of $\sigma_i \sqrt{n-1}$ (figure 18).

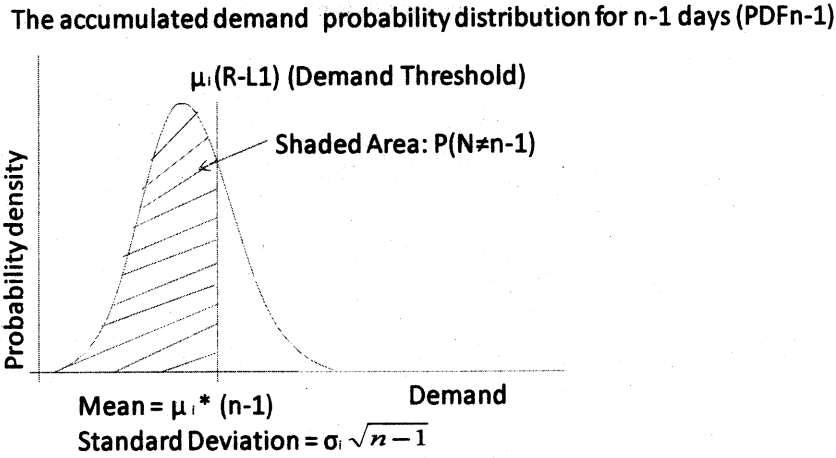


Figure 18 Graphical Explanation of $P(N \neq n-1)$

$P(N = n | N \neq n - 1)$ for Case 1 can be rewritten as

$$P(N = n | N \neq n - 1) = \frac{\int_{x=0}^{\mu_i(R-L1)} \{ \text{PDF}(x)_{n-1} \times \int_{k=\mu_i(R-L1)-x}^{\infty} \text{PDF}(k)_1 \} dk dx}{\int_{x=0}^{\mu_i(R-L1)} \text{PDF}(x)_{n-1} dx}$$

In the equation above, x is the accumulated demand for $n-1$ days.

¹² $P(A \text{ and } B) = P(B)P(A|B)$

Simply replacing $\mu_i (R - L1)$ with $\mu_i (R - L1) + \beta$ will adjust the equation for the CASE 2. See Figure 19 for graphical aid.

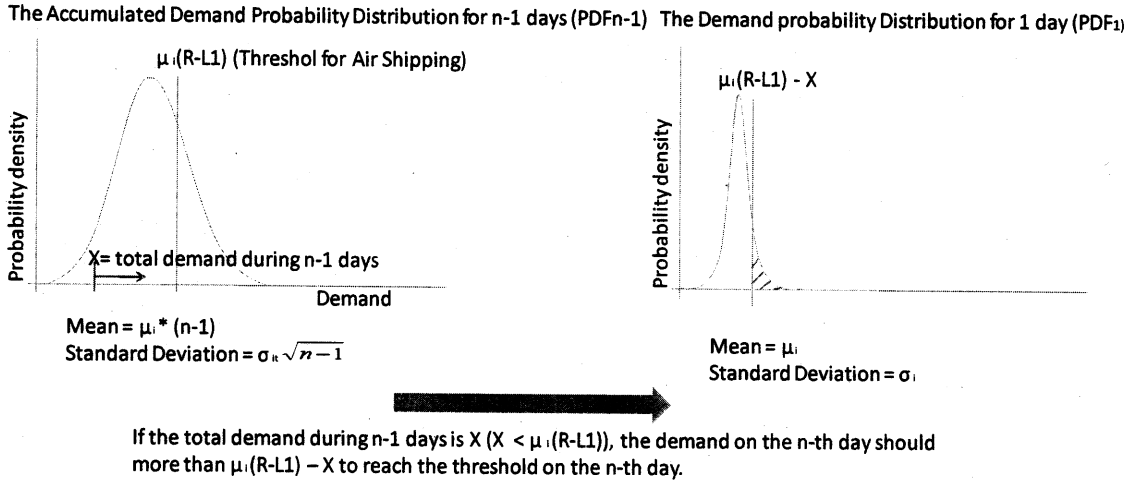


Figure 19 Graphical Explanation for $P(N = n | N \neq n - 1)$

Therefore,

$$P(N=n|T) = \frac{P(N \neq n-1 \text{ and } N=n)}{P(T)} = \frac{P(N \neq n-1) \times P(N=n|N \neq n-1)}{P(T)}$$

$$= \frac{\int_{x=0}^{\mu_i (R-L1)} \{PDF(x)_{n-1} \times \int_{k=\mu_i (R-L1)-x}^{\infty} PDF(k)_1\} dk dx}{P(T)}$$

Once the air shipping amount on the n-th day and the probability $P(N=n|T)$ are obtained, the average air shipping amount can be calculated.

The average amount of air shipping item i

$$\sum_{n=1}^{R-L1} \{(\mu_i (R - L1 - n) + z\sigma_i \sqrt{R - L1 - n}) \times P(N = n|T)\}$$

7.2.2.3.3 Air Shipping Cost

With the probability of air shipping and average amount of air shipping calculated, the air shipping cost can be calculated as follows:

Air shipping cost = The Probability of air shipping per cycle
 × Average amount of air shipping per cycle

- × Total cycle number per year
- × Air Shipping Cost per unit weight

7.2.2.3.4 Other Cost Changes

Safety Stock Cost Saving

- Safety Stock Cost Saving = Safety stock with the single ocean mode
 – Safety stock with the dual mode

$$= z\sigma_1\sqrt{R + L2} - z\sigma_1\sqrt{L1} - \beta$$

Cycle Stock Change

To calculate the cycle stock changes, the ocean cycle stock and air cycle stock in the dual mode calculated first. Denote the average amount air shipping per cycle as T_A .

- Ocean cycle stock in the dual mode = $\frac{\mu_j}{2} R_{\text{Dual Mode}} - T_A$, where $R_{\text{Dual Mode}}$ is the review period for the regular ocean shipping.
- Air cycle stock in the dual Mode = T_A

Therefore, the total cycle stock in the dual mode is

- Total Cycle Stock of the dual mode = Ocean cycle stock in the dual mode + Air cycle stock in the dual mode = $\frac{\mu_j}{2} R_{\text{Dual Mode}}$

The cycle stock change is, therefore,

- Cycle Stock Change = $\frac{\mu_j}{2} (R_{\text{Dual Mode}} - R_{\text{Ocean single}})$

Pipeline inventory Change

- Pipeline inventory of the single ocean mode

$$= \mu_j L2 - \text{unfulfilled demand of the single ocean mode} \times L2$$
- Pipeline inventory of the dual mode

$$T_A \times L1 + (\mu_j - T_A) \times L2 - \text{unfulfilled demand of the dual mode} \times L1$$

Therefore, the pipeline inventory change is

- Pipeline inventory change = Dual mode pipeline – Ocean single mode pipeline

$$= T_A \times (L1-L2)$$

$$+ \text{unfulfilled demand of the single ocean mode} \times L2$$

$$- \text{unfulfilled demand of the dual mode} \times L1$$

Unfulfilled demand terms are second order, so that they are negligible. Therefore, the pipeline inventory change with only first order terms is

- Pipeline inventory change = $T_A \times (L1-L2)$

Since L1 is less than L2, the pipeline inventory goes down in the dual mode.

Lastly, If the optimal R for the dual mode is different from the optimal R for the single ocean mode, the total fixed cost of ocean shipping changes because the total annual number of ocean shipping changes.

7.2.2.4 Dual Mode Optimization Model Development

Similar to the ocean shipping optimization model, the dual mode optimization model has four different parts: Input, Decision Variable(s), Result, and Calculation. Inputs are same as those for the ocean optimization model while there are two decision variables in the dual mode: 1, Additional safety stock β above $z\sigma_i\sqrt{L1}$, and 2, the review period R. R is an integer variable. In reality, the shortest ocean shipping interval is half of a week. Therefore, if R is one, that corresponds to half of a week of. The actual ocean shipping interval can be calculated by multiplying R by half of a week. Both of β and R have bound constraints. β should always be greater or equal to 0 (non-negative condition) and R should be greater than 0 but smaller than 104 (= number of weeks per year *2). The result part presents the net impact of the dual mode, which is the amount of savings generated by the dual mode compared to the single ocean mode. Since air shipping probability calculations is non-linear, and there is also a square root term in the safety stock calculation, this is also a non-linear optimization model. Figure 20 is a snap shot of the model.

**Dual Shipping
Mode
Optimization
Model**

Inputs

Category	Description	Value	Unit
Daily Demand	Mean	500	Kg
	Variability (sigma)	100	Kg
Transit Lead Time	Ocean Lead Time (L2)	25	Days
	Air Lead Time (L1)	2	Days
Shipping Rates	Fixed Ocean Shipping Rate	386	\$ per shipment
	Variable Ocean Shipping Rate	0.2	\$/kg
	Fixed Air Shipping Rate	20	\$ per shipment
	Variable Air Shipping Rate	1.8	\$/kg
Others	Desired Service Level	95%	%
	Weight to Value conversion ratio	50	\$/Kg
	Z level	1.644854	
	Cost of Capital	10%	%/yr

Decision Variables

Description	Value	Unit
Additional Safety Stock over $\mu_i \sqrt{L1}$	0.003	Kg
Ocean Review Period (R)	3	0.5 wks

Result

NET IMPACT	\$	3,013.48	GAIN
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Figure 20 Snap Shot of the Dual Mode Optimization Model

Because Excel can't perform an integral, $P(N=n | T)$ should be re-written using a discrete random variable. By changing the probability density function of the accumulative demand for n-1 days to a probability histogram with a discrete random variable j, $P(N=n | T)$ can be expressed in a discrete form.

The Accumulated Demand Probability Distribution for n-1 days (PDFn-1)

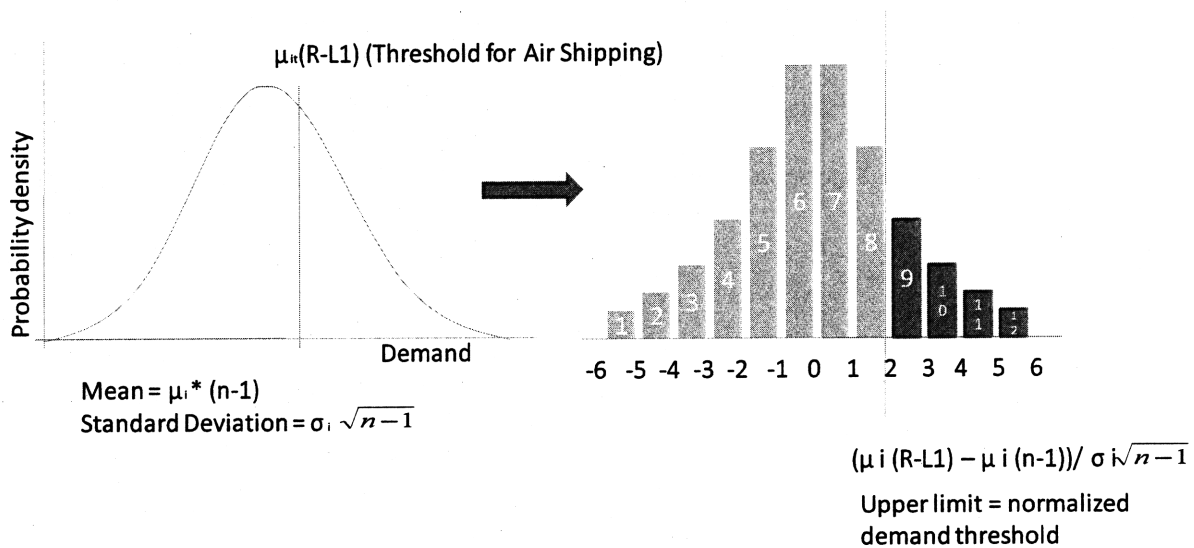


Figure 21 Changing a Continuous PDF to a Discrete Histogram

Discrete Variable j	Bar	Area = A(j)	
-6		$\Phi(-6)$	9.8659E-10
-5	1	$\Phi(-5)-\Phi(-6)$	2.8566E-07
-4	2	$\Phi(-4)-\Phi(-5)$	3.1385E-05
-3	3	$\Phi(-3)-\Phi(-4)$	0.00131823
-2	4	$\Phi(-2)-\Phi(-3)$	0.02140023
-1	5	$\Phi(-1)-\Phi(-2)$	0.13590512
0	6	$\Phi(0)-\Phi(-1)$	0.34134475
1	7	$\Phi(1)-\Phi(0)$	0.34134475
2	8	$\Phi(2)-\Phi(1)$	0.13590512
3	9	$\Phi(3)-\Phi(2)$	0.02140023
4	10	$\Phi(4)-\Phi(3)$	0.00131823
5	11	$\Phi(5)-\Phi(4)$	3.1385E-05
6	12	$\Phi(6)-\Phi(5)$	2.8566E-07

Table 4 Calculations for Discrete Areas

$$P(N=n|T) = \frac{\int_{x=0}^{\mu_i(R-L1)} \{PDF(x)_{n-1} \times \int_{k=\mu_i(R-L1)-x}^{\infty} PDF(k)_1\} dk dx}{P(T)}$$

$$= \frac{\sum_{j=-6}^{\text{upper limit sigma}} A(j) \times (1 - \Phi(\frac{\mu_i(n+1)+j*\sigma_i\sqrt{n+1}-\mu_i}{\sigma_i}))}{P(T)}$$

Where $\frac{\mu_i(n+1)+j*\sigma_i\sqrt{n+1}-\mu_i}{\sigma_i}$ is the normalized j with the mean of μ_i and standard deviation of σ_i which are the mean and standard deviation for the demand distribution of the n-th day. The shipping weight if the demand hits the threshold on the n-th day is $\mu_i(R-L1-n)+z\sigma_i\sqrt{R-L1-n}$. Below is a snap shot of the excel model for the $P(N=n|T)$ and the average amount of air shipping calculations.

Average Weight of Air Shipping - Air shipping weight on n-th day and probability P(N=n|T)

- If inventory reaches the threshold on n-th day, how many we have to ship.
- What is the probability that the inventory reaches the threshold on n-th day

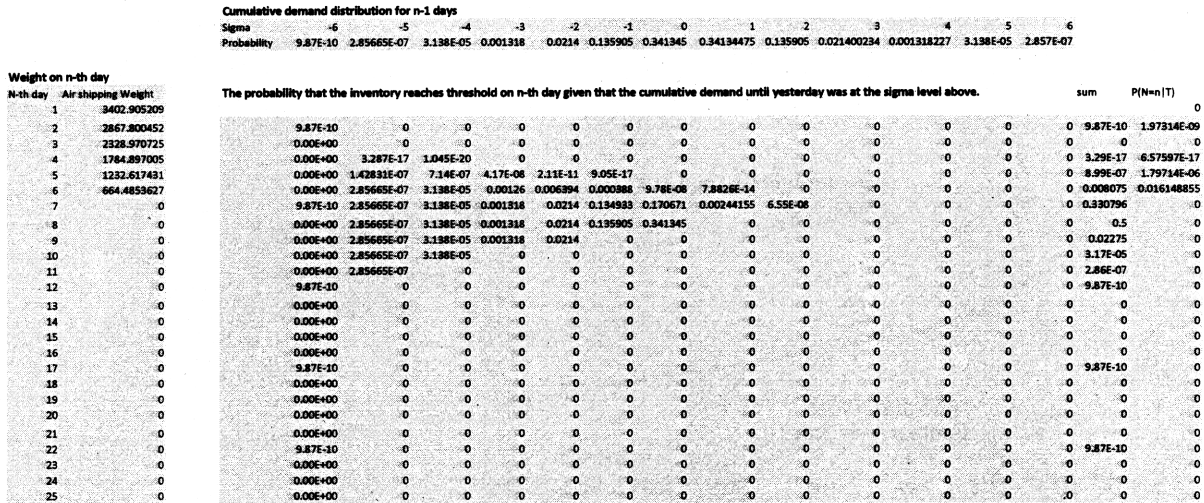


Figure 22 P(N=n|T) and Shipping Weight Calculations

7.2.2.5 Result and analysis

The optimal solution for 500 kg of the mean of the daily demand and 100 kg of the variability of the daily demand suggests having one and a half week of R and no additional safety stock above $z\sigma_1\sqrt{L1}$ (β). The solution brings \$ 3019.48 of annual savings by changing from the single ocean mode to the dual mode. Similar to the ocean analysis in the chapter 7.3.4, the sensitivity analysis tells how the factors affect the net impact. Where the mean of the demand is greater, less safety stock above $z\sigma_1\sqrt{L1}$ and shorter review period are needed. As the variability of the demand becomes greater, more safety stock above $z\sigma_1\sqrt{L1}$ is needed but the optimal review period becomes shorter. Greater weight to value conversion ratio requires smaller amount of additional safety stock and shorter review period. The transit lead time difference between the ocean and air has positive relationship with the net impact, whereas the cost difference between the ocean and air has negative relationship with the net impact. The weight to value frontier in Figure 23 will assist logistics managers in making a decision on whether to use the dual mode. Because the dual mode optimization model has two decision variables, there are more chances to obtain greater savings than the savings from the ocean optimization where only one decision variable exists. As seen in the frontier below, there is no frontier with less than 200 kg of variability, which means if the variability is less than 200 kg, the dual mode is always more profitable than the single ocean mode.

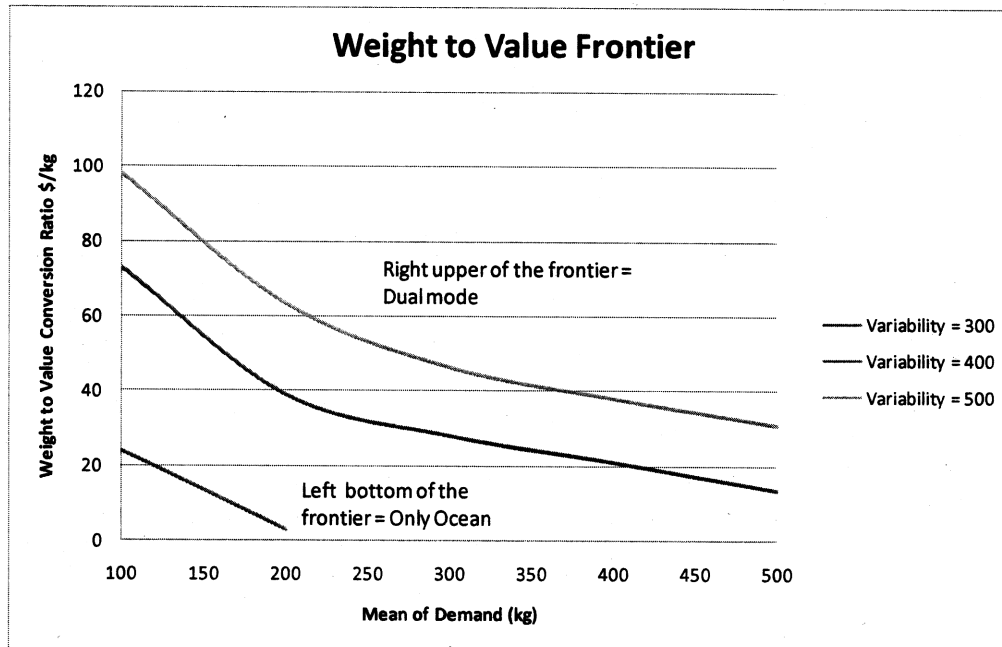


Figure 23 Example of Weight to Value Frontiers for the Dual Mode

7.2.3 Past Study on the Dual Mode

The dual mode concept is not certainly new. Other analytical approaches to the dual mode can be found from past studies. The optimization model in this thesis assumes that stock-out penalty cost is significant, so that the model tries to minimize the possibility of stock-out. However, Tagaras and Vlachos (Tagaras George & Vlachos Dimitrios, 2001) took different approach. They developed an approximate expected cost function per cycle and tried to minimize the cost. The expected cost function includes the cost for stock-out, inventory holding cost, and emergency shipping (air shipping) cost. Instead of optimizing the trade-off between inventory level, mainly safety stock, and additional air shipping cost as done in this thesis, Tagaras and Vlachos aimed at optimizing the trade-off among three above cost components by calculating the best base stock levels for regular and emergency orders. Base stock here means the stock level up to which they order. They assumed that the safety stock in the dual mode system is fairly large and they focused more on deciding the base stock levels rather than calculating safety stock.

7.3 Other Concerns for Ocean Shipping

Not only quantitative analysis but also qualitative evaluation for ocean shipping is necessary.

- Salt water may harm quality of the aircraft parts. Since the time during which the parts are exposed to salt water is over 4 weeks in case of trans-pacific shipping, it is possible that materials can be damaged by salt water during shipping.
- If Less than Container Load shipping is used, Honeywell's shipment will share the container with the other company's shipments. Because Honeywell's shipment has to wait to be consolidated with the other company's shipments at the port, there are more chances for the shipments to get damaged.
- Shipping cost is calculated with an assumption that the materials are going to be consolidated at one port in the US. Since the material suppliers are spread around the US, consolidation in one port would result in high in-land transportation cost.

8 Opportunity 3- Network optimization and Forwarder Selection

The primary objective of this section is to analyze the Honeywell's logistics network between the US and China and to provide the optimized network and forwarder suggestions.

8.1 Overview

Honeywell has more than 50 US raw material suppliers shipping to its OEM sites in China and those raw material suppliers are spread around in the US while there are two main destinations in China. Both of Honeywell sites in China are mainly using heavy weighted air (HWA) cargo service for the regular shipments from the raw material suppliers to their sites. However, when expedited shipment is required, they use small parcel expedited service whose lead time is about 4 days. Although both of two sites in China are using HWA service, the HWA freight forwarders contracted with each site are different. The freight forwarder of one of the Honeywell China OEM sites has two consolidation locations in the US and ships the consolidated materials to China. The other freight forwarder of the other OEM site in China ships directly from the suppliers to the site. Figure 24 illustrates the current logistics network.

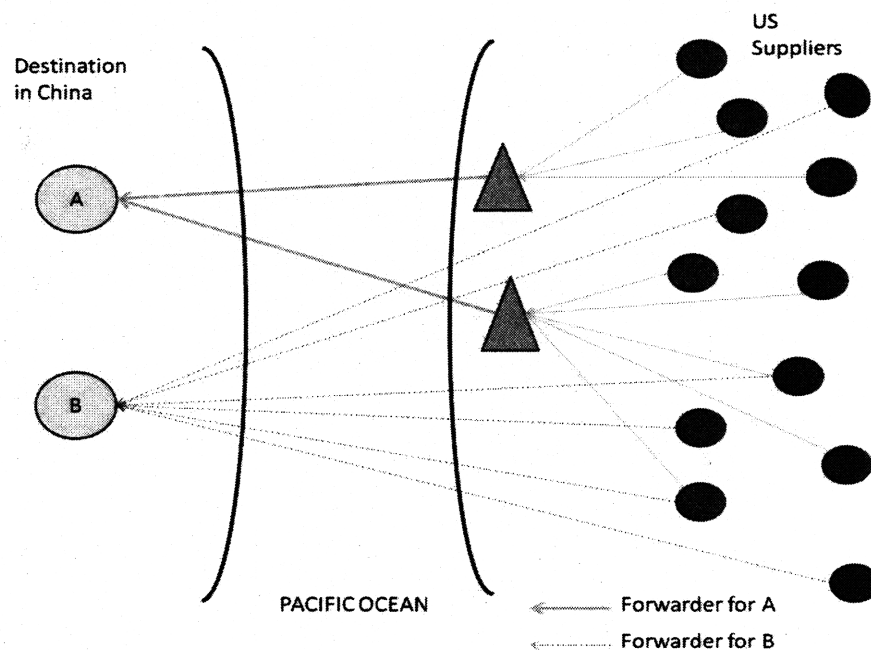


Figure 24 Honeywell's Current China Logistics Network

8.2 Improvement Opportunities

8.2.1 Risk Pooling¹³

The current network has improvement opportunities. If two destinations (two OEM sites in China) use common materials, having a warehouse in China that stores the common materials can reduce the safety stock inventory. Let's say both of OEM sites use the material A whose demand standard deviation is σ_A and direct shipping lead time from the supplier for the material A to the sites is L. Then, both of two OEM sites should keep $z\sigma_A\sqrt{L}$ of safety stock. The total safety stock in the system is $2z\sigma_A\sqrt{L}$ in this case. However, if a warehouse that's near both of OEM sites supplies the material A to the sites, the warehouse should keep the safety stock of $z\sigma_A\sqrt{2L}$ because the demand standard deviation seen by the warehouse is equal to the standard deviation of the sum of two sites' demands. This option can save the safety stock carrying cost but it requires an investment to build or buy a warehouse.

8.2.2 Number of Freight Forwarders

Reducing the two freight forwarders to one freight forwarder for the entire network could save logistics costs.

- The total volume on this logistics network is not enormous, so that one freight forwarder is capable of handling the entire flows.
- If two Honeywell China sites use one same forwarder, the selected forwarder will have larger volume than each forwarder covers now, which means Honeywell offers bigger business to the freight forwarder. Therefore, in this case, Honeywell will have more negotiation power against forwarders than they have with two forwarders.
- If the selected forwarder has consolidation facilities in the US, the volume per trans-pacific shipment will increase, which implies that the total transportation cost would decrease due to economies of scale of HWA shipping.
- Some of the suppliers are shipping materials to both of the site A and B. If both sites use one freight forwarder, suppliers, e.g. senders, can consolidate materials going to both of A

¹³ The concept of risk pooling is introduced in the book, *Designing and Managing the Supply Chain*, Simchi-Levi, Kaminsky, Simchi-Levi, Third Edition, Chap. 6.

and B and send it to the consolidation location. This implies the in-land transportation cost between suppliers to the consolidation location will be reduced due to the increased volume per shipment.

These points strongly suggest that Honeywell should have one freight forwarder for the flows going to both of the destination A and B.

8.2.3 Consolidation of the Materials from the Different Suppliers

The benefits of consolidation over point-to-point direct shipping are:

- Consolidation can significantly reduce the transportation costs especially when the average volume and weight of shipments are low. Some of Honeywell's suppliers are shipping very low volume and light shipments, which incurs high shipping cost (\$/weight). However, by doing consolidation, unit weight shipping cost will decrease as the effect of fixed cost reduces. (Economies of Scale)
- The transit lead time may increase because of consolidation. And increased lead time leads to increase of inventory that the site A and B has to keep. However, the current transit lead time with existing forwarders is already more than 10 days. This implies that the inventory increase due to the increased transit lead time would not be significant.

There are some downsides of the network with consolidation and deconsolidation.

- The complexity of consolidation and deconsolidation processes would require additional costs.
- After deconsolidating the materials in China, the forwarder should use local transportation to deliver materials to the final destinations. Each destination is doing customs clearance in its own city because they have built a relationship with their local customs office. That means the materials should move from the deconsolidation location to the destination city without being declared at customs. In this case, the material should be transported using a customs bonded truck until it arrives at the customs in each city. Customs bonded trucking is more expensive than normal trucking.

If we don't want to go through deconsolidation process in China, the forwarder can send separate shipments from the US consolidation location to each of destination. Then, Honeywell can make

savings in the bonded trucking cost. However, the volume per trans-pacific shipment will be reduced and this will lead to higher trans-pacific costs. Since the trans-pacific transportation cost is relatively larger compared to the local bonded trucking cost, Honeywell should focus on making the trans-pacific volume per shipment bigger by consolidation.

Figure 25 shows the suggested network with one freight forwarder, two consolidation locations in the US and one deconsolidation location in China.

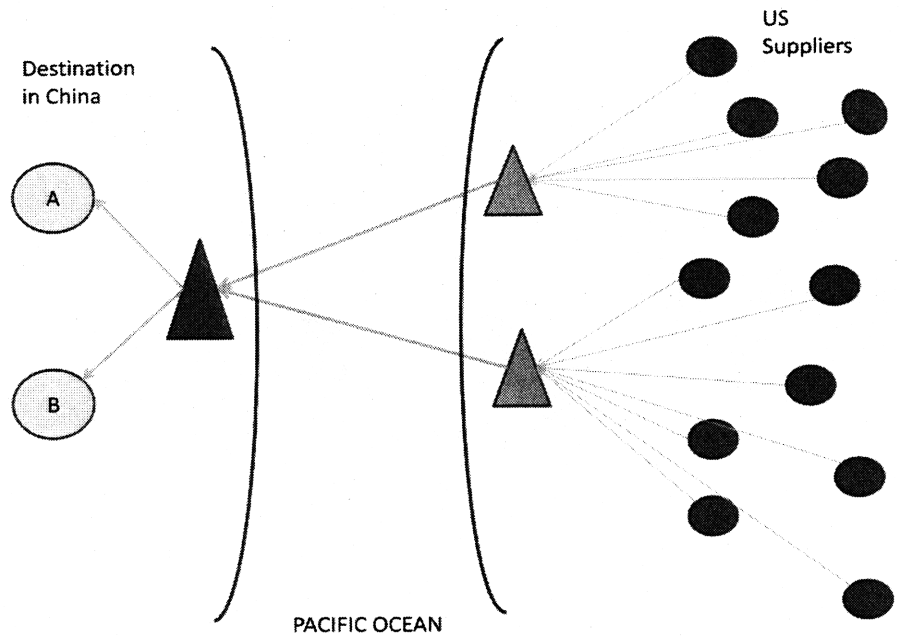


Figure 25 Improved Network

8.2.4 The number of Consolidation Locations

The discussion in the previous sections says that having one freight forwarder and setting up consolidation and deconsolidation locations will be the most cost effective logistics network solution. Then the next question would be how many consolidation locations we should have in the US. The number of consolidation locations affects: 1, US inland transportation cost, 2, trans-pacific transportation cost, 3, consolidation complexity, and 4, deconsolidation complexity. Figure 26 shows the relationship between each of above point and the number of consolidation locations. There are trade-offs among those four points. US inland transportation cost and consolidation complexity

decrease as the number of consolidation locations increases. However, trans-pacific transportation cost and deconsolidation complexity will decrease as the number of consolidation locations increases. Therefore, it is hard to say whether having a small number of consolidation locations is good or a large number is good. We have to take the geographic distribution of the material suppliers, e.g. senders, and the feasibility of consolidation in the selected location into account. Best way of doing this is to be partner with freight forwarders.

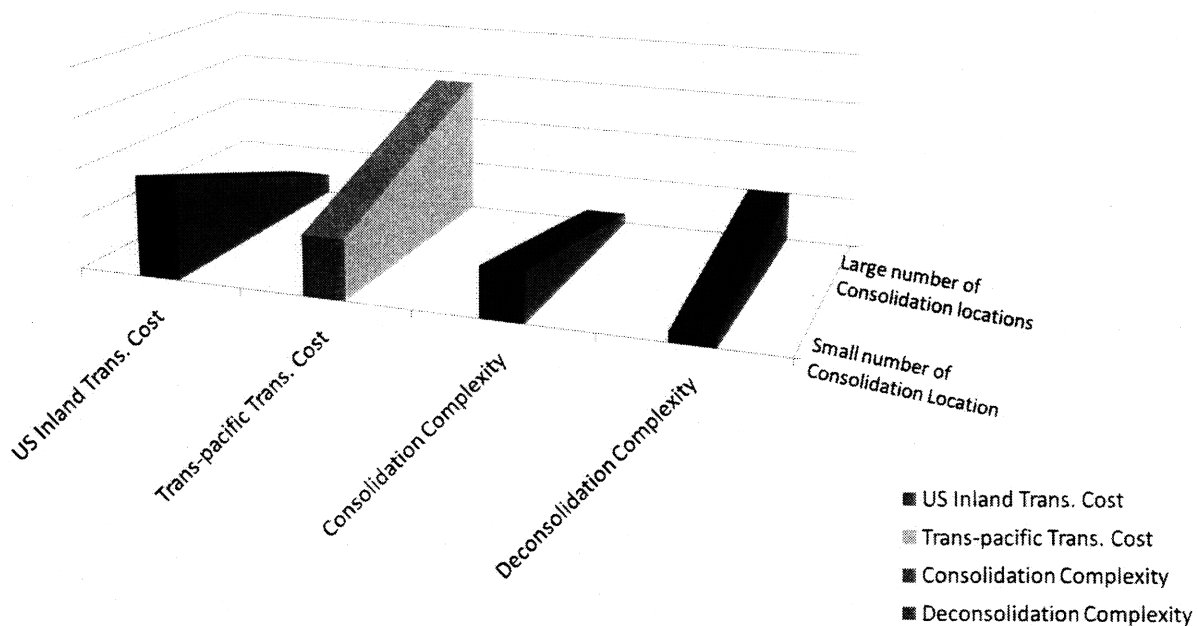


Figure 26 Trade-offs by the Number of Consolidation Locations

8.2.5 Collaboration with Freight Forwarder while Keeping Competition

Collaboration with freight forwarders allows us to explore more realistic consolidation opportunities. The project team shares the shipment information such as shipment frequency, average shipment weight, and origin-destination pairs with freight forwarders. And at the same time, the team wants to continuously keep its negotiation power against the freight forwarders to secure cheap and reliable services. Two things need to be done for this. First, the company should have several freight forwarders in its pool and keep competition among them. Second, although the company has several

business units, it has to approach the freight forwarders as one company. By that way, the company can offer bigger business to the forwarders, so that it could have bigger negotiation power. These two are actually what Honeywell is doing now. Honeywell does frequently re-bid for freight forwarding rates at the corporate level.

In the course of the project, the shipment information was shared with four freight forwarders and the project team found the possible consolidation opportunities with them. As seen in Table 5, different freight forwarders have expertise in different areas. The total cost really depends on where the each freight forwarder's expertise is and how well that expertise is aligned with the internal and external conditions of logistics network. These conditions include the distribution of origins, shipment frequency, average shipment volume, oil price, political situation, and so on. For example, the freight forwarder A which can serve cheapest service is far better in FSC than the other carriers. Forwarder A's FSC is lowest and less vulnerable to the external conditions. During the time when FSC is higher, forwarder A will be better than B and D. However, if FSC goes down, the forwarder B will turn out to have the better rate. If FSC fluctuates widely, the forwarder A will be better because it has almost fixed FSC. Therefore, to find a cheap and reliable forwarder, each forwarder's expertise should be identified, and then the expertise should be evaluated by internal and external conditions of the logistics network.

Forwarder	Consol. Location	Inland	Trans-Pacific	Dest.	FSC	Total	Avg. \$/kg
A	LAX, JFK	1.00	1.00	1.00	1.00	1.00	2.06 \$/kg
B	LAX, JFK DFW, ORD	0.67	0.51	0.89	4.61	1.05	2.15 \$/kg
C	LAX, ORD	1.10	1.51	0.80	0.88	1.23	2.43 \$/kg
D	13 locations	0.47	0.88	0.82	4.82	1.18	2.54 \$/kg

Normalized by Carrier A's data

Terminology

Dest.: In China bonded trucking

FSC: Fuel Surcharge

Table 5 Consolidation Opportunities with Four Freight Forwarders

8.2.6 Result and Further Decisions that need to be made for HWA Implementation

The selected forwarder, A, turned out to be able to save up to 17% of current spending. This represents a larger increase than any of the other improvement opportunities of this thesis.

8.2.6.1 Decision 1 - Consolidated Heavy Weighted Air (HWA) Vs Small Parcel Service (SPS) selection

There are additional decisions that need to be made after a freight forwarder is selected. This section discusses a shipping guideline on when to use HWA and when to use Small Parcel Service (SPS).

The consolidated HWA service is generally cheaper but slower than the point-to-point SPS service. In addition to the case when there are urgent shipments, the SPS can also be used when the weight of shipment is light. The fixed cost of HWA is higher than that of SPS service, which implies that HWA service requires a certain level of volume to pass the weight break-even point. With two consolidation points in the US, Honeywell can consolidate the small amount of shipments from the suppliers, so that they can have enough volume to use HWA service in most cases. The problem here is pick-up transportation from the supplier's sites to the consolidation location. There is a case when weight of shipment is too light, so that the consolidated HWA becomes more expensive than the point-to-point SPS because of high pick-up transportation cost of HWA. It is necessary to provide the suppliers with a shipping guideline that helps to determine when to use HWA and when to use SPS in different weight ranges.

The consolidated international HWA consists of three different transportation links: 1, Pick-up transportation, 2, consolidated trans-pacific transportation, and 3, destination delivery transportation. The shipment volume of the trans-pacific transportation is consolidated volume. In case of Honeywell, they have only two destinations. Thus the destination delivery volume can also be thought as consolidated. The volume of pick-up transportation, however, has less chance of being consolidated because the suppliers are widely spread, so that each supplier sends materials directly to the consolidation location. In order to calculate the weight break-even point between the consolidated HWA and the point-to-point SPS, marginal HWA shipping cost should be compared to the point-to-point SPS cost.

Marginal HWA shipping cost of a small amount shipment

Figures 27-30 show the cost structure of three parts of transportation. The marginal pick-up transportation cost can be determined by the pick-up transportation cost structure assuming that there is no another volume to be consolidated together from the supplier. However, in case of the trans-pacific and destination delivery costs, the consolidated volume (shipments from the other suppliers) already exists, so that the marginal cost depends on the level of the already existing consolidated volume. This analysis assumes that the additional shipment can be consolidated with the existing consolidated volume. From the Figures below, if average weekly consolidation volume is around 1200 kg, the marginal trans-pacific cost is 2.4 \$/Kg and the marginal destination delivery cost is 0.26 \$/Kg. Therefore the total marginal cost can be calculated by summing the curve of pick-up transportation cost structure with 2.4 \$/Kg plus 0.25 \$/kg. By comparing the marginal cost to the SPS cost structure, the break-even weight point can be obtained. Figure 30 shows that if the weight of a shipment is lighter than 14 kg, it is recommended to use the point-to-point direct SPS service.

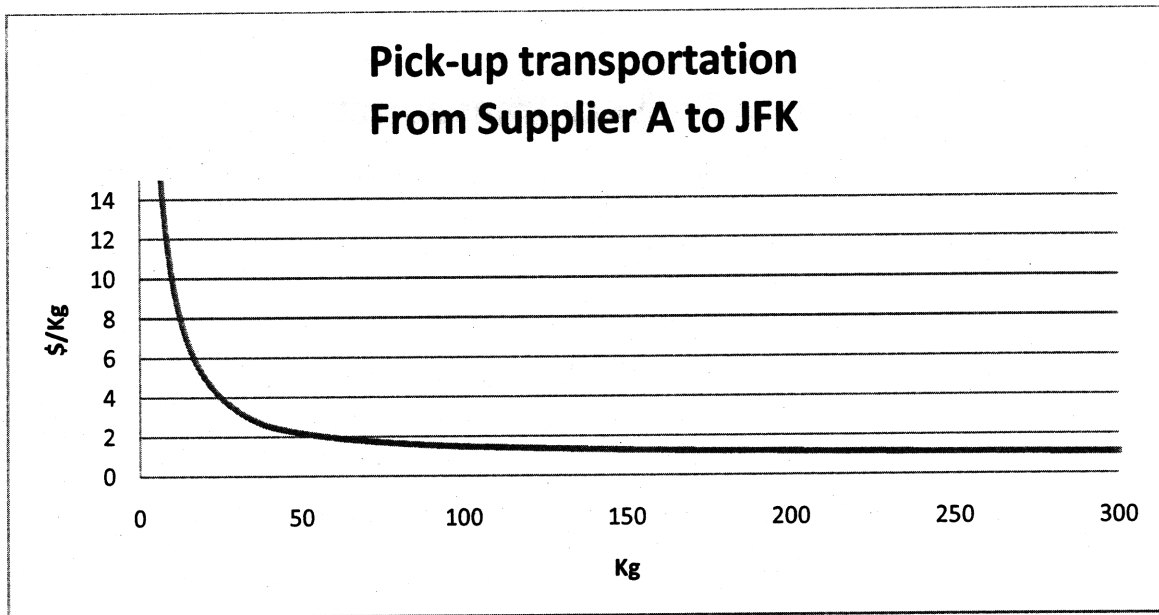


Figure 27 Pick-up Transportation Cost Structure (From an anonymous freight forwarder)

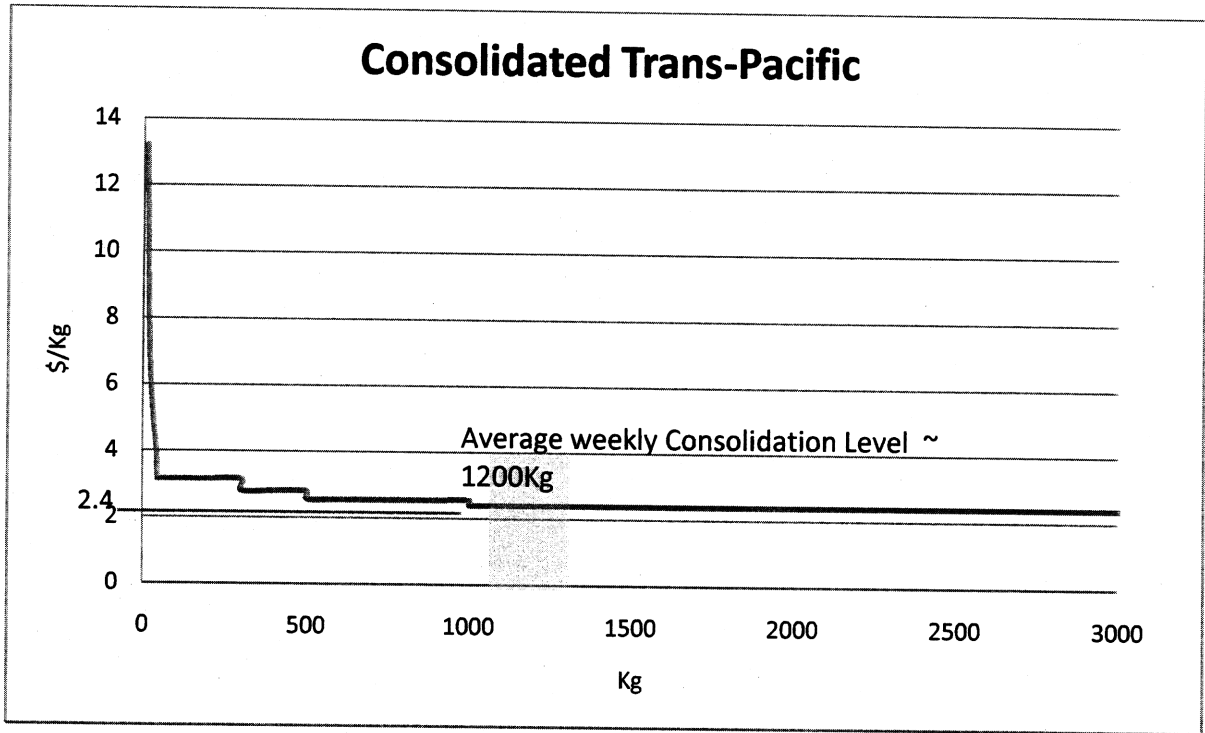


Figure 28 Consolidated Trans-pacific Transportation Cost Structure (From an anonymous freight forwarder)

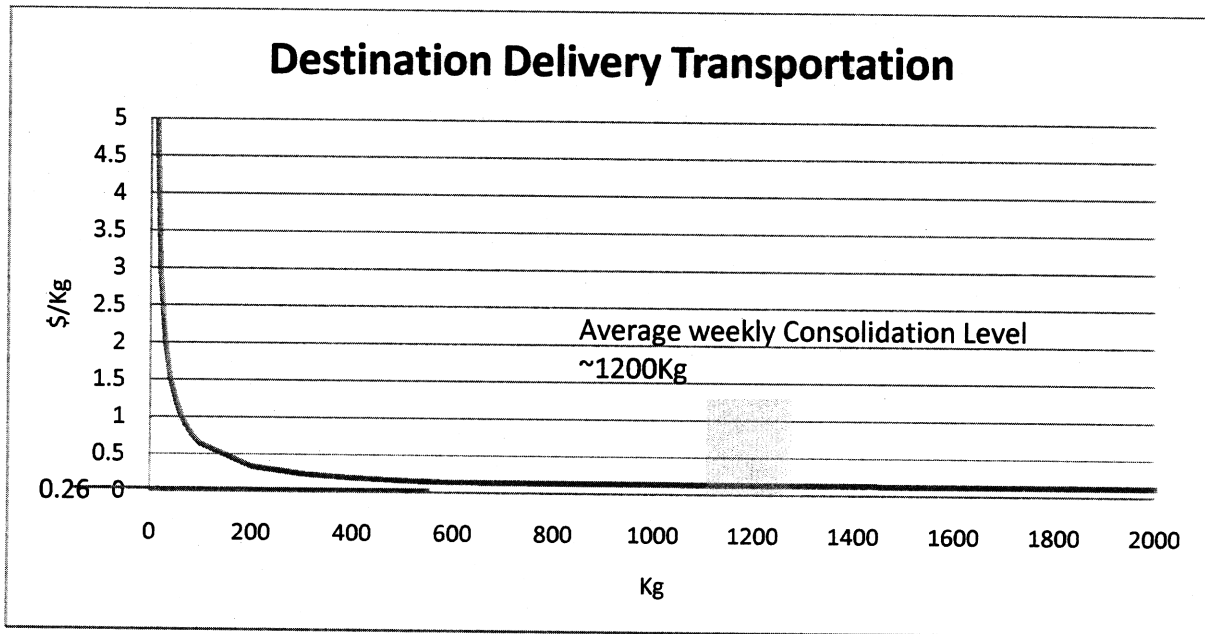


Figure 29 Destination Delivery Cost Structure (From an anonymous freight forwarder)

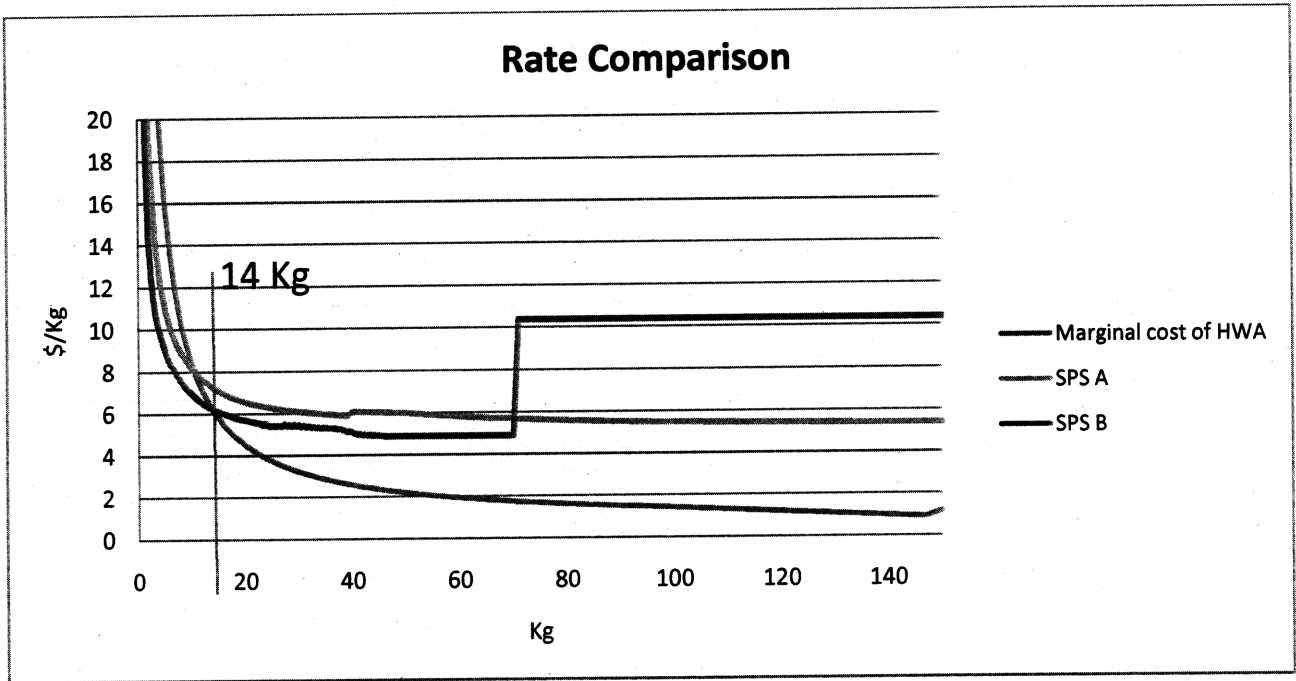


Figure 30 Comparison between HWA and SPS (From an anonymous HWA freight forwarder and SPS carriers)

8.2.6.2 Decision 2 - HWA shipping frequency and Safety Stock

The other decisions that need to be made for HWA are 1, The HWA shipping frequency, and 2, safety stock. The dual mode optimization model developed in the chapter 7.4 can aid making these two decisions. The ocean lead time and shipping rates in the model need to be replaced with the HWA lead time and rates, and the air lead time and rates need to be replaced with the expedited lead time and rates.

**Regular
Shipping Period
Optimization
Model**

Inputs

Category	Description	Value	Unit
Daily Demand	Mean	500	Kg
	Variability (sigma)	100	Kg
Transit Lead Time	HWA Lead Time (L2)	10	Days
	Expedited Lead Time (L1)	3	Days
Shipping Rates	Fixed HWA Shipping Rate	50	\$ per shipment
	Variable HWA Shipping Rate	5	\$/kg
	Fixed expedited Shipping Rate	20	\$ per shipment
	Variable expedited Shipping Rate	7	\$/kg
Others	Desired Service Level	95%	%
	Weight to Value conversion ratio	50	\$/Kg
	Z level	1.644854	
	Cost of Capital	10%	%/yr

Decision Variables

	Description	Value	Unit
	Additional Safety Stock over $\sigma \sqrt{LT}$	0.001	Kg
	Ocean Review Period (R)	2	0.5 wks

Result

NET IMPACT	\$	4,211.90	GAIN
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Figure 31 HWA Shipping Frequency and Safety Stock

With ten days of the HWA transit lead time and three days of the expedited lead time, weekly HWA regular shipping (R=2) turned out to be most profitable.

9 Opportunity 4 - Material Supplier's Warehouse in China

9.1 Overview

This section provides an analysis on the possibility to use the material supplier's warehouse in China. The idea originates from the fact that three material suppliers accounting for about 70% of material supply to Honeywell China have their warehouse in China. The suppliers ship raw materials over the ocean to their warehouse in China, implying that the suppliers have more experience of ocean shipping than Honeywell does. Also suppliers' volume to China is big enough to fully enjoy the economies of scale of ocean shipping. If Honeywell buys materials not from the supplier's US site but from the supplier's warehouse in China and let the suppliers be in charge of shipping to China, volume for Honeywell will be consolidated with the suppliers' existing volume, making the overall supply chain cheaper. Honeywell can also share the risk of ocean shipping with the suppliers by buying in China. This will encourage a good chance of price improvement from the suppliers' perspective, because Honeywell has to pay something for the compensation of risk sharing. Since the suppliers have experience in ocean shipping, and the volume for Honeywell is relatively smaller than what suppliers are stocking in their warehouse in China, the incremental risk to the suppliers is almost negligible. Therefore, this movement to the supplier's warehouses is a win-win strategy both to Honeywell and Suppliers.

In order to make this happen, Honeywell and the suppliers need to negotiate the new material price. The main objective of this section is to provide a guideline for price negotiation and to discuss custom related issues involved in buying materials from the suppliers' warehouse in China.

9.2 Price Negotiation Guideline

9.2.1 Overview

In negotiating the price, we need to have a maximum price that we can offer. Upper bound in the guideline tells the maximum price. At the same time, the lower bound should be estimated as well. If we offer the price lower than the lower bound, the suppliers would not accept it because they lose money compared to the current status. Therefore, the upper and lower bound of the price provide the range of price we need to target during the negotiation. This section will show how to prepare the upper and lower bound of the price.

9.2.2 The Upper Bound Calculation

In order to calculate the upper bound of the price, we need to compare the current total landed cost to the new total landed cost. Recall the composition of total landed cost. Total landed cost in this case means the total cost that Honeywell has to spend to have a desired material in its China operations.

Total Landed Cost = Purchase price + Transportation cost + Duties, taxes and fees

- Purchase price is the value of the materials that the buyer pays to the suppliers.
- Transportation cost is included in the total landed cost only when the buyer pays for transportation. Since Honeywell's contract with suppliers is mostly based on Ex-works¹⁴, transportation cost is included in the total landed cost.
- Duties and taxes are imposed on the exported and imported goods by the exporting and importing countries' governments. Fees include brokerage and document fees for customs clearance. The law for duties and taxes are different from country to country. For example, in the US, imposing export duties and taxes is unconstitutional.¹⁵ In case of China, if the imported good is not sold in China but processed and shipped out of China after being processed, China import duties and taxes are waived.¹⁶ This kind of goods is called process trading goods. If Honeywell imports the materials from the US to China, Honeywell can declare them as process trading goods. However, if the suppliers imports materials and sell them in China, it is difficult to declare them as the process trading goods. The issues related to process trading goods will be discussed later in this chapter.

The current total landed cost

Honeywell currently pays for all of these costs except China import taxes.

¹⁴ Ex-Works is one of the simplest and most basic shipment arrangements that place the minimum responsibility on the seller with greater responsibility on the buyer. In an EX-Works transaction, goods are basically made available for pickup at the shipper/seller's factory or warehouse and "delivery" is accomplished when the merchandise is released to the consignee's freight forwarder. The buyer is responsible for making arrangements with their forwarder for insurance, export clearance and handling all other paperwork.

¹⁵ According to the 277. Export Duties of The Constitutional Law of The United States, among the express limitations upon the powers of congress, enumerated by the (AnconaDeborah., 2005)Constitution is that which provides that "no tax or duty shall be laid on articles exported from any State."

¹⁶ Excerpted from Honeywell's study material regarding Chinese import and export duties and taxes.

Current Total Landed cost = Current Purchasing price
 + Transportation from the supplier site to Honeywell China (Air)
 + US export customs clearance brokerage and documentation fee
 + China import customs clearance brokerage and documentation fee

The new total landed cost if buying from the suppliers' warehouses in China

If Honeywell buys the materials from the suppliers' warehouses in China, Honeywell doesn't pay for transportation costs from the US to China and customs clearance related fees. Suppliers will pay for those costs, which will be reflected in the new material purchasing price. But Honeywell has to pay local transportation from the suppliers' warehouses to Honeywell China sites if the contract is based on Ex-Works.

New Total Landed Cost = New purchasing price
 + Local transportation cost

Honeywell prefers to buy the materials from supplier's warehouses in China since Honeywell expects the new total landed cost will be lower than the current total landed cost. Therefore, the new purchasing price should meet the following condition:

Current Total Landed Cost \geq New Total Landed Cost = New purchasing price
 + Local transportation cost

This condition gives us the upper bound of the new purchasing price which Honeywell shouldn't pay more than by substituting the definition of the landed costs.

New Purchasing Price \leq Current Purchasing Price
 + Transportation from the supplier site to Honeywell China (Air)
 + Export customs clearance brokerage and documentation fees
 + China Import customs clearance and documentation brokerage fees
 - Local transportation cost

9.2.3 The Lower Bound Calculation

To calculate the lower price bound, we have to look at the incremental cost that the suppliers have to pay in order to sell materials from the warehouses in China. Assuming that the suppliers expect the buyer to pay the incremental costs, the following relationship can be driven.

$$\text{Incremental Cost} + \text{Current Purchasing Price} \leq \text{New Purchasing Price}$$

Then the next question is what the incremental costs are. The following is the list of incremental costs that they have to pay.

- Ocean transportation cost – Assuming that the suppliers already have large volume to ship to China together with the volume for Honeywell, Full Container Load ocean shipping can be used. In estimating the ocean shipping cost we also need to know how often the suppliers ship materials to their warehouses. Since this movement is a win-win strategy to both of Honeywell and the suppliers, two parties need to work on together and share information for the better estimation.
- US customs clearance and documentation fees– Since Honeywell has done this, there is enough information on these costs.
- China import customs and documentation clearance fees – Since Honeywell has done this, it's easy to estimate these costs as well.
- China import duties and taxes – Currently, Honeywell imports the materials and uses custom bonded handbook to declare the imported materials as process trading goods, which are tax-waived. However, in order for the suppliers to be waived, there are some conditions to fulfill. Those conditions will be discussed in Chapter 9.4.
- Inventory cost – Since the suppliers now have more inventory than before, the cost associated with increased inventory should be taken into account. Three different inventory costs are considered: inventory carrying cost for increased cycle stock, pipeline inventory, and safety stock, inventory obsolescence cost, and additional warehouse maintenance cost.

Therefore, the lower price bound that the suppliers' minimal acceptable price is as follows.

$$\text{New Purchasing Price} \geq \text{Current Purchasing Price}$$

$$+ \text{Transportation from the supplier's site to their warehouses (Ocean)}$$

- + US export customs and documentation clearance fee
- + China import customs clearance brokerage and documentation fee
- + China import duties and taxes
- + Additional cost (inventory, warehouse maintenance, and obsolesce cost)

9.3 Result and Analysis

Using the real data on the cost components listed above, the upper and lower price bound calculation for specific suppliers can be performed. Different cost components come with different units. For example, the transportation cost is in the unit of USD/kg whereas the customs clearance fees are in the unit of USD/shipment. Therefore, a common unit is needed and the author took a percentage out of the current purchasing value for the common unit (Figure 32). The excel work sheet gives the upper and lower price range for a specific supplier based on inputs.

What is interesting is the gap between the upper and lower price bound is highly dependent on the value per weight. For the supplier whose average material value per weight is higher than that of the other suppliers, the gap between the upper and lower price bound is tighter, which means it is hard to reach a successful negotiation point. This is because higher average material value per weight results in tighter gap between air and ocean transportation costs. Also high average value per weight increases the inventory carrying cost, which is one of the components of the lower bound. Table 6 and Figure 33 show the relationship between value per weight and the price range gap. Value per weight gives an idea on the easiness and feasibility of the negotiation. Therefore, prior to starting negotiating with a supplier, it is important to check the average material value per weight of the supplier.

NEW purchase price range calculation

Input			
ITEM	VALUE	UNIT	REMARK
Supplier		A	
US export customs related fee	\$ 50.00	\$/shipment	
China import duties and taxes	10%	% of landed value	Landed value includes Transportation
Local transportation in China	0.1	\$/Kgs	From Supplier's warehouse to the Hon. China site
China import customs related fee	\$ 50.00	\$/shipment	
# of annual shipments by suppliers	4		From Supplier's shipping plan
# of annual shipments by Honeywell	58		From Honeywell's current shipping practice
Total Annual Weight	26438	Kgs	Specific data for Supplier A
Average Value/weight	6.68	\$/Kgs	Specific data for Supplier A

Calculation			
Shipping by Honeywell			
FREIGHT RATE	VALUE	UNIT	REMARK
Air freight rate	56%	% of current price	Used one of air forwarders \$/kg

Customs related fees	VALUE	UNIT	REMARK
US export customs related fees	3%	% of current price	Drived from annual number of shipments
China import customs related fees	1.64%	% of current price	Drived from annual number of shipments

Duties and Taxes	VALUE	UNIT	REMARK
China import duties and taxes are waived	0%	% of current price	Declared as processing trade goods

Shipping by the supplier			
FREIGHT RATE	VALUE	UNIT	REMARK
Ocean freight rate	12%	% of current price	Used one of ocean carriers \$/kg

Customs related fees	VALUE	UNIT	REMARK
US export customs related fees	0.11%	% of current price	Drived from annual number of shipments
China import customs related fees	0.11%	% of current price	Drived from annual number of shipments

Duties and Taxes	VALUE	UNIT	REMARK
China import duties and taxes are	11%	% of current price	May not be levied.

Local transportation	VALUE	UNIT	REMARK
Local transportation	1.50%	% of current price	From Supplier's WH to Hon. China site

Additional Supplier side cost	VALUE	UNIT	REMARK
Inventory holding cost (Cycle)	1.25%	% of current price	
Inventory holding cost (Pipeline)	0.55%	% of current price	
WH maintenance cost	0.05%	% of current price	Assumption
Obeslence cost	0.10%	% of current price	Assumption

Output			
Low bound	VALUE	UNIT	REMARK
Low bound	124.91%	% of current price	
High bound	156.45%	% of current price	

Negotiated new price	143%	% of current price	This is an input.
Annual Savings	\$ 23,642.40		Based on the % of negotiated new price

Figure 32 Upper and Lower Price Bound Work Sheet

Value/Weight (USD/Kg)	5	10	15	20	25	30	35	40
Upper bound	178.2%	140.6%	128.1%	121.8%	118.0%	115.5%	1.13742	1.123992
Lower bound	132.1%	123.5%	120.6%	119.2%	118.3%	117.8%	1.173592	1.170516
Gap	46.1%	17.1%	7.4%	2.6%	-0.3%	-2.2%	-3.6%	-4.7%

Table 6 Value/Weight vs. Price Range Gap

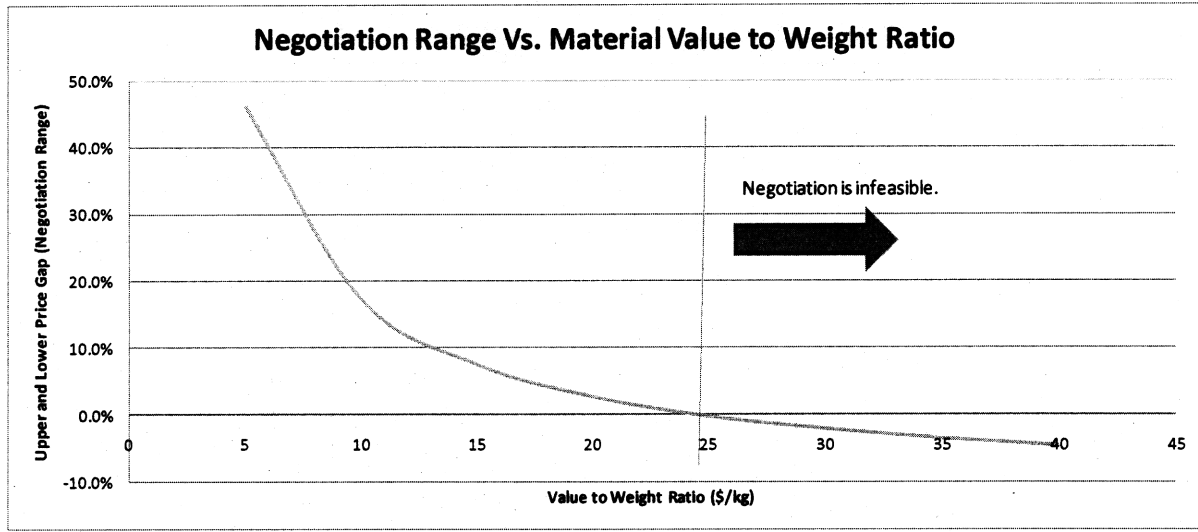


Figure 33 Negotiation Range Vs. Material Value to Weight Ratio

Another factor that affects the price range is the China import tax rate. China import duties and taxes push the lower price bound up. Thus, higher import duties and taxes rates result in more difficult negotiation. The following section shows the details of China import duties and taxes.

Because of the duties and taxes, among three suppliers that have warehouses in China, only one supplier who has lowest average value per weight was able to save total annual spend by 16% with this option. See Table 7.

Supplier A		
Average value/kg	6.68	\$/kg
Low bound	124.91%	% of current price
High bound	156.80%	% of current price
Negotiated New price	140%	middle of the range
Annual spending saving in %	16%	
Supplier B		
Average value/kg	16.8	\$/kg
Low bound	117.76%	% of current price
High bound	117.91%	% of current price
Negotiated New price	117.83%	middle of the range
Annual spending saving in %	0.08%	
Supplier C		
Average value/kg	36.07	\$/kg
Low bound	115.12%	% of current price
High bound	115.47%	% of current price
Negotiated New price	115%	middle of the range
Annual spending saving in %	0.17%	

Table 7 Savings from Buying in China

9.4 Study on China Import Duties and Taxes – Processing Trade Goods¹⁷

China import duties and taxes can be waived if the materials are declared as processing trade goods. Processing trade goods are the goods that will not be sold in China but will only be processed and re-exported out of China within a prescribed time limit. In order to declare imported goods as the processing trade goods, the entity that's importing goods should obtain processing trade enterprise status. The processing trade enterprise will be given custom bonded handbooks, where they keep the track of materials' import and export status. Once the imported materials are recorded in the custom bonded handbook at the import customs, the materials are in a bonded status. When they are re-exported, the bonded status will be cleared. Honeywell is a processing trade enterprise, so that it hasn't paid China import duties and taxes for the imported materials.

In order to keep this tax benefit even when suppliers are importing materials to China, there are several issues to be addressed. First of all, the importing entities, e.g. suppliers, should obtain the processing trade enterprise status. Since suppliers are mainly selling the imported materials within China without processing, it may be hard to obtain the processing trade enterprise status. One of the ways they can think of is to create a legal entity that is supposed to declare materials only for Honeywell and other processing trade enterprises. The legal entity has to process the materials in its

¹⁷ The discussion in this section is based on Honeywell's study materials regarding Chinese import and export taxes and duties. Website, http://www.export.gov/china/exporting_to_china/importregs.asp?dName=exporting_to_china, also contains up to date and useful information regarding Chinese customs regulations.

warehouse to the minimal extent that can be approved as processing by Chinese government. Then, Honeywell and the suppliers can follow the regulations about transferring the materials to the other processing trade enterprise for further processing. According to the Chinese customs regulations, the transferor and transferee should register their transfer plans with the customs and need to receive an approval to transfer processing trade goods between entities. If the materials supplier can transfer the materials to Honeywell and Honeywell re-export the processed materials, they don't have to pay import duties and taxes. Many uncertainties are involved in this process. Customs in different cities may have different perspectives about granting processing trade enterprise status and about approving transferring materials to the other processing trade enterprise. Furthermore, creating a legal entity and getting approval from the government require time and money. Collaboration between Honeywell, the material suppliers and other processing trade enterprise will make their voice stronger and reduce the uncertainty.

10 Challenges in Implementation

10.1 Overview of Organizational Challenges in Change Management

One of the key challenges of the project was driving a change in the Honeywell's current AP logistics practice. The transition to the AP region of Honeywell Aerospace has started recently, so there was no centralized logistics data recording system, no dedicated person to the AP logistics, and weak consistency in logistics practice among sites in the US and the AP region. The sites in China had different logistics and production planning practices from the practices of the US sites. One of the goals of the project was to develop a common AP logistics strategy that can be controlled by Honeywell's central logistics organization. In order to do this, the strategy should be accepted by both of the US and China site. Also an effective way of communicating the logistics strategy between the US and China sites had to be created.

Honeywell cares more about inventory costs than transportation costs. Thus, Honeywell prefers the transportation solutions that don't affect inventory level. Although China Honeywell sites are under the Honeywell's umbrella but there were also challenges in obtaining supports for the project and transferring the strategy to the China sites. These challenges can be analyzed using a three-lens approach developed by MIT (Ancona Deborah, 2005, pp. 12-15) In the following sections, the implementation challenges faced during the project will be analyzed by three-lenses: strategic, cultural, and political lenses. In addition, effective implementation processes and communication method with people at a distance will be discussed.

10.1.1 Strategic Issues

Logistics decisions generally affect two different costs: inventory and transportation costs. This implies that logistics strategy should be evaluated based on the effect on both of those two costs. A new transportation solution could result in higher inventory but if the savings in the transportation exceeds inventory increase, the solution can improve the company's overall supply chain performance. The balance of these two factors is, however, often ignored in many cases when the logistics decisions are made. The reasons for this can be found by looking at how the company's organizations are structured, what the goals are that each organization has and how they measure the organizations' performance.

In Honeywell Aerospace, the pure transportation decision is being made by a logistics team in the Integrated Supply Chain organization. The Integrated Supply Chain organization is responsible for reducing total spend on supply chain, which includes the inventory, transportation, and purchasing costs. However, the company's recent focus primarily has been on reducing the inventory cost. As a result, people tend to think the inventory costs are more important than the transportation costs. The AP logistics project had to convince the buyers to use a transportation solution which can reduce the total logistics cost (inventory costs + transportation costs). But what's more important to buyers than reducing total logistics cost was keeping lower inventory. This situation was worse in China Honeywell sites. There was even no organization dedicated to transportation. The buyers are also in charge of transportation. The issue here is that one team has two different, possibly opposite, goals: Keeping low inventory level and reducing transportation costs. In the US, Integrated Supply Chain organization is focused on achieving these two goals and in China sites, the buyers' team works on these goals. However, since company has emphasized only part of the solution, the importance of the two goals is out of balance.

If one team has two different goals, there should be a solution implemented to balance the two goals. Dividing one team into two teams and locating both of two teams at the same level in the organization structure would be a good solution for this. The higher level organization for those two teams should pursue balance of the two goals. Creating performance measurement indicators for the organization reflecting both goals will help. In this case, not just having the inventory level but having total landed cost as the performance indicator would result in better logistics management (figure 34).

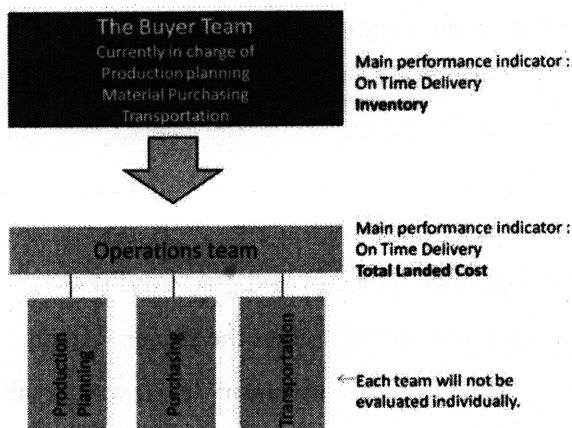


Figure 34 Suggestion for Strategic Organization Design

10.1.2 Cultural Issues

China Honeywell sites had many cultural differences from the US Honeywell sites. China sites are more focused on running day-by-day operations, so process improvement is not a wide spread concept among employees. Some of the employees even thought they can not make an impact on the company. They wanted to do a given work and did not want to change what they were used to. This might be because of lack of employee education on lean and continuous improvement and also might be because of Chinese people's different view about the leadership. People that the author met had a tendency to think the leadership comes with their title and position in the organization. Since this is a cultural issue, the best way to resolve this would be to increase interaction between the China sites and the US sites. Honeywell has a rotational program where they select high potential people and rotate them in different organizations in the company. This program provides the high potentials with opportunities not only to learn more about different organizations in the company but also to transfer good practice of one organization to the other organizations. Honeywell China has sent several leaders to the US sites as a part of this program and Honeywell US has also sent the leaders to the China sites and let them interact with Chinese employee face to face. Lastly, even among the China sites, there is a cultural difference. The author found that people in further west are less familiar with western style of management. For example, People in Shanghai are more familiar with the US management style than people in Nanjing. If Honeywell tries to increase people interaction between the US and China, it will be expensive. If Honeywell can develop Shanghai office as a leader of all the China sites and let Shanghai office to propagate the US culture to the other China sites, it would be effectively able to reduce the cultural different between the US and China.

10.1.3 Political Issues

Each team that has a stake in the project has its own performance indicator and goal. And those teams are under different managers' control. This brings political conflict when the project affects different teams in a different way. Since the project can possibly increase inventory level, which will affect some of teams' performance, it would have helped the project to go smoother if each team's performance indicators included logistics costs. For example, if buyers' performance is measured not

only by their inventory level but also by their logistics spending, the project would have drawn much more attention of the buyers.

Another political issue faced during the project arose from the relationship between the Chinese employees hired through US Honeywell and employees hired through local China sites. Obviously, there is a big difference in the compensation between those two types of employees and the roles of the different types of employees are also different. The employees hired through the US Honeywell are usually working in a China site temporarily to conduct a project aimed at making a short-term improvement. In order for them to make a short-term improvement, support and help from the local employees are required. However, from the local employees' perspective, working with those employees visiting their sites temporarily and trying to make changes would not be comfortable. Some of them might think they would lose their jobs if they help those short-term improvement makers. The extent of this conflict depends on the attitude of the temporary visitors. In China, building personal relationships with co-workers is important. If the temporary visitors can build a good personal relationships with local employees in a short time, that could be one of the ways to ease the conflict.

10.2 Communication Challenge with People at a Distance

In addition to the issues analyzed by three lenses, communication with China sites was also a challenge of the project. The project needed support of the China sites and had to manage Chinese employees to understand the new strategy and get it implemented in the China sites. Different languages and different time zones made this hard. Because the project leaders were not located at the China sites, it was also hard to remind local employees of the importance of the project. In the situations where long distant management is required, some additional steps are useful.

- In the beginning of the project, it is highly important to make people at a distance understand the importance of the project. Explanation on how the project would affect current practices is a useful step. It will be then easier to keep attention of those people through the course of the project. If this is not successful, the outcome of the project would not have enough input of the people at a distance and this becomes a big obstacle during implementation.

- Regular teleconferences are the way to focus the people’s attention on the project. By doing this regularly, the project can be kept up with the most recent input and data from the site at a distance.
- Creating clear and visible messages is important. When selling an idea or creating a new guidance, it is necessary to think from the perspective of the people at a distance. By doing this, we will see what is unclear to them. But verbal communication is not enough. The message should be communicated in a visible way, for example in a document form.
- A way to connect more than two stakeholders of the project should be developed. The project leader should analyze who the stakeholders are, what information each stakeholders need, and where they can find the information. Figure 35 shows the example of the stakeholder analysis and the information flow.

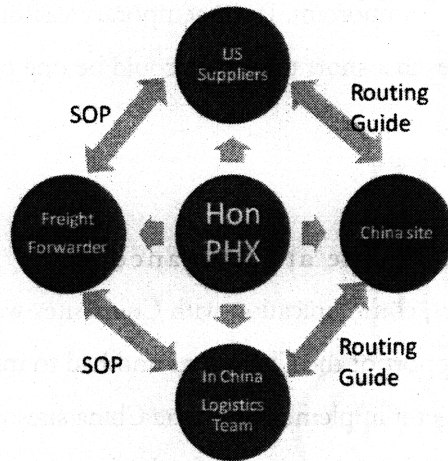


Figure 35 Stakeholder Analysis and Information Flow

11 Conclusion and Next Steps

Four different improvement opportunities are significant but are not always possible. As shown through analysis, each opportunity works under the specific condition. Logistics managers and operations managers should be able to analyze their logistics conditions and make relevant decisions. The order consolidation opportunity through order synchronization can increase shipping volume per shipment, so that it can save fixed cost per order placement. But it will increase total inventory level. Where fixed cost per order placement is higher and the value of inventory is lower, this option is more attractive.

The ocean shipping opportunity can save transportation cost because ocean shipping is in general cheaper than air shipping. But due to the longer lead time of ocean shipping, the inventory will go up. Where the difference between ocean and air shipping costs is higher and the inventory value is lower, the ocean shipping option is more attractive. The mean and variability of demand also affects the decision. The weight to value conversion ratio frontier will support the ocean shipping decision. If air shipping is still used while ocean shipping is regular shipping method, there is another optimization opportunity between safety stock level and air shipping costs for urgent shipment (A dual-mode system). Where air is more expensive than ocean and value of inventory is lower, the dual mode option is less attractive. A weight to value conversion ratio frontier showing the break-even weight to value conversion ratio with different mean and variability of demand were developed to graphically aid the decision.

If there are more than one origin and destination, the network optimization can be considered. If a common good is delivered to different destinations, setting up a warehouse which stores the safety stock for both of destinations can reduce the level of safety stock. The flows coming from several different origins and going to different destinations can be consolidated before the trans-pacific shipping to save the large fixed cost of trans-pacific transportation. 3rd party logistics providers have more experience and expertise in network optimization than the manufacturing company has. It is therefore recommended to work with 3rd party logistics providers to find the best and feasible solution.

Lastly, non-logistics options should be considered. The possibility of buying materials from the supplier's warehouse in China is not a logistics option but can affect logistics costs. Logistics

managers should keep in mind that logistics costs consist of not only transportation cost but also duties and taxes and should understand how different options affect those costs.

This thesis aims to provide the general supply chain decision guidelines and detailed analysis to help to understand structure of trade-offs of each supply chain decision. The models used to evaluate the each supply chain option in the thesis can help to better estimate logistics costs for each option.

As a next step, the models can be integrated into the total landed cost model of the company which aids the decision on global sourcing, which will result in better estimation of the total landed costs.

12 Bibliography

- Ancona, D. e. (2005). *Managing For the Future: Organizational Behavior & Processes*. N.p.: Southwestern/Thomson Learning Publishers.
- Anupindi, Chopral, Deshmukh, Mieghem, V., & Zemel. (Second Edition). *Managing Business Process Flows : Principles of Operations Management*.
- Fawcett, S. E. (1992). Strategic logistics in co-ordinated global manufacturing success. *INT. J. PORD. RES.* , Vol. 30, No. 4, 1081-1099.
- Fawcett, S. E. (1990). *The status and impact of logistics issues in the success of co-production via maquiladoras*. Michigan State University.
- Feller, B. (2008). Development of a Total Landed Cost and Risk Analysis Model for Global Strategic Sourcing. 53.
- Rosenfield, D. B. (1996). Global and variable cost manufacturing systems. *EUROPEAN JOURNAL OF OPERATIONAL RESEARCH* , 325-343.
- Shapiro, R. D. (1984). Get leverage from logistics. *Harvard Business Review* , 119-126.
- Simchi-Levi, Kaminsky, & Simchi-Levi. (Third Edition). *Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies*.
- Tagaras, G., & Vlachos, D. (2001). A Periodic Review Inventory System with Emergency Replenishments. *Management Science* , Vol. 47, No.3, pp. 415-429.