Ship-Pack Optimization to Minimize Fulfillment Costs from Manufacturing to Customer

by

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B.S., Georgia Institute of Technology (2016)

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Abstract

Ship-pack optimization is a crucial tool for companies to reduce operations cost in their distribution system. Cost elements including transportation costs between manufacturing and distribution, transportation costs between distribution and customer, distribution center labor costs, and distribution box costs are all influenced by the ship-pack size from manufacturing to distribution. Companies that control their distribution channels want to be sure to minimize the amount of repacking that occurs between manufacturing and distribution to the customers. "Each-orders" occur when a company must fulfill an order outside of the ship-pack quantity sent from manufacturing. These "each-orders" incur more distribution handling costs, customer complaints, and more costly freight terms, thereby carrying a high "cost-to-fulfill" number relative to the amount of product sold to customers. This thesis explores two ways to reduce operational costs through adjusting ship-pack delivery. The first is an optimization to change the ship-pack quantity, which results in a savings of around 5% of operational costs annually. The second is an optimization of customer ordering behavior, which results in a savings of around 9% of operational costs annually.

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Lastly, I would like to thank my parents, William and Elizabeth, for their continuous support throughout my life.

Note on ResMed Proprietary Information

To protect information that is proprietary to ResMed, the data presented has been modified to represent relative values rather than absolute values. Only approximated financial data has been provided due to the confidential nature of such information. The time period of analysis was conducted during the COVID-19 pandemic, which is not representative of current operations. Additionally, the figures and data labels included may have been altered to protect competitive information and should be viewed as illustrative rather than representing actual data.

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Chapter 1: Introduction and Background

1.1 ResMed Overview

ResMed is a market leader in digital health and cloud-connected medical devices. ResMed seeks to provide treatment for patients with sleep apnea, chronic obstructive pulmonary disease, and other respiratory diseases. The company was founded by Peter Farrell in Australia, and is now headquartered in San Diego, California [1].

ResMed is a rapidly growing company. ResMed has been expanding their portfolio of offerings. ResMed has made recent acquisitions in the digital health space and is committed to providing leading solutions in the software-as-a-service space. Since their founding in 1989, they have become the market leader in their industry. ResMed's goal is to improve 250 million lives in out-of-hospital healthcare by 2025. The sleep apnea market alone is valued at $14.5 billion [2]. Crucial to meeting this market demand will be optimized operations to meet the varied customers of ResMed.

1.2 ResMed's Customers

ResMed serves a variety of customers. As of January 2022, ResMed has 115 million patient accounts in their out-of-hospital care network. The total addressable market for sleep apnea, chronic obstructive pulmonary disease, and asthma is expected to be 936M, 380M, and 330M respectively [3].

ResMed has a global footprint, with operations in Asia, Australia, North America, South America, and Europe. 70% of ResMed's revenue, or $2 billion in FY 21, was generated through North America. The focus of this thesis is on the customer base in the United States and Canada.

Although ResMed interacts with individual patients through their own retail arm and through their digital ecosystem, the focus of this thesis will be on a simplified version of ResMed's customers. These three customer segments are: "Nationals", "Digital-Wholesalers", and home medical equipment providers, abbreviated as "HME". These terms may not be used within ResMed but fits to illustrate their relationship to ResMed Operations.

"Nationals" refers to large companies that have their own patient ecosystem. An example is the United States Department of Veteran Affairs, one of ResMed's largest customers. These customers will order large quantities of ResMed product, house it in their own inventory systems, and then serve their own patients. Generally, these orders carry the lowest cost-to-fulfill for ResMed as their high order quantities lead to favorable shipping terms and minimal additional handling at the distribution center. These customers are most likely to benefit from optimized ship-packs.

"Digital-Wholesalers" refers to large companies that have their own patient ecosystem but a significantly larger number of branches and distribution centers than "Nationals". These orders are difficult to reduce operational costs, as orders are fulfilled in multiple small shipments to customers' addresses disbursed across a wide geographic area. However, this thesis outlines the costs incurred by these customers to ResMed operations. This baseline analysis is the first of its kind for the company.

Lastly "HMEs" is a blanket term for the smaller customers of ResMed. These customers may be servicing as few as 1-3 patients. They may be a small family office in rural Georgia. Additionally, these customers do not benefit as much from optimized ship-pack sizes, except in the cases where ship-pack size recommendations are very small. However, ResMed can benefit from influencing these customers to order on a weekly, monthly, or quarterly basis.

1.3 ResMed Distribution Operations

ResMed's North America distribution operations are simplified in Figure 1.

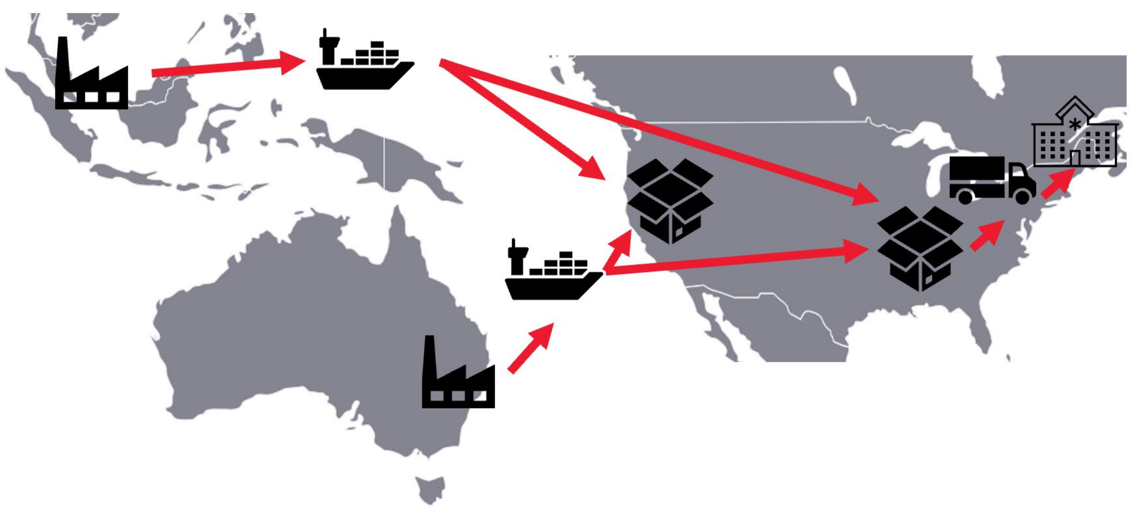

Figure 1. Simplified Version of ResMed's Distribution Chain

This thesis focuses on ResMed's North America Operations. ResMed manufactures product in Sydney and Singapore. Product is then shipped via sea or air freight to two distribution centers. These distribution centers are in Moreno Valley, CA and Atlanta, GA. Product is placed into the inventory at these locations until an order is released and product is shipped to the customer. Customers may then have their own distribution chains to the end user. Each portion of this distribution chain incurs costs to ResMed. These costs are further detailed in a later section.

From October 2021 to September 2022, ResMed fulfilled orders of over 80M products for over 5K customers. The cost of this operational endeavor was around $50M. Therefore, a reduction of operational costs by even 2% can result in $1M of savings which can be reinvested in product, pricing incentives, or other areas.

Product is packaged in Sydney in a ship-pack configuration. For example, Mask 1, one of ResMed's most popular products, may be shipped in a quantity of 32. Masks may look like the one depicted in Figure 2. These ship-packs are then placed on a pallet of 15 ship-packs for a total product quantity of 480 per pallet. These numbers are the result of an optimization to maximize product per pallet. This ensures that ResMed is minimizing logistics costs between manufacturing and distribution on a per product basis. Each product has its own unique ship-pack quantity and pallet quantity; however, most products share a similar ship-pack size as ResMed has sought to consolidate the number of ship-packs in inventory at their manufacturing sites.

Figure 2. A ResMed Mask

Once a pallet of Mask 1 arrives in Atlanta, it can take several routes within the warehouse based on customer orders and available inventory. These various routing paths are illustrated in Figure 3 and detailed below.

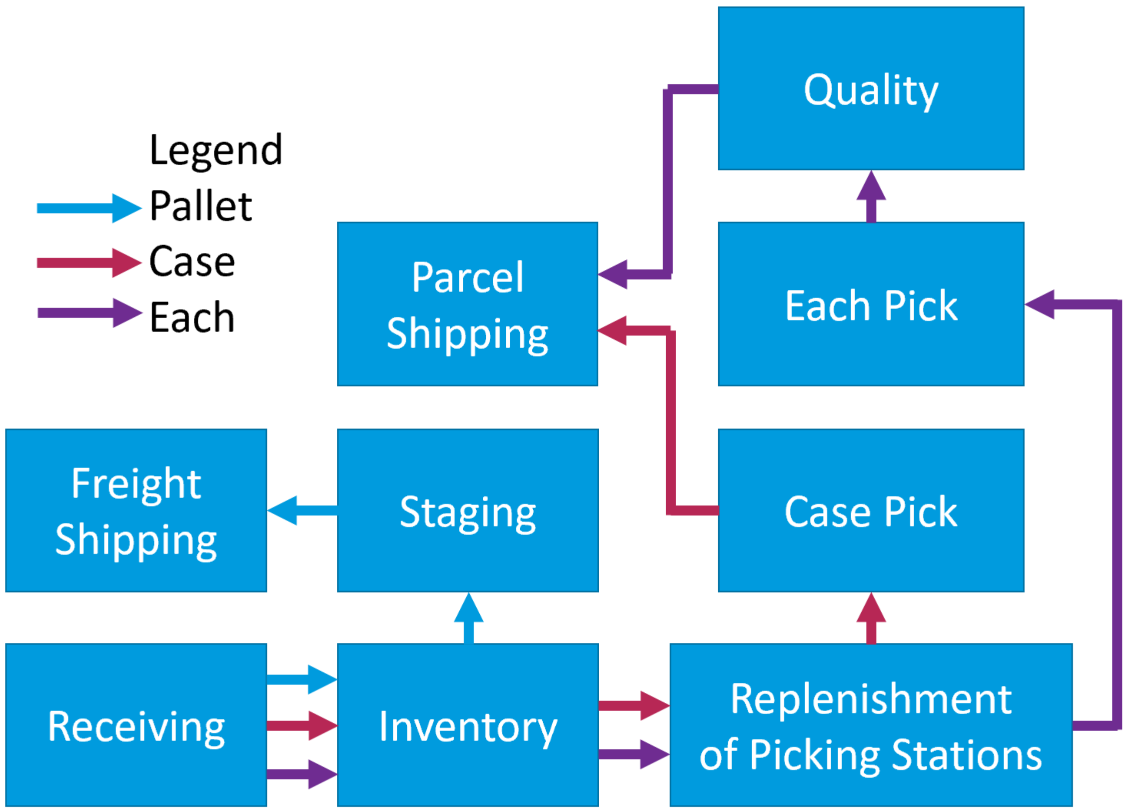

Figure 3. Simplified Version of ResMed's Warehouse Operations

Product arrives as a pallet at "Receiving". Product is then placed into "Inventory" in the digital management system. If a customer has ordered a pallet, then the pallet is moved to "Staging" and then out of the warehouse via "Freight Shipping". These are the cheapest orders to fulfill, as they incur minimal handling and have the most generous freight terms on a per kilogram basis. A pallet of product is shown in Figure 4.

Figure 4. Pallet of Product

"Case-Orders" are fulfilled in the original ship-pack configuration. Pallets are placed into a physical inventory system consisting of several rows of shelving. When an order is released the pallet, or a number of ship-packs, are retrieved by an operator in a forklift and placed on a belt at the "Case-Pick" module. These orders are relatively easy to fulfill. Operators release the product as appropriate, and the ship-pack is prepared to be sent to the customer. It is important to recognize that the ship-pack is never opened, and that the customer is receiving the same ship-pack that left manufacturing. This is great from an operational standpoint as there is no need for a new box, no need for additional handling, and minimal complexity.

"Each-Orders" are fulfilled similar to "case-orders", however instead of the forklift operator placing product in the "Case-Pick" module, they place them in the "Each-Pick" module. This area is teeming with personnel. Operators must cut open the ship-pack boxes, pick out the individual number of products ordered, place these items in a new box, and then send it down the line for additional handling in a "Quality" section. This process incurs quality issues such as shipping too little, too much, or the incorrect product to customers. The basis of this thesis is to minimize the amount of product that moves through as an "each-order" and increase the amount of product shipped as a "case-order" and "pallet-order". All orders are then given to third party logistics companies in the "Parcel Shipping" area.

ResMed operational costs as pertains to order fulfillment were around $50M for the past fiscal year. These costs are generally composed of shipping (70%), labor (30%), distribution boxes (2%), and customer complaints (1%). All percentages are approximate. Although operational costs due to customer complaints are relatively small compared to the other segments, they have several difficult to quantify and qualitative consequences which are covered in a later section.

1.4 Project Motivation

The project charter was to identify opportunities within ResMed Commercial Operations to:

1. Increase customer satisfaction
2. Reduce ResMed spend
3. Increase revenues

Through conversations with 34 “ResMedians” and external partners across Commercial Operations, Customer Service, Distribution, Finance, Logistics, Manufacturing, Marketing, Product Engineering, Pricing and by analyzing ResMed’s past year fulfillment of 2M customer orders for 80M products, the project focus narrowed to case-pack optimization. ResMed’s growth has led to a non-optimized supply chain as the operations team has tried to meet increased market demand. ResMed needs to quantify their cost to fulfill so that they can know where to focus efforts to reduce costs. This can be accomplished by optimizing ship-pack quantities and influencing customers to order on a predictable and recurring basis.

1.5 Problem Statement

The problem statement of this thesis is to create a model to accurately detail the total business costs of ResMed’s fulfillment operations. This model must be able to be utilized by ResMed’s operations team to optimize ship-pack configurations and to showcase the cost savings of influencing customer ordering behavior.

1.6 Methods

1.6.1 Digital Data Gathering

Customer order data is housed in a third-party cloud provider. A single line of order data includes the customer's name, shipping address, order date, shipping date, SKU, and ordered quantity. ResMed's North America Operations fulfilled 2M customer orders for 80M products in the past fiscal year. This annual data was then imported into Tableau and Microsoft Excel for further analysis. The optimization model was created and distributed to the Commercial Operations team on Microsoft Excel, due to the team's familiarity with the program and ease of obtaining insights.

1.6.2 On-site Data Gathering

Data was collected at both of ResMed's North America distribution centers. Data gathering included site visits, interviews, and time-series studies. This thesis is informed by interviews of 34 "ResMedians" across manufacturing, marketing, finance, operations, logistics, and engineering. Time-series studies were conducted at the Atlanta distribution center for the three fulfillment types: each, case, and pallet picks. These time series studies established an average "touch-time" for each fulfillment type. This "touch-time" would inform the average labor rate incurred to fulfill an order. These time-series studies were then validated through conversations with distribution center leaders and an analysis of the distribution center's average daily distribution throughput recorded on the digital cloud.

1.6.3 Data Validation

The model's output was compared against the known annual operations costs outlined in section 1.3. The model's predictive operational costs, including expected error rates, are within 8.2% of the actual operational expenses. This error rate and the model's validation are covered in further detail in section 3.2.

1.7 Literature Review

Case-pack optimization with specific regards to distribution chains, has sparse sources in the literature. Most research in conjunction with optimal ordering has focused on the Economic Order Quantity (EOQ). EOQ is the order quantity that minimizes total holding and ordering costs for the year [4].

The research detailed in this section has generally centered around two-echelon distribution systems, in which a single company operates both the distribution center and retail stores. This is not the case for ResMed, as ResMed is generally not selling physical products directly to end-users. Therefore, EOQ is not relevant to this thesis. Principally, because ResMed is generally solely the supplier of product. ResMed would benefit from customers implementing predictable EOQs on a rolling basis. However even then, there is still room for case-pack optimization because ResMed will lower operational costs by avoiding fulfilling orders as "each-orders".

Karimi, Graves, and Ren [5] explored ship-pack optimization in a two-echelon distribution system with product obsolescence. They modeled cost elements as functions of ship-pack quantities. They explored the following cost components:

1. Distribution center receiving operations
2. Distribution center put-away operations
3. Distribution center picking operations
4. Store handling costs
5. Inventory-related costs

They found that 65.6% of Stock Keeping Units (SKUs) were already operating at the optimal ship-pack quantity. However, a change to the remaining SKUs resulted in operational savings of 9%. The difference between ResMed and Gamma, the company they investigated, is that ResMed is not concerned with store handling costs or inventory-related costs as pertains to the store, as these are the operations of ResMed's customers. Additionally, the authors created a model based on predictable ordering tendencies that Gamma controls. ResMed does not have that luxury, as they are sending product to customers that have their own individual ordering and inventory policies. Also, they do not model transportation costs, which are one of the most significant cost components for ResMed. However, the methodology by which they developed the distribution center cost functions are relevant to this thesis.

Wen, Graves, and Ren [6] analyzed a retailer employing a two-echelon distribution system. They specifically focused on three ship-pack choices: "each", "inner", and "case". This is analogous to ResMed's distribution chain which differentiates between "each-orders", "case-orders", and "pallet-orders". Similar to ResMed, Beta the company they researched, observed greater handling costs for "eachs" at the distribution centers due to warehouse associates spending time cutting open cases to fulfill smaller orders. Differences between ResMed and Beta are similar to those outlined in the previous paragraph. Additionally, the authors made an assumption that transportation costs are irrespective of ship-pack choices as Beta replenishes stores on a fixed schedule. This is not the case for ResMed, as they use third-party logistics firms, such as the United Postal Service, to send product as customers order. The authors were able to conclude that their ship-pack optimization model could reduce operating and inventory holding costs by 0.3-0.4%, a major cost savings for multi-billion-dollar revenue retailers.

Byanna [7] continued the work of the previous research into Gamma, by incorporating the cost penalties associated with lost sales due to ship-pack optimization. Additionally, the author modeled obsolescence costs as it pertains to a seasonal retailer. Although neither of these developments pertain to ResMed, the conversation pertaining to lost or gained sales due to ship-pack optimization will be discussed in later sections. The author found that the retailer could save up to 1.8% of costs on a per-product basis by moving to optimal ship-pack quantities and restricting fulfillments to multiples of ship-packs.

Wensing, Sternbeck, and Kuhn [8] analyzed the impact of ship-pack sizes on distribution logistics efficiency for non-perishable products in grocery retailing. They assume that transportation costs are not influenced by the ship-pack size based on a study of packaging density. This assumption does not hold for ResMed, as will be detailed in a later section. They identify that some SKUs ship-packs need to be enlarged, and some need to be reduced. Interestingly, they realized that most cost savings can be incurred by creating “one case-pack size for all stores”. This could be a potential option for ResMed, if they are able to appropriately segmentize their customer base and offer tailor made ship-packs for certain customer bases. However, creating multiple distinct ship-packs is non-trivial for the medical device industry, as the cardboard boxes must undergo strenuous testing and certification due to regulations in the industry. The authors concluded with a case study of a large European retail chain and found potential cost savings of 20% by optimizing ship-packs.

Argueta, Cardona, Alban, and Moreno [9] conducted an analysis of a Colombian consumer packaged goods company. They took into account the cost considerations mentioned above but expanded the research to account for cost of ship-pack boxes, maximizing pallet space, transportation costs, and the marketability of the ship-packs to customers. The last element is not pertinent to ResMed for this model but will be touched on in a later section. The authors found significant cost savings associated with reducing distribution center handling time. Overall, their model was able to project a total logistics cost savings of 8.2% through ship-pack optimization.

The cost-to-fulfill model detailed in the next chapter is novel to this literature. The model is capable of recommending ship-pack changes based on manufacturing packaging costs, transportation costs, handling costs, distribution packaging costs, and customer complaint costs for real-world demand. This model, unlike the previously cited, is unique to a company primarily operating as a distributor of their product, rather than owning the end-user interaction.

Chapter 2: Cost-to-Fulfill Model

2.1 Overview

The cost-to-fulfill model captures the operational cost of fulfilling an order. These operational cost elements include manufacturing packaging costs, distribution center labor costs, transportation costs, costs incurred by customer complaints, and distribution center packaging costs. Transportation and distribution center labor costs are further differentiated based on the type of order. Customer orders can be bucketed into 16 order categories. These order categories were created during this research. These categories each incur unique cost elements due to their fulfillment type. These are outlined in Table 1.

Example Product	Mask 1	Ship-Pack/Case QTY 32	Pallet QTY 480
Category Name	Example Order Quantity	Category Name	Example Order Quantity
Pallet	480	Pallet & Within 30% of a Case	503
Case	32	Case & Within 10% of a Case	62
Pallet & Case	512	Case & Within 20% of a Case	60
Each	5	Case & Within 30% of a Case	56
Case & Each	34	Pallet & Each	485
Mixed	515	Within 10% of a Case	30
Pallet & Within 10% of a Case	510	Within 20% of a Case	27
Pallet & Within 20% of a Case	508	Within 30% of a Case	24

Table 1. Order Categories

Generally, the optimization model will try to reduce the number of orders that fall outside of the "Pallet", "Case", and "Pallet & Case" categories. The differentiation of orders within 10%, 20%, and 30% of a case, does not impact the total operational costs incurred by fulfillment. However, they are important to highlight so that ResMed knows which customers are almost ordering in optimal quantities. These are customers that they can potentially influence to order in multiples of ship-packs.

The model only focuses on one SKU at a time. This is because each SKU may necessitate a unique ship-pack size. However, the model is easily adaptable to incorporate any type of SKU.

2.2 Assumptions

2.2.1 Inventory

The model assumes that inventory is available in the warehouse for shipment. Due to logistics constraints, ResMed is often forced to send product in split shipments. For example, let us assume that a customer ordered 32 of Mask 1, but there is only 17 available in the warehouse. Typically, ResMed would send the 17 items to the customers as soon as possible, and then wait until the remaining arrived at the warehouse. This is known internally as a "split-shipment". This is ignored for a variety of reasons. First, ResMed believes that their inventory will become right-sized as the logistics industry continues to recover from COVID-19 pandemic induced constraints, specifically as pertains to suppliers in China. Additionally, ResMed can potentially move to a "release-when-available" policy for certain customers. This would mean that the example order of 32 would not be sent to a customer until all 32 items are in inventory.

2.2.2 Split-shipments

The model assumes that orders are fulfilled from one warehouse. Similar to the above assumption, if ResMed receives an order of 32 for Mask 1 and 17 are in Atlanta and 15 are in Moreno Valley, then they may fulfill this single "case-order" as two "each-orders". This is indicative of ResMed's commitment to their customers but is ignored as a possibility in the model.

2.2.3 Pallets

The model assumes that all "pallet-orders" are fulfilled as pallets. For example, if ResMed does not have a full pallet of product on hand, then they may build the pallet from available inventory in the warehouse. Using Mask 1 as an example again, if a pallet is not available, then the distribution center team will pick 15 ship-packs through the "case-pick" module and build the pallet from the ground up. This should then incur a labor cost equivalent to 15 "case-orders", rather than one single "pallet-order". However, due to the lack of data tying built pallets to order numbers, this is not accounted for.

2.2.4 Freight

The model assumes that all orders are fulfilled on the same freight terms. This average is detailed in a following section.

2.2.5 Distribution Packaging Costs

The model assumes that all distribution packaging costs are the same. These costs are incurred by using generic boxes between 900 and 5,000 cubic inches. This average is detailed in a later section.

2.2.6 Manufacturing Packaging Costs

The model assumes that all manufacturing packaging costs are the same for different types of boxes used. This average was used because specific cost numbers could not be obtained.

2.2.7 No Scalable Freight Cost Reduction

The model assumes for simplicity that there are no economies of scales gained with freight companies. For example, the operational cost of shipping one pallet today and one tomorrow is the same as shipping two pallets today. In reality, a company may be able to negotiate favorable freight terms on large orders.

2.3 Customer Ordering Data

The model uses customer ordering data for North America between October 2021 and September 2022. This period was used to model the most up-to-date order fulfillment and to compare cost savings to the past fiscal year's operational costs. The model focuses on ingesting unique order numbers, SKU name, and SKU quantity. Order numbers are unique to customers. Order numbers are also unique to destination. For example, if a customer were to order 100 items of one SKU, but send them to two locations, this would be two orders summing to 100 total items. For example, 55 to one location and 45 to another location. The reason for this choice is to match distribution operations with customer ordering behavior, thereby not impacting customers. This choice is consistent with ResMed's mission to create best-in-class customer service. Later, an analysis is shown of operational savings if customers were restricted to ordering on a weekly, monthly, and quarterly basis.

2.4 Function

2.4.1 Optimization Function

$$TC = \sum_{j=1} \sum_{i=1} LC + FC + CCC + MPC + DPC \tag{2.1}$$

TC is the total cost of ResMed's fulfillment operations. Total costs are summed for all SKUs j. Total costs are summed for all orders i. LC is the labor cost. FC is the freight cost. CCC is the customer complaint cost. MPC is the manufacturing packaging costs. DPC is the distribution manufacturing cost. All the variables within the summation are unique for a particular order and SKU combination. These individual costs drivers will be detailed in further sections.

2.4.2 Labor Costs

$$LC = p * plc + c * clc + e * elc \tag{2.2}$$

LC is the labor cost of a unique order and SKU combination. p is the number of pallets in an order. plc is the pallet labor cost. c is the number of cases in an order. clc is the case labor cost. e is a binary variable for whether or not the order processed as an "each order". elc is the each labor cost.

Each node of the distribution chain shown in Figure 1 has an associated labor cost, based on the number of personnel operating the node and the amount of time a single product is processed. Labor costs are based on the type of order categories.

For example, for a mixed order of 515 of Mask 1, there would be a one *plc,* one *clc*, and one *elc*. For another example, for an order of 64 of the same SKU, there would be no *plc*, two *clc*, and no *elc*.

2.4.3 Fulfillment Type

$$p = \left\lfloor \frac{oq}{pq} \right\rfloor \tag{2.3}$$

$$c = \left\lfloor \frac{oq - p * pq}{spq} \right\rfloor \tag{2.4}$$

$$eq = oq - p * pq - c * spq \tag{2.5}$$

$$e = \{0,1\} \tag{2.6}$$

$$eq \leq e * M \tag{2.7}$$

p is the number of pallets for an order. *oq* is the quantity of product that a customer ordered. *pq* is the pallet quantity, or the amount of this specific SKU that can fit on one standard shipping pallet, as seen in Figure 4. *c* is the number of cases that an order demands. *spq* is the ship-quantity. The ship-pack quantity is the number of items in a ship-pack or case. Each SKU has a unique *spq*. This is the decision variable for the model. The model will vary *spq* to find the optimal quantity that each SKU should be packaged in at the manufacturing site. *eq* is the each quantity. This is the amount of items that must be processed through the "each module" because they are smaller than the size of a ship-pack quantity or case. *e* is the condition of whether an order requires processing through the "each module". *M* is equivalent to the ship-pack quantity.

Orders are fulfilled in three methods as stated in the previous chapter. Orders are fulfilled as “pallet-orders”, “case-orders”, or “each-orders”. Some orders are a mix of two or all three of these types of orders. The fulfillment type associated with each order is unique to the ship-pack quantity, *spq*. An order will have a unique number of pallets, *p*, cases, *c*, and “eachs”, *eq*.

If an “each order” consists of one or 31 items, there is no difference for the labor cost. This is because the process of fulfilling an order of one item or 31, in the case of Mask 1, is generally the same. An operator picks out either one or 31 masks and places them into a generic box. The only difference is the operator having to count one or 31 masks. The time that a box is on the conveyer belt is similar. This is why *e* is either 0 or 1.

2.4.4 Freight Costs

$$FC = FBC * \left(p + c + \frac{e}{uip}\right) + FWC * sw * (p * pq + c * spq + eq) \qquad (2.8)$$

FC is the freight cost of a unique order and SKU combination. *FBC* is the freight base cost. *uip* is the unique number of items in an order. *FWC* is the freight weight cost. *sw* is the SKU’s weight.

Freight data was compiled in partnership with a third-party freight auditor. The source data is difficult to incorporate as freight tracking numbers are not matched to order numbers. Therefore, we cannot properly identify the freight costs of any particular order number.

Therefore, generalizations were created based on cost per kilogram. Data was initially segmented into 330 different categories, based on weight and company service levels. An example of a company service level is Federal Express 2 Day Economy. Analysis of the data showed a natural grouping of 6 freight categories. These categories provide a $/kg basis which is used to calculate freight costs for any individual order.

Freight costs are also based on initiation costs. For example, for personal shipping with a national carrier, there may be a cost curve such as the one show in Figure 5:

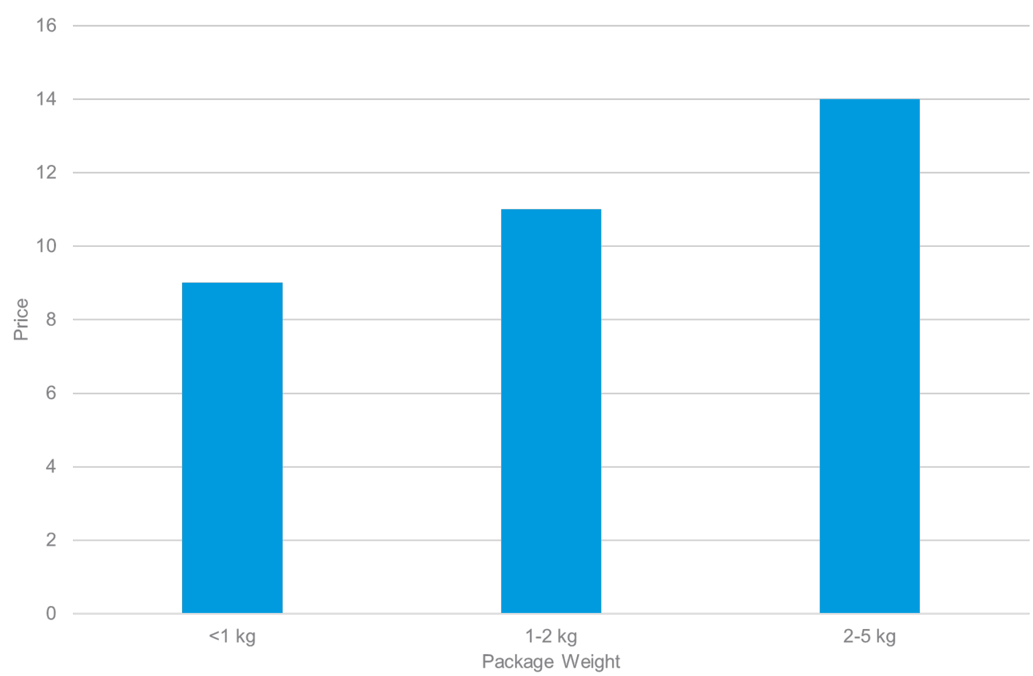

Figure 5. Example of Personal Shipping

In this example, there is an initiation fee of $9.00, and then subsequent additional charges based on the weight of the package. Each order will carry an initiation fee, *FBC*, which will be the same regardless of the order category.

Small orders tend to include multiple SKUs in one box. For example, the customer may order one mask, one CPAP device, and three filters, and due to the size of these items, they can all be placed into one package. Therefore, the model uses a constant, *uip*, to indicate the amount of unique items in a package. Multiple SKUs will share the cost of packaging and of the freight base cost. In the above example, there would be a packaging and freight base cost for the one mask, the one CPAP device, and the three filters, but those costs would sum to the cost of one package. The constant, *uip*, is the average number of unique items found in small "each-orders".

2.4.5 Customer Complaint Costs

$$CCC = \frac{e}{oqsku}(CTS + elc + FBC + FWC * e * sw + DPC) \tag{2.9}$$

CCC the customer complaint cost of a unique order and SKU combination. *oqsku* is a constant, as the total number of "each-orders" from the previous fiscal year. *CTS* is cost-to-serve of the customer service team. *DPC* is the distribution packaging cost.

Customer complaint costs were based on customer complaints unique to shipping incidences in FY 2022. Examples of shipping induced customer complaints include the following:

1. Over-ship – Too much product was sent to the customer
2. Short-ship – Too little product was sent to the customer
3. Incorrect product – The wrong product was sent to the customer

Analysis of the data showed that 96% of customer complaints were tied to "each-orders". This makes sense, as these are the orders where manual labor is introduced into the process. For example, for an order of 31 of Mask 1, an operator must cut open a box and count exactly 31 items. This process lends itself to errors. Due to the high rate of customer complaints associated with "each-orders", this cost function is only applied to "each-orders".

Each of these three types of complaints induce a labor cost associated with the customer service center, a freight cost, a distribution center labor cost, and a distribution packaging cost, as the company sends product or receives product.

Every "each-order" has the potential to become a customer complaint. Customer complaints are not unique to products but are unique to processes of the distribution chain. The constant *oqsku* allows for the known customer complaint costs from the previous fiscal year to be applied to individual orders.

2.4.6 Manufacturing Packaging Costs

$$MPC = \frac{oq}{spq} mb \qquad (2.10)$$

MPC is the manufacturing packaging cost. *mb* is the manufacturing box cost.

Manufacturing packaging costs are based on estimates of the cost of packaging at the manufacturing sites in Sydney and Singapore. Costs are spread across all the products that make a ship-pack quantity. For example, if the cost of packaging was $1.00, and the ship-pack quantity was 10, then each individual item would carry a manufacturing packaging cost of $0.10.

2.4.7 Distribution Packaging Cost

$$DPC = \frac{e}{uip} db \tag{2.11}$$

Distribution packaging costs are based on estimates of the cost of packaging at the distribution centers in Moreno Valley, CA and Atlanta, GA. Costs are only associated with "each-orders", as "pallet-orders" and "case-orders" are fulfilled with the original ship-pack. The cost of a package is irrespective to how many items make up an "each-order". If a customer orders five masks or one mask, they will receive the same box, and therefore ResMed will incur the same distribution packaging cost.

2.5 Constraints

This section details two constraints to the model.

2.5.1 Pallet Density

$$\frac{pq}{spq} \in \mathrm{Z} \tag{2.12}$$

Recommendations are constrained to maximize pallet density. In other words, the ship-pack quantity is constrained to numbers that maintain the current pallet quantities. When dividing the pallet quantity by the ship-pack quantity, the quotient must be an integer. ResMed has spent years optimizing pallet density, and this will not change at this time.

There is potential for this constraint to be relaxed under one condition. This condition is that the sum of cost savings for all the above cost drivers outweighs the transportation costs between manufacturing and the distribution centers. As of this writing, those transportation costs are the most expensive operational cost at ResMed, and therefore this constraint cannot be relaxed.

2.5.2 Ship-Pack Size

$$spq \leq 100 \tag{2.13}$$

Ship-packs must fit on the conveyer belts of the picking modules. Therefore, there is an upper limit to their size. The solution space has been restricted to ship-pack sizes of and below 100 items.

2.6 Summary of Variables and Parameters

Table 2 below presents a summary of the variables used.

Symbol	Variable	Symbol	Variable	Symbol	Variable
oq	Ordered Quantity	*elc*	Each Labor Cost	*CCC*	Customer Complaint Cost
p	Pallets in an order	*clc*	Case Labor Cost	*CTS*	Cost-to-serve a Complaint
c	Cases in an order	*plc*	Pallet Labor Cost	*MPC*	Manufacturing Packaging Cost
e	Eachs in an order	*FC*	Freight Cost	*mb*	Manufacturing box cost
pq	Pallet Quantity	*FBC*	Freight Base Cost	*DPC*	Distribution Packaging Cost
spq	Ship-pack Quantity	*FWC*	Freight Weight Cost	*db*	Distribution box cost
eq	Each quantity	*oqsku*	Order quantity of all SKUs	*uip*	Average unique items in a distribution package
LC	Labor Cost	*sw*	SKU weight		

Table 2. Summary of Variables and Parameters

2.7 Chapter Summary

This chapter details the cost-to-fulfill model that can optimize ship-pack quantities to minimize total operational costs across the entire distribution chain, from manufacturing to the customer. This chapter details the assumptions, constraints, inputs, decision variable, and minimization function of the model. This model is novel to the literature in that it considers manufacturing packaging costs, customer complaint costs, and transportation to the customer. Additionally, this model is unique in that it serves for a distributer of product to customers, rather than as a two-echelon distribution system. The following chapter will summarize the findings of the model's output.

Chapter 3: Analysis

3.1 Overview

This chapter details the results of the model described in Chapter 2. First, the current cost-to-fulfill is described, with details on achieving validation when compared to the actual operational costs of ResMed. Second, the findings of the optimization model are described, and a specific use case is highlighted. Third, a secondary finding is described which pertains to the implementation of weekly, monthly, and quarterly ordering cadences. This chapter concludes with a discussion of pricing levers, qualitative benefits, and future research opportunities.

3.2 Current Cost-to-Fulfill

The model was first analyzed based on current ship-pack quantities. ResMed carried over 1500 SKUs in the past fiscal year. Due to the computational intensity of importing data and running the model, only the top selling 54 SKUs were chosen. These SKUs constitute over 50% of order numbers and over 60% of ordered quantity. That is, these items were present in over 50% of total orders and were over 60% of the actual product that flowed through the distribution center.

Two cost estimates were used to validate the model. One was based on extrapolating operational costs across all orders based on the percentage of order numbers calculated by the model. The other was based on extrapolating operational costs across all orders based on the percentage of ordered quantity calculated by the model. The reason for choosing both methods for validation are the following. For one, it is not the case that the top selling items by order number are necessarily the same as the top selling items by ordered quantity. Order numbers will undergo their own journey through the distribution chain. This will incur operational costs, as outlined in the previous chapter. However, ordered quantity also influences these operational costs, as that will influence cost functions through the variable oq. Therefore, both methods were chosen to try to validate the model.

The model was validated by comparing the cost-to-fulfill output with actual costs over the past fiscal year. A multiplier was applied to the model outputs, to account for the remaining order numbers and ordered quantity. When the order number multiplier is applied, the model overshoots the actual operational costs by 5.1%. When the ordered quantity multiplier is applied, the model undershoots the actual operational costs by 11.2%. Any conclusions from the model must account for this range of outcomes, 5.1% above and 11.2% below the calculated average. The truth of the model output lies somewhere in the middle. As SKUs are added to the model analysis, we see a small decrease in operational expenses when considering order numbers. On the other hand, as SKUs are added, we see a larger increase in operational expenses when considering ordered quantity. The only way to truly validate the model would be to calculate the operational output for all 1500 SKUs. Figure 6 compares the actual operational costs with the two types of model validation.

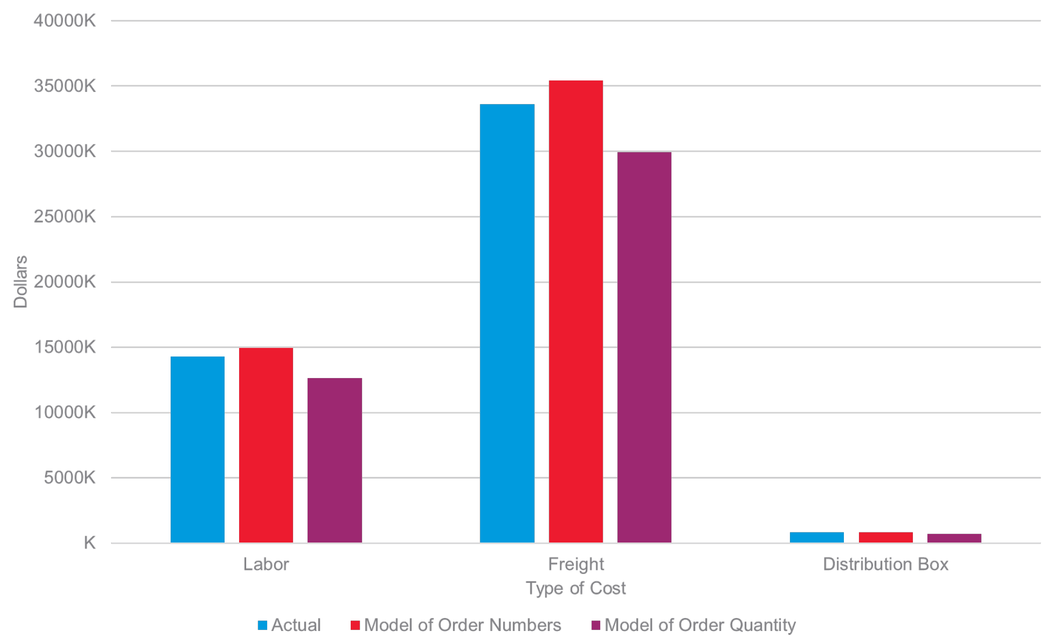

Figure 6. Model Validation

The cost-to-fulfill model is the first time that ResMed has visibility on the cost of fulfilling orders across the entire distribution chain. This analysis is crucial to implementation of cost saving measures for two reasons. First, ResMed can see that only a few SKUs alone account for over 14% of operational expenses. Although it may be unlikely that ResMed changes ship-pack quantities for all items, the current cost-to-fulfill model will indicate where they should deploy company resources to tackle the largest cost drivers.

Second, the cost-to-fulfill model breaks down customer ordering behavior. ResMed can see which customers are closest to ordering in ship-pack quantities, and the associated costs for them not doing so. This allows the sales team, operations team, and customer service team to focus on influencing customer behavior that will drive immediate operational cost benefits. This insight is crucial to piloting programs to optimize customer behavior that can later be expanded to the rest of the customer base.

3.3 Optimized Ship-Pack Cost-to-Fulfill

The optimized ship-pack cost-to-fulfill model finds that ResMed can save over 5% or over $2M dollars, by optimizing ship-pack quantities. The bulk of this cost savings is in minimizing multiple shipments of product and reducing labor costs at the distribution centers. Interestingly, some SKUs increase in ship-pack quantity, while some SKUs decrease in ship-pack quantity. This is expected, as there is a balance between larger packages saving costs at the manufacturing site, and reducing the freight base costs, but incurring larger costs due to distribution center handling. Ultimately each SKU will be different, as they are trying to conform to customer ordering behavior.

Figure 7 shows the cost savings associated with five ship-pack changes of some of the top selling items of the past fiscal year. The blue bar indicates the new operational costs if case changes were implemented. The red bar indicates the cost savings from the current baseline. The current baseline is the aggregate of the blue and red bars for each mask.

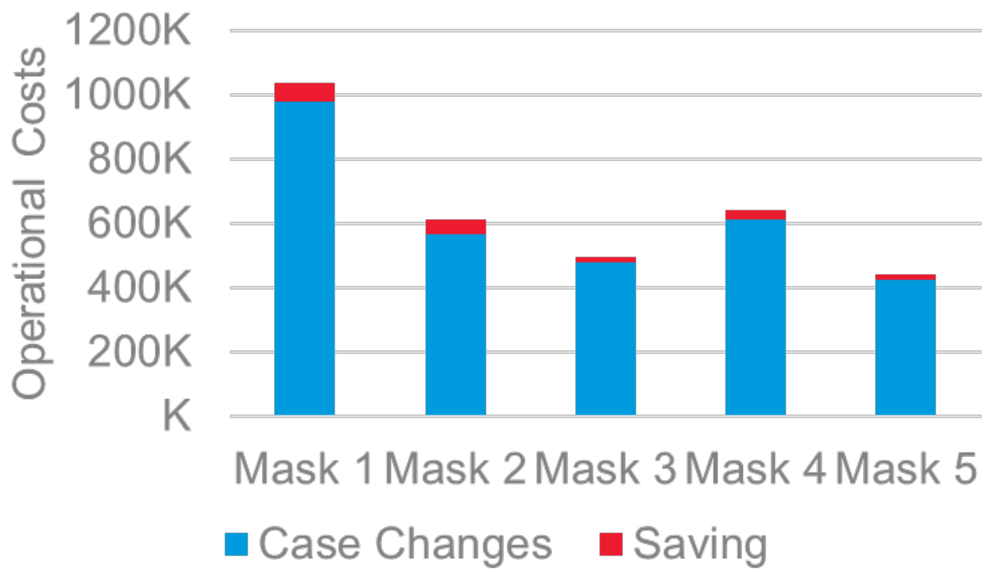

Figure 7. Total Savings from Five Ship-Pack Changes

These savings must be balanced with costs not captured by the model. Mainly this is the capital investment of certifying new boxes. This cost function should include the labor cost of the ResMed packaging engineers to design a new box, the cost of testing the product with a new box, and any increased costs due to renegotiating with a supplier. Despite these potential costs, they are unlikely to reach 5% of operational expenses. Additionally, this capital investment would be on a one-time basis, whereas the cost savings would be realized on a recurring annual basis from the current baseline.

3.4 Optimized Ordering Cadence Cost-to-Fulfill

An additional study was conducted using the cost-to-fulfill model. This study analyzed customer ordering behaviors and sought to identify operational cost savings by influencing customer behavior. This motivation led to the creation of a secondary model; the optimized ordering cadence cost-to-fulfill. ResMed stands to gain operational savings of over 9% or over $4M dollars if all customers were to move to a weekly ordering cadence.

This model operates similar to the one outlined in Chapter 2. The only change is that instead of ingesting unique order numbers, tied to customers and destination, the model aggregates all customer orders for a period. Customers are further separated by end destination. This is an assumption that even if customers were to order on a recurring basis, they may still want differentiated destinations based on their own retail sites, hospitals, and customers. Figure 8 show the cost savings from five top-selling SKUs by moving to an ordering cadence of weekly, monthly, and quarterly.

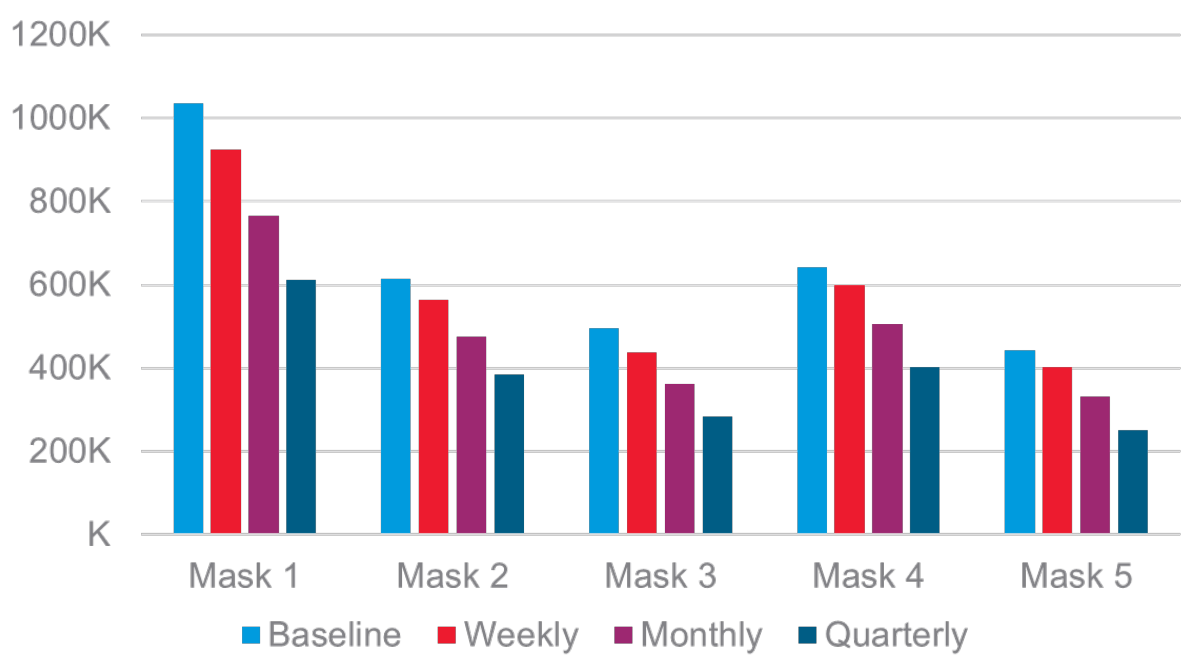

Figure 8. Savings from Customer Ordering on a Weekly, Monthly, and Quarterly Cadence

Although restricting customers to a monthly or quarterly basis may seem unrealistic, conversations with some customers indicate that monthly ordering is their preference. Due to the wide variety of customer segments that ResMed sells to, only a partial implementation of these cadences could be implemented. However, if all ResMed customers were to move to a monthly cadence, ResMed could realize operational savings of 24%. Savings would climb to 38% if customers were to order on a quarterly cadence.

3.5 Operational Costs from Digital Wholesalers

An unrealized study was conducted to analyze the cost of ResMed acting as a distributor for the “digital wholesaler” customer segment. ResMed is incurring significant operational expenses by distributing to multiple locations for “digital wholesalers”, rather than a single distribution center for these major customers. The model for this study was modified from the model in Chapter 2. This model aggregates orders by customers. This is a change, as the model outlined previously aggregated orders by customer and destination. Although this study was not carried to completion, one case study was developed for one of the largest customers of ResMed. Figure 9 outlines the findings.

Figure 9. Operational Costs from Digital Wholesalers

ResMed is incurring almost an additional $1M dollars on an annual basis for one of their major accounts. This is the first time that ResMed has an accurate account of how much it costs the company to fulfill orders in this way. ResMed may be able to use this information for future contract negotiations.

3.6 Pricing Levers

The medical device industry's economics are very complex. Different states have different reimbursement rates. Different health insurers have different reimbursement rates.

One area that companies can explore with this model, in particular with the optimized ordering cadence, is what pricing premiums or discounts they may want to offer customers to encourage ship-pack ordering. For example, by looking at the total operational savings from increasing "case-orders" relative to "each-orders", a company can then offer cost savings to a customer and still save overall by streamlining operations.

This may have the add-on effect of a revenue gain. For instance, if a customer is used to ordering 30 of Mask 1, and the ship-pack quantity is 32, they may incur a pricing premium due to the operational complexity incurred by the distributor. However, when properly incentivized to order 32 of this product, they avoid the premium and the distributor gains an additional sale of two items. Palazon and Delgado found that offering pricing premiums is more effective than pricing discounts for high price conscious customers [10]. This could be an area of interest for future research opportunities.

An analysis of pricing levers must include whether or not the increased ordered quantity on a per order basis leads to an overall increase in ordered quantity for the fiscal year. Customers may just “pull-forward” their demand to avoid pricing premiums on non-optimized order quantities. This would not result in an overall gain of sales from a customer.

Figures 10 and 11 illustrate the increased operational costs for non-optimal ordering.

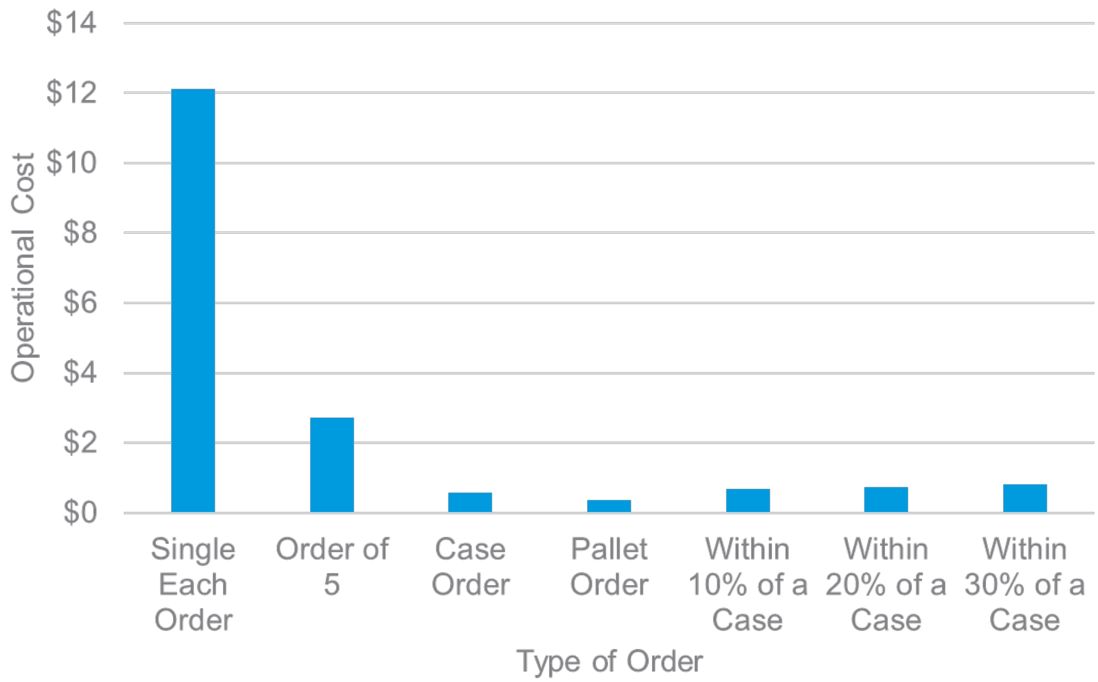

Figure 10. Operational Cost Per Product

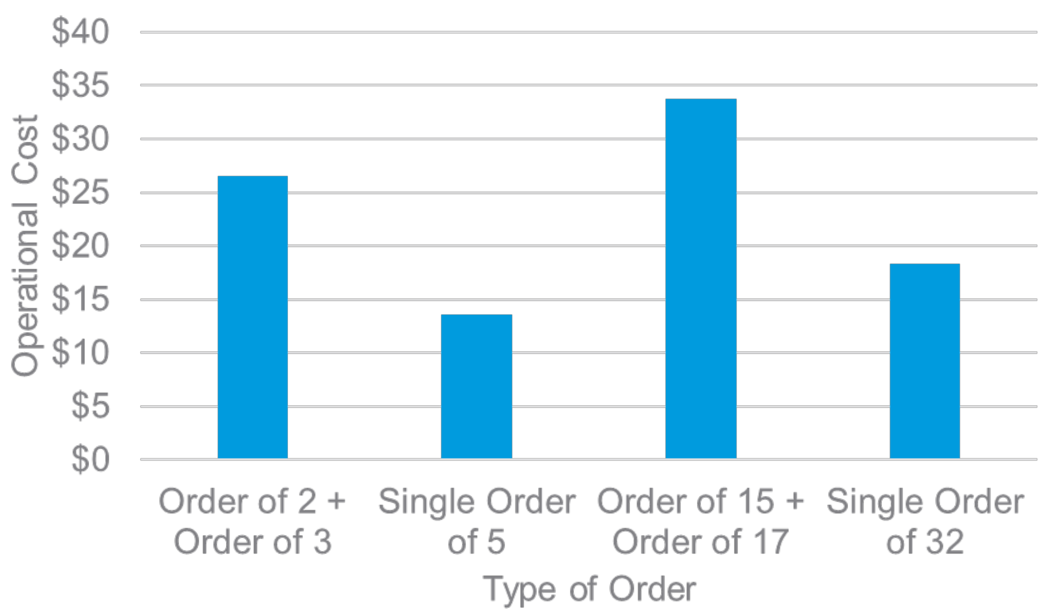

Figure 11. Operational Cost of Shipments

Figure 10 clearly shows the benefits of encouraging customers to order in optimal numbers. The cost of fulfillment of small orders is significantly higher than "case-orders". Figure 11 illustrates the costs incurred by sending multiple shipments of the same order. This is primarily driven by doubling of the freight base cost. A potential area of interest for ResMed is implementing a policy in which orders are only released when a customer has ordered a certain threshold quantity. This would avoid sub-optimal order quantities from being released and generating duplicative shipping and picking efforts.

3.7 Qualitative Benefits

The previous sections detailed quantitative benefits to ResMed by optimizing ship-pack quantities. In addition to these benefits, there are some qualitative benefits. These benefits are hard to quantify but could be the subject of another research thesis or focused project within ResMed.

3.7.1 Customer Complaints

It is likely that the cost of a customer complaint is higher than that captured by the model. For example, if a customer does not receive the correct product, this will create a negative impression of the company, and may induce a customer to purchase from a competitor. Conversely, providing a good customer experience is crucial to retaining customers. Reichheld and Schefter found that increasing customer retention rates by 5% can induce a profit increase of 25% to 95% [11]. Customer retention is crucial, as another study has found that the likelihood of selling to an existing customer is 60-70%, whereas selling to a new customer is 5-20% [12].

Should customer complaints escalate to higher management, these complaints would incur higher labor costs not captured by the current model. When they are attending to a customer complaint, they are not attending to the other portions of the business that need their focus. A customer complaint can morph into a case of crisis response, which leads to a significant drain on human capital resources.

An unpublished accompaniment study conducted during this thesis period into customer ordering behaviors after a customer complaint showed mixed findings. In some cases, customers would order less frequently after a customer complaint. However, in some cases, customers would increase their ordering frequency after a customer complaint. It may be that smaller HMEs are more susceptible to changing their suppliers after a bad shipping experience, as they are less likely to carry large inventories. Therefore, going days without critical inventory may impact their relationship with their own patients. Larger companies may be more immune to shipping issues, as they can still satisfy their own patients with their large inventories. This could be the subject of another thesis, to determine the true cost of a customer complaint to customer ordering frequency.

3.7.2 Marketing

ResMed brands their ship-packs as they leave Sydney and Singapore. The branding of this box costs ink, the maintenance of the ink pressing machine, and increased time on the line for the ink pressing process. A picture of a ResMed branded box is shown on Figure 12.

Figure 12. ResMed Logo on Ship-pack

This is a marketing opportunity for ResMed, as these packages are intended to go to their final customers. Additionally, packaging at the manufacturing facility may be done to incorporate aesthetic value to the customer. However, when a package is fulfilled outside of the ship-pack multiples, the ship-pack is cut open and discarded. ResMed is branding their boxes for their warehouse associates in this case. The product is then placed in an unmarked distribution box, and the customer is left to open a generic cardboard box upon receiving their product. An increase in "case-orders" relative to "each-orders" will increase the marketing reach of ResMed via branded boxes.

3.7.3 Operational Complexity

Decreasing "each-orders" relative to "case-orders" will decrease customer complaints, distribution handling time, and poor freight terms. There should also be additional benefits by reducing the operational complexity of the warehouse operation. Instead of numerous warehouse associates operating the "each-module", they may be able to focus on right-sizing inventory or improving throughput at another function of the distribution center. Reeves, Levin, Fink, and Levina found that increasing complexity in systems leads to a decrease in understandability of the system [13]. This can then lead to unmanageability and unpredictability. ResMed's operations have grown increasingly complex as local optimal solutions have been created to meet new customer segments. ResMed must ensure that any local solutions are not having a global negative impact on distribution operations. One potential solution is to create a modular distribution center. One side of the distribution center would be focused on shipping to larger customers with minimum order quantities, and one side of the distribution center would be focused on the needs to smaller customers.

3.8 Future Research Opportunities

3.8.1 Revenue impact by restricting customer ordering to ship-packs

An area of interest for ResMed is to potentially restrict customer ordering to ship-pack quantities. This may create a revenue gain, as customers who would typically order 80-90% of a ship-pack must now order the full ship-pack. However, this could also lead to a revenue loss if customers decide to search elsewhere. This can be further complicated by the idea of only restricting certain types of customers and establishing a pricing premium for orders outside of ship-pack quantities. Zhao and Katehakis detail how implementing minimum order quantity creates a challenge for customers to manage their supply chain efficiently [14]. ResMed may find that instigating this burden on their customers is not worth the operational benefits. This is a worthy area of further research to model the revenue impact of such decisions.

3.8.2 Assemble product at the Distribution Center

The costliest part of the distribution chain is shipping between overseas manufacturers and the distribution center. This leg could be eliminated if product was manufactured and assembled next to the distribution centers. This could then facilitate a distribution process by which SKUs have multiple ship-pack sizes for different customer segments. Customers would need to order within those ship-pack sizes; however, they would have a wide variety. The variety of ship-pack sizes would be due to the relaxing of the pallet density constraint, which is currently in place to minimize the transportation costs per product. A study from Bain & Company shows that improving the efficiency of a distribution network can lower costs by 10-25% and improve on-time delivery by 95% [15]. This is an interesting area of research, and any author would have to explore the various complexities and cost functions associated with moving manufacturing, or parts of the assembly process, to the customer's region.

Chapter 4: Conclusions

Ship-pack optimization affords companies a tool to significantly reduce operational costs and improve the customer experience. In addition to the quantitative savings incurred by reducing freight expenses, labor costs, and packaging costs, there are also several qualitative benefits. Qualitative benefits include an improved customer experience, more marketing opportunities, and reduced operational complexity.

Implementation of ship-pack changes requires successful prioritization from a company's leadership. Ship-pack changes in the medical device industry requires extensive testing and designing from packaging engineers. Ship-pack changes also impact customers. The sales and marketing teams must lead the effort to engage with customers about ship-pack changes.

This thesis detailed an optimization model for ship-pack quantities that accounted for the entire distribution chain from manufacturing to the customer. Companies must consider the entire distribution chain, as a change in ship-pack quantity may impact any of the several company functions detailed in Chapter 2. This model estimates that ResMed could save around 5% of operational costs by implementing ship-pack changes.

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