Evaluation of Outbound Operations Improvement Projects for Distribution Centers

by

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ABSTRACT

Improving the operations within a distribution center by reducing waste can result in significant cost savings. One area with a large potential for improvement is outbound order packaging. With a limited number of box sizes stocked and available in the distribution center to package orders, some orders will inevitably be shipped in boxes that are larger than needed, thus creating huge waste on the shipping cost. Three potential solutions are proposed to reduce the empty physical volume within shipping packages and thus reduce freight cost and waste. The three solutions are: introducing new packaging options such as envelopes and paks, creating an optimal box selection strategy, and adopting a custom box-making system to the current process flow. For each option a systematic evaluation method is established, containing the analysis on financial returns, implementation difficulty and resources requirements, and the sustainability impacts. The method is utilized to evaluate three solutions proposed for Waters Global Distribution Center specifically as a sample case study. Finally, recommendations are made to Waters Corporation based on the evaluation results.

Thesis Supervisor: Stephen C. Graves
Title: Professor of MIT Sloan School of Management and Mechanical Engineering

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Chapter 1. Introduction

1.1 Problem Statement

Improving the efficiency within a distribution center by reducing waste and optimizing process flow can result in significant cost savings regarding distribution center operations. One area with a large potential for improvement is outbound order packaging. Shipping costs are calculated by courier service providers based on the actual package weight or the dimensional weight, whichever is higher. With a limited number of box sizes stocked and available in the distribution center to package orders, some orders will inevitably be shipped in a box that is larger than needed to accommodate the products inside. This unnecessary extra volume means that some portion of the cost is due to shipping the air within the box—a cost that can be eliminated or reduced if a better packaging choice were to be utilized.

The team explored and proposed three potential solutions to reduce the empty volume within shipping packages and thus reduce freight costs. The three solutions are: introducing new packaging options such as envelopes and paks, creating an optimal box selection strategy/algorithm to assist workers in choosing the most economical stock box for packaging, and creating an integration plan for adding custom box-making technology to the current packing process flow.

1.2 Motivation

The motivation of this project is to reduce the waste caused by the unnecessary empty volume within shipping packages. This packing problem is quite common for distribution centers and there is huge waste in freight cost, as well as excess corrugate usage and more CO_2 emission. Therefore, it is valuable to develop some potential solutions, followed by detailed evaluation to quantify the impacts and difficulty of implementation.

1.3 Objective

The key objective for this thesis is to evaluate the three proposed solutions for packing problem from different perspectives to provide recommendations for distribution centers. An evaluation method for these outbound improvement projects at distribution centers will be established, and it will contain three main components – financial, implementation and sustainability. Then this method will be utilized to evaluate the three solutions proposed for Waters GDC specifically as a sample case study.

1.4 Scope

The scope of this thesis is limited to the proposal and evaluation of three solutions for domestic shipping at Waters Global Distribution Center (GDC). Special shipments, such as hazardous material and cold chain shipments, as well as international shipments (account for less than 10% of GDC total shipments) were not considered.

Furthermore, this thesis only analyzed three potential solutions from three main perspectives. There are other factors that may need to be considered for actual execution.

1.5 MIT Team and Work Distribution

The MIT team consisted of 3 people: Jessica Harsono, Bowen Zeng and Dehui Yu, the author of this thesis. The team analyzed the problem, established the baseline, and proposed three potential solutions together. Thus chapter 2 and 3 of this thesis were co-authored by the whole team. The author of this thesis focused on the adoption analysis of envelops/paks and the evaluation of the solution. Bowen Zeng's thesis [1] covers the development of the optimal box selection algorithm and its implementation. Jessica Harsono's thesis [2] covers the operational analysis regarding the implementation of the custom box maker

Chapter 2. Background

The Waters Corporation is the sponsor and host company for this thesis project and is the subject of the research conducted. This section provides background on the Waters Corporation as a business and breaks down the functions within their Global Distribution Center (GDC). The history of MIT's collaboration with Waters and relevant past thesis projects are briefly discussed to provide context and scope for this thesis.

2.1 Waters Corporation

Waters Corporation is the world's leading specialty measurement company focused on improving human health and well being through the application of advanced analytical science technologies. Founded by Jim Waters in 1958, Waters serves life sciences, food sciences, and materials sciences through a connected portfolio of chromatography, mass spectrometry, and thermal analysis innovations. With approximately 7,200 employees worldwide, Waters operates directly in 31 countries, including 15 manufacturing facilities, 3 distribution centers, with products available in more than 100 countries. The company's main headquarter is located in Milford, Massachusetts, U.S.A. [3].

Waters' products include high-performance liquid chromatography (HPLC), ultra-performance liquid chromatography (UPLC) and mass spectrometry (MS) technology systems and support products. In addition, the company also provides thermal analysis, rheometry and calorimetry instruments, as well as other software-based products [4].

Waters is a publicly-traded company listed on the New York Stock Exchange. The market cap was 13.99 billion USD on August 2nd, 2019 [5]. For the 2018 financial year, Waters had 2.4 billion USD revenue and 599 million USD free cash flow. Of the 2018 sales, 38% came from Asia (18% from China and 7% from Japan), 35% from America (28% from the US), and 27% from Europe. From the end market perspective, 56% of the revenue was from the pharmaceutical industry, 19% from material sciences and 15% from the food and environment market [6].

2.2 Waters/MIT Collaboration & Past MIT Projects

Waters and the MIT Master of Engineering in Advanced Manufacturing and Design program have collaborated annually since 2013 on projects ranging from product design, R&D, manufacturing process control, to operations improvement, and to supply chain. Every academic year, a team of MIT student researchers from the program address projects from various departments at Waters to realize current strategic goals and provide new perspectives for the future of the company. Past projects have resulted in patent-worthy scientific applications and have helped bring fresh innovative ideas into the history of scientific development existing at Waters. Having an outsider's opinion helps them to gain fresh viewpoints on their challenges. In addition to the student team, a faculty advisor offers subject matter expertise to guide the students' work. At the same time, the students develop contextual thinking by getting a holistic view of the business and gaining tangible industry experience.

Although the Waters/MIT collaboration has existed since 2013, this thesis marks the second year that projects have been carried out at Waters' new Global Distribution Center (GDC) located at Franklin, MA. This new warehouse is larger and can support more capacity than the previous warehouse located at Waters' headquarters in Milford, MA. In 2018, the previous MIT student team led an exploration phase characterizing the new GDC and proposing various improvement pathways for project categories including optimization, digitization, automation, and standardization. The two main projects they ultimately pursued were radio frequency identification (RFID) for products within GDC and the creation of a heat map suggesting how to allocate SKUs storage locations within GDC in order to strategically ensure that the fastest moving products were the most easily accessible to workers [7]. These projects focused primarily on the picking side of warehouse operations, while this year's projects focus more on the operations associated with packing orders. The definitions of picking and packing are elaborated later in this chapter.

The projects chosen by the MIT students during any particular year typically align with the state of the company and in areas where immediate short-term to mid-term returns are desired. This keeps the projects relevant to students' academic field and ensures that the necessary resources are readily available to realistically carry out tasks and provide the most value to the company.

2.3 Water Global Distribution Center (GDC)

The Global Distribution Center (GDC), where this thesis was conducted, is one of Waters' three distribution centers. The corporation operates two other distribution centers internationally: the

European Distribution Center (EDC) in the Netherlands and the Asian Distribution Center (ADC) in Singapore. GDC is the largest among them and is the only distribution center in the United States. In addition, GDC functions more comprehensively compared with the other two as it ships both to the other two distribution centers as well as to customers globally. GDC is a 15-minute driving distance from the global headquarters of Waters in Milford, MA, where the original GDC was located. With this relocation in October 2017, GDC was scaled up to a 56,000-square-foot modern facility with various types of storage to match the pace of the company's growth. As of August 2019, GDC maintains over 14,000 distinct SKUs in over 20,000 separate storage locations consisting of 97% of the warehouse's designed capacity (based on the current layout). The corporation projects a compound annual growth of 6% in terms of outbound flows in the next five years, and such a fast growth rate has already started to impose both storage capacity and operation challenges to GDC [8].

2.3.1 Warehouse Functions

GDC functions as a warehouse to store all of Waters' current inventory within the United States. SKUs are received from vendors and production locations and are used to re-stock the active SKUs in their current storage locations or are placed in any available space if the designated locations are full. Occasionally, new products will be procured and must also be stored. GDC must store enough safety inventory to provide a high level of service to customers and keep the order lead time low. All of the storage locations are labeled using a chronological numbering system that spans the entire length of the warehouse and lets pickers know the location of an item on their order list.

Figure 1. Inventory overflow during end of quarter

GDC also serves to distribute products to customers and fulfill orders both domestically and internationally. Customers are typically laboratories, engineers, scientists, and smaller distributors. Products in GDC are also distributed to the other two distribution centers (ADC and EDC) depending on the inventory levels and current needs. Domestic orders are typically smaller and more common, with only a few large freight orders that need to be shipped on pallets, while international orders are almost always large freight orders. Orders are almost always picked, packed, and shipped on the same day that the orders are placed. Orders are shipped via a variety of methods such as air or ground with multiple carriers such as FedEx and UPS, depending on the request of the customer.

2.3.2 Warehouse Layout

The GDC floor plan is shown in Figure 2. Below are descriptions of relevant areas within GDC:

Office/Cafeteria

The GDC manager, leads, supervisors, and other employees have offices at the front of the building. There are cubicles for computer and desk work and a conference room to hold meetings.

Inbound Receiving Dock

All arriving products enter GDC through the inbound receiving dock where they are unloaded off trucks. The items are transported on pallets or in carts and are scanned and digitally documented by receivers before being placed within GDC.

High Bay Storage

High bay storage is used for large items such as instruments, machines, and pallets of products. They span multiple stories high and require a forklift to access some of the topmost SKUs. The high bay area is the storage space that is furthest from the pack stations and requires the most walking to get to by the pickers.

Shelving and Cabinet Storage

The lower shelving and cabinet storage is used for smaller SKUs such as columns, spare parts, and literature/software. These locations do not require a forklift to access and are closer to the pack stations.

Cold Storage

The cold storage area holds all of the products that require freezing or refrigeration. It also holds the necessary equipment needed to properly package these products for shipping.

Hazardous Materials Storage

The hazardous materials storage area holds items that require special caution, such as chemical or flammable substances. Most of these products also have an expiration date and must be monitored for quality. The area can be isolated from the rest of the distribution center in case of fire or flood.

International Pack Station

The international pack station deals with all orders being shipped outside the United States. There is more floor space to accommodate the large shipping containers and pallets used for freight orders and no conveyor belt since there are fewer shipments.

Domestic Pack Station

The domestic pack station sees greater package throughput and takes care of all orders shipped within the United States. These packages are smaller and can fit on a gravity conveyor, which is shared between the pack benches. Orders are packaged at the benches and sent down the conveyor for shipping.

Outbound Loading Dock

Once orders are packaged and ready for shipment, they are sent to the outbound loading dock either by cart or by forklift/pallet jack. Trucks of multiple delivery carriers come at specified times of the day to pick up packages for shipment.

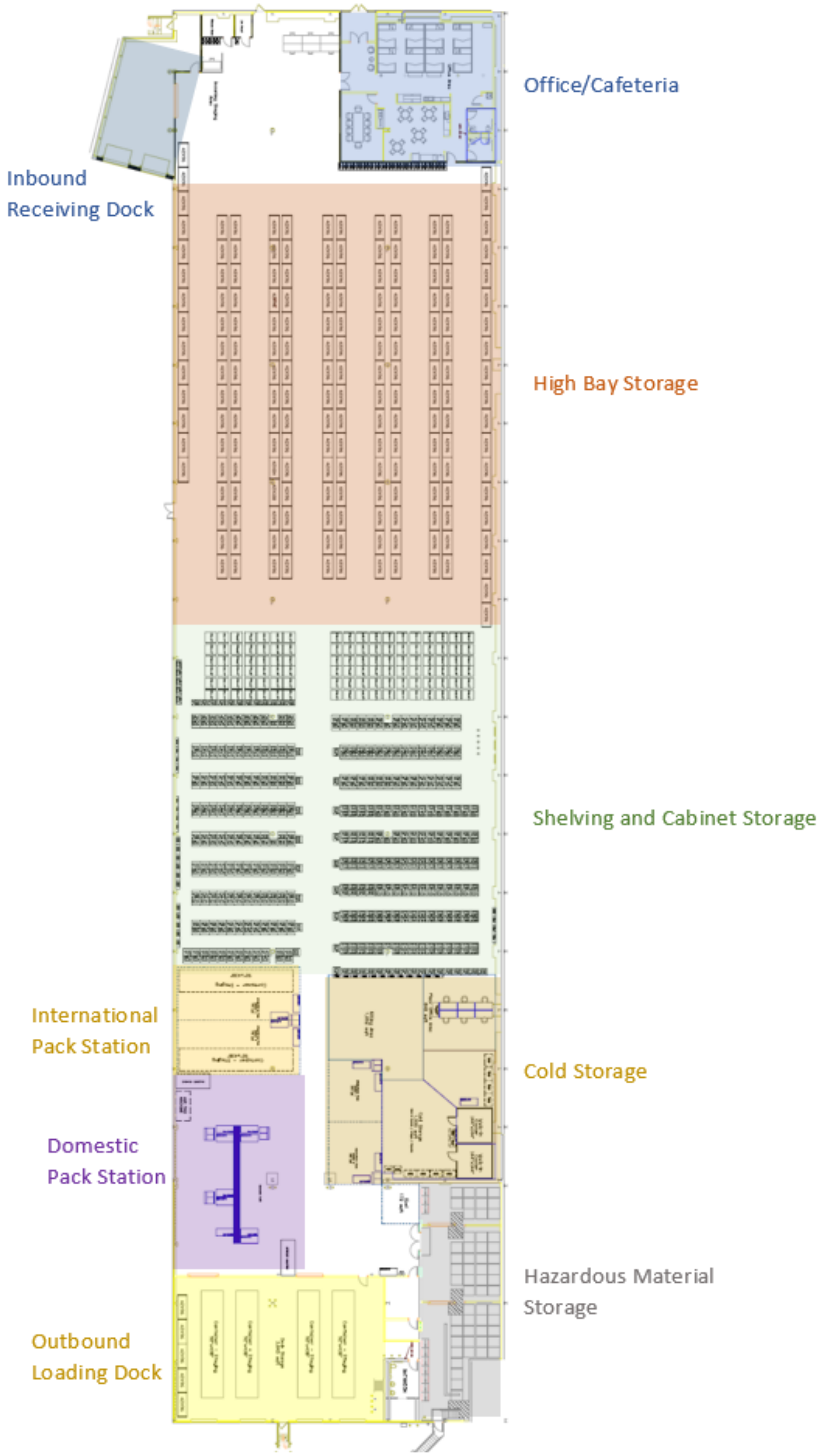

Figure 2. GDC Warehouse Floor Plan (to scale)

2.3.3 Worker Roles

The GDC employs around 20-30 full-time workers at any given time, with some temporary employees hired during busy seasons (usually during EOQ) or for special projects. Workers at GDC have various roles as following:

Distribution Operations Supervisor: Responsible for managing the operations of GDC and making sure all the procedures are implemented effectively.

Inventory Control Specialist: Responsible for conducting daily reporting and making inventory adjustments and removing any product from the warehouse that has been identified as reaching the minimum remaining shelf life.

Section Lead: Responsible for supervising all processes within the specific section and providing necessary instructions/support for material handlers, such as order dropping and work assignment.

Material handler: Responsible for the actual material handling processes ranging from receiving, picking, packaging to shipping. The workers are cross-trained but a material handler will only perform one duty based on the work assignment within a specific time period to avoid mistake propagation. The specific handling activities are as follows:

> *Receiving:* Worker unloads incoming pallets of product from trucks into GDC via the receiving dock and scans items into SAP to verify their delivery. They take the product and store it in available locations within GDC.

Picking: Worker receives printed copies of orders from the section lead detailing which SKUs to retrieve from GDC storage. They walk with a cart and can fulfill multiple orders for every trip to and from the packing stations. Occasionally, certified forklift drivers are necessary to retrieve SKUs stored in the high bay area.

Packing: Worker stands at a packing bench stocked with all of the necessary materials to pack an order. They receive a cart full of picked orders and begin processing them one by one. They scan/verify each item of the order into SAP, select and assemble a stock sized cardboard box, place the order into the box, add plastic pillows as void fill, seal the box with packing tape, and print and stick the delivery label for the order onto the box. They place the completed box on a conveyor, where packaged orders accumulate.

Shipping: Worker stands at a bench with a weight scale and computer with a special shipping program located at the end of the packing area. They take all of the packaged orders and scan the delivery label, weigh the order, and print out the appropriate shipping label. If there are missing fields in an order's shipping information or any incorrect information, then the worker has to correct it before completing the shipping label for that order. Once the shipping label is placed on the package, it is fully ready to be sent to the outbound loading dock where it will be picked up by a truck.

2.3.4 SAP and Warehouse Management System

SAP, which stands for "systems, applications, and products in data process", is a German multinational software corporation that makes enterprise software to manage business operations and customer relations. Its software shares the same name with the company [9].

GDC widely uses SAP as a warehouse management system (WMS) to link the inbound and outbound activities:

1. Material receiving (inbound)
2. Order creation (outbound)
3. Order verification (outbound, packing station)
4. Internal shipping label generation (outbound, packing station)
5. Shipping label generation (outbound, shipping station)
6. Customer relation report generation and analytics (enterprise level)

SAP links data among all above activities to ensure each SKU and each order are traceable during operation. Using SAP as a WMS is to create a digital twin of all storage locations. Because of the versatility of SAP, it often integrates with other software and modules to fulfill special functions. For Waters' GDC, SAP integrates with CMS WorldLink to centrally manage domestic and international shipments by multiple carriers.

2.3.5 GDC Outbound Operations Value Stream Mapping

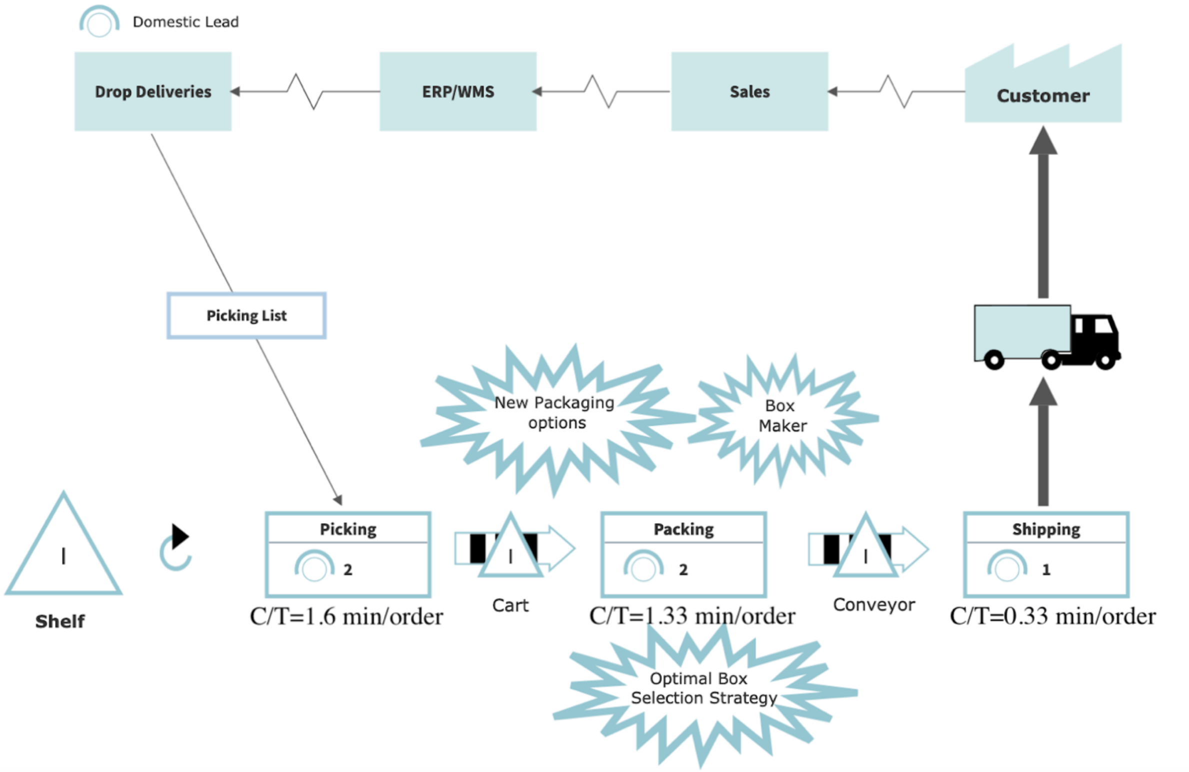

Figure 3. Value stream map of Waters GDC domestic outbound operations

Value stream mapping, also called "material and information flow mapping" at Toyota, is a method of lean management that is used to analyze the current state of a process and then to design an improved future state to reduce waste. A value stream focuses on areas that add value to a product or service [10].

In order to have a better understanding of GDC's current practices, a value-stream map was made by the team. Since the scope of this project is within the domestic outbound operations of GDC, the manufacturing and inbound processes were not included. The components of the GDC outbound operations value stream mapping are presented as follows and shown in Figure 3:

Information flow:

After customers (either external or internal) place orders, the order information will be transferred to Waters' sales department, and then to the Enterprise Resource Planning (ERP) system and WMS hosted by SAP. The domestic lead at GDC then will drop the deliveries from the server and print out hardcopy picking lists for the orders.

Material flow:

The picker will grab one cart and pick the corresponding products from different storage locations based on the assigned picking lists from the domestic lead. After all the items are picked, the picker will push the cart to a packing station. The packer will then verify the products via WMS and pack them accordingly. The packed boxes will be put on the conveyor belt and moved to the shipping station. A material handler will weigh the packed boxes and print out the actual shipping label and sort them into different bins for couriers to collect.

Figure 3 also shows the cycle time (C/T) for each step. The cycle time was measured per person, since there is some variance of the number of workers at each station. The average throughput rate for current operation is 55 orders/hour.

Personnel:

For normal operation, on average there are two pickers, and two packers working together for domestic deliveries, and there is one worker that handles the shipping process.

Chapter 3. GDC Packing Problem

For GDC packing problem, the team explored and developed potential solutions to reduce the box volume per order and in turn reduce waste. This involved introducing new packaging options such as padded envelopes, creating algorithms to assist packers in choosing the most economical stock box while packaging an order, and creating an integration plan for adding custom box-making technology to the current packing process flow.

3.1 Waters Corporation Goals

We describe here three company goals as they relate to the operation of the GDC:

Reduce freight cost: Waters spends more than 10 million USD on logistics every year. Therefore, even a small percentage of improvement will yield a large amount of savings. With a finite number of box sizes stocked and available in the distribution center to package orders, some orders will inevitably be shipped in a box that is larger than needed to accommodate the SKUs inside. This unnecessary extra volume means that some of the cost is used to pay for shipping the air within the box—a cost that can be eliminated or reduced if orders were able to be packaged in smaller boxes.

Increase GDC capacity and throughput: GDC is currently operating at 97% capacity in terms of storage space, and the rental contract for the facility will not terminate until 2027. There is limited space to conduct any further expansion work. Therefore, Waters is keen on finding methods to accommodate for future growth, which is projected to be 6% annually, by more efficiently utilizing GDC resources. In addition, during every EOQ, there is a sharp demand surge, a situation that requires GDC to hire additional contract operators to yield matching throughput. Hence, Waters also aims to improve the efficiency of GDC operations and internal logistics.

Typically, if fast-moving products that are commonly ordered by customers can be placed closer to the pack stations, then the pickers do not have to walk as far to retrieve them. The heat map project from the previous year optimized the locations of the SKUs to minimize the walking time of pickers. However, the labor hours required to re-arrange the entire warehouse have not yet been put in and the proposed layout has not yet been implemented.

Sustainability: Sustainability, defined by the United Nations as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" is also an emphasis of Waters Corporation. Waters' sustainability efforts focus on six areas: customer collaboration, innovative solutions, value chain management, environment and safety responsibility, community engagement and employment [11]. For this project, the applicable sustainability impact will be mainly on the environment, and the specific target is to reduce box sizes for packing orders. Smaller boxes yields two sustainability benefits. One is to reduce corrugated cardboard usage; the second is to reduce the shipping volume, which can then decrease CO2 emission.

3.2 Current Packing Operations

At GDC, finished goods are packaged in a manner that conforms to customer requirements and corporate goals: minimizing possible transport damage, being cost-effective, providing accurate processing of all customer orders, while maintaining efficient inventory control. GDC ships both domestic and international orders, with international shipments accounting for less than 10% of GDC outbound shipments. International orders are typically pooled by location and sent out in large batches using containers. The packers already have an efficient way to trim the top of these containers and minimize their total volume. More opportunity lies in the domestic shipments, due to the greater number of orders and the room for process improvement. Therefore, the scope of this thesis was narrowed down to domestic outbound operations.

The Standard Operating Procedure (SOP) for domestic order packing is as follows:

Finished goods will be overpacked by **selecting a shipping box** that allows enough space on all sides. Packing material (air pads) is then added to fill up voids and to protect the product during shipping. Given the available box sizes, every effort is made **to minimize the overall size of the package, which minimizes freight costs and the use of shipping supplies.** The primary objective of ensuring adequate protection of the finished goods will not, however, be compromised. Larger products that are pre-packaged in suitable shipping boxes, usually instruments and products that will not fit inside one of the standard shipping boxes, do not need to be over packed. Certain products are marked on the product label as "Direct Shipment-Overpack Not Required". These products can be shipped as packaged.

Currently, GDC uses 15 standard-size stock boxes, and the detailed names and dimensions are shown in Table 1. For domestic and Canadian shipments, only the top 12 box selections are in use, while the FED Box, D-container and E-container are used for international shipments only. In addition, the FedEx Small, Medium and Large boxes can only be used for FedEx express service [12].

Table 1. Standard-size stock boxes available at GDC for packing

Box	**Outside Dims (in)**		
	L	W	H
J12	11	8	5
J14	13	10	6
J18	18	14	8
J22	20	16	10
J64W	26	16	14
Square box	13	13	7
Small Column	16	6	6
Large Column	17	9	9
MD262020	26	20	20
SMALL FEDEX (FedEx Express only)	13	11	2
MEDIUM FEDEX (FedEx Express only)	14	12	3
LARGE FEDEX (FedEx Express only)	18	13	4
FED BOX (not for small pack)	40	20	26
D-CONTAINER (not for small pack)	50	43	61
E-CONTAINER (not for small pack)	47	32	31

As evidenced by the SOP, Waters does aim to find the optimal size box for each delivery from this set of boxes. However, the box selection process is purely based on the packer's experience and personal judgment. Therefore, the team proposes multi-dimensional solutions on hardware, software and management perspectives to systematically improve the packing operations.

3.3 Shipping Cost Calculation

The shipment charging method for GDC is summarized in this section. Waters has many courier service providers, including FedEx, DHL, UPS, Horizon Air Services etc. Since FedEx shipped about 90% of GDC outbound shipments in 2018, this shipping cost explanation is based on FedEx’s method, while other companies' methods are similar.

FedEx rates are mainly based on the shipping zones. Shipping zones are categorized based on the distance between the sender address and the recipient address [13]. For example, for shipments within the contiguous U.S., 0-150 miles are categorized as Zone 2, 151-300 miles as Zone 3, 301-600 miles as Zone 4, and so on. Figure 4 is an example of the published rates for one zone, and the format is common for other zones. As Figure 4 shows, for each zone, the freight rates are decided by the service type, packaging, and billable weight. The billable weight is either the actual weight or the dimensional weight of the package, whichever is larger. The dimensional weight is calculated as the package volume divided by a specific dimensional factor defined by the annual contract between Waters and FedEx.

U.S. Express Package Rates: Zone 2[1]

Shipments moving generally 0–150 miles from origin to destination anywhere in the contiguous U.S.

Delivery Commitment[2]	Next day by 8 or 8:30 a.m.	Next day by 10:30 a.m.	Next day by 3 p.m.[3]	2nd day by 10:30 a.m.	2nd day by 4:30 p.m.[3]	3rd day by 4:30 p.m.[3]
	FedEx First Overnight®	FedEx Priority Overnight®	FedEx Standard Overnight®	FedEx 2Day® A.M.	FedEx 2Day®	FedEx Express Saver®
FedEx® Envelope up to 8 oz.	$ 53.15	$ 23.15	$ 22.80	$ 18.13	**	**
FedEx® Pak	*	*	*	*	*	*
Shipments in All Other Packaging / Maximum Weight in Lbs.						
1 lb.	$ 57.69	$ 27.69	$ 25.79	$ 19.13	$ 17.52	$ 15.45
2 lbs.	58.05	28.05	27.24	19.46	17.82	15.73
3	61.40	31.40	29.61	19.79	18.12	16.18
4	63.85	33.85	31.93	20.39	18.66	16.46
5	64.59	34.59	32.50	20.98	19.22	16.74
6	69.18	39.18	34.30	21.90	20.06	18.09
7	69.65	39.65	35.40	22.83	20.91	18.38
8	70.00	40.00	37.26	23.74	21.74	19.11
9	70.51	40.51	38.58	25.00	22.89	19.26
10	70.87	40.87	38.73	26.18	23.04	19.45
11	76.73	46.73	41.52	27.36	25.06	23.10
12	78.65	48.65	42.91	29.70	26.39	23.60
13	79.32	49.32	43.38	30.85	28.25	25.73
14	80.15	50.15	45.06	32.36	29.65	26.01
15	80.51	50.51	46.80	34.63	30.78	26.30
16	82.36	52.36	47.78	35.46	31.50	27.76
17	86.87	56.87	50.21	36.54	32.47	28.66
18	87.33	57.33	51.71	37.77	33.56	30.46
19	87.70	57.70	53.10	39.24	34.88	31.24
20	88.00	58.00	54.08	39.40	36.09	31.53

Figure 4. Package rates for FedEx U.S. Express shipping [source: FedEx]

In addition, Waters Corporation has specific contractual discounts that apply to the basic freight rates (excluding fuel, tax, special handling fees, and other miscellaneous charges). Therefore, the net charge will be less than the published rates.

3.4 Baseline Establishment

As the ultimate goal of the team was to optimize package sizes to reduce cost and improve sustainability, it was important to establish a baseline for the empirical packing method adopted by GDC. In 2018, there were around 130,000 outbound shipments from GDC, and 56% of them were charged-by-volume domestic FedEx shipments (including Canada). Because a large number of orders was charged by volume, reducing their package size would yield potential savings. To evaluate the current packing performance, a simple and effective metric was proposed, the average shipping air percentage, $\overline{A}$, which is defined as follows:

$$\overline{A} = \frac{1}{N_0}\sum_{i=1}^{N_o} a_i \times 100\%$$

$$a_i = 1 - \frac{\sum_{j=1}^{n_{s_i}} q_{s_{ij}}(l_{s_{ij}} w_{s_{ij}} h_{s_{ij}})}{v_{b_i}}$$

where N_0 is the total number of charged-by-volume domestic FedEx orders, a_i is the fraction of air in the ith order air fraction, v_{b_i} is ith order box volume, n_{s_i} is number of SKU(s) in ith order, $q_{s_{ij}}$ is quantity of jth SKU in ith order, and $l/w/h_{s_{ij}}$ are the dimensions of the minimum bounding rectangle (MBR) of kth SKU in ith order.

With the average shipping air percentage as a metric, the team could not only understand the current packaging performance but also can now compare the metric before and after a potential solution is applied to evaluate the effectiveness of the solution.

3.4.1 Baseline Data

The team acquired all the necessary data to establish the baseline case from Waters' SAP. Three primary reports, "SLD Veraction", "Waters 99% of demand", and "GDC_0001", were downloaded and merged to create the master data sheet shown in Figure 5.

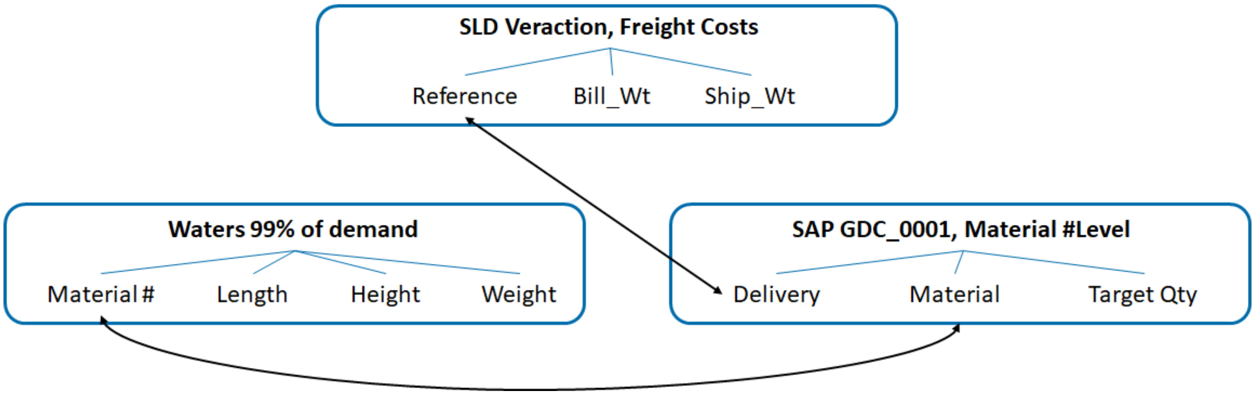

Figure 5. Data Structure for the GDC packing baseline establishment

“SLD Veraction” contains high-level order-level info such as order reference number, billable weight, and its ship weight. It is worth mentioning that if an order’s ship weight is equal to the billable weight, this order is charged by weight so reducing the package size of this order will not affect its shipping cost. Therefore, the data used to build the baseline were filtered to only include the orders whose billable weights do not equal to their ship weights.

“GDC_0001” contains detailed SKU information associated with each order, including delivery (order) reference number, material (SKU) reference number and targeted quantity of an SKU. If an order contains multiple SKUs, this order is listed as multiple lines (rows) in “GDC_0001” and the number of lines is equal to the number of SKUs of this order. As shown in Figure 5, “GDC_0001” is linked to “SLD Veraction” via the same order reference numbers.

“Waters 99% of demand” datasheet is a detailed SKU information lookup table, including data such as material (SKU) reference number, each order’s detailed MBR dimensions and weight collected by an industrial cubic scanner. This database covers over 10,000 SKUs, consisting of 99% of the actively demanded SKUs of Waters. However, due to the early stage of warehouse digitization, the database is still not comprehensive yet with information for around 4000 SKU not logged along with some partially missing/fault data associated with the logged SKUs. Therefore, to establish an unbiased baseline, only orders with complete SKU data were included in the baseline analysis. Waters 99% of demand is linked to “GDC_0001” via the same SKU reference numbers.

3.4.2 Key Assumptions

Due to the incomplete nature of the data, there are several key assumptions for the baseline establishment:

1. Because SAP did not log the box dimensions associated with each order, the team reconstructed volumes of box, v_{b_i}, from the billable weight in “SLD Veraction” database. Because an order’s billable weight is equal to the order’s volume divided by a contract dimensional factor, with known billable weights, the real order volumes were estimated by multiplying the dim factor to the billable weights. However, such an order volume estimation may increase the average shipping air percentage because FedEx rounds each bill volume to the next higher integer, and thus instead of using the interior box volumes, the exterior box volumes were used. Furthermore, as FedEx conducts order dimensioning for Waters and transfers order billable weights back to SAP, the team assumed that the dimensioning process of FedEx was fair and accurate.
2. The team assumed the data in “Waters 99% demand” were all accurate and well maintained. However, due to the manual dimensioning process and the existence of

SKUs with irregular shapes, a certain percentage of the SKU dimensional and weight data might be off or corrupted.

3. The team also assumed that all orders to be analyzed were overpacked with one or more cartons. However, in reality, there is a small portion of orders that are shipped in own containers (SIOC), such as Lenovo ThinkStation for liquid chromatography equipment. Those orders' packages cannot be further optimized, but because the SKU info did not contain SIOC tags, the team had no mean to exclude those false opportunities.

3.4.3 Baseline Analysis Results and Opportunities

There were 69,660 charged-by-volume FedEx domestic and Canada orders incorporated in the baseline analysis. The average shipping air percentage is 66.7%, with a standard deviation of 20.8%, lower and upper quantiles of 54.6% and 83.1%, respectively. This result is consistent with the observations made by the MIT team while visiting and observing the orders packaged at GDC.

To quantify the potential saving opportunity, several customized box maker services were used to be a benchmark specifying the upper bound of the saving. Those automated box machines can cut and fold the optimal fit corrugated box for each order stacked in a rectangular form, therefore minimizing air content in packages. A leading custom box maker company, Packsize, claimed that their service can reduce average shipping air percentage down to 18-20%. If the orders of Waters are still shipped by overpacking with corrugated cartons, then other less capital intensive optimal packaging solutions, such as the software-based one, can generate a saving within this

40% window, which was regarded as a large saving opportunity that motivated the team and Waters' stakeholders to pursue the optimal packing strategy project further.

Chapter 4. Evaluation Method and Current Performance

There are three potential solutions the team has considered and analyzed. Solution 1 will be only adding envelopes and paks into current standard packaging set. Solution 2 will be incorporating the box selection optimization strategy. Solution 3 will be totally adopting the automated box maker system.

In order to compare these three solutions and provide recommendations to Waters Corporation, three major evaluation criteria were selected:

1. Financial performance: Since the team did this project for a commercial company, the financial performance must be the most important factor to consider. Without a solid return, it will be very hard to justify and finally get the approval for any improvement project.

2. Implementation: the difficulty level of the implementation will also affect the decision-making process a lot. Because currently the warehouse is operating based on the existing systems such as SAP and WMS, then the time frame and resource requirements for all these solutions must be evaluated.

3. Sustainability: as a publicly traded company, Waters emphasizes its sustainability/social responsibility and aims to save corrugate use and reduce CO_2 emission as much as possible. Therefore, sustainability performance will also be a factor that needs to be considered.

Remark:

In this analysis, it is assumed that the throughput after all three improvement initiatives will be no less than current level and enough for GDC's normal operations. The detailed analysis regarding the capabilities, throughput and process flow will be presented in Jessica Harsono's thesis [2].

4.1 Financial

This project will not generate revenue directly, and all the financial returns will come from the savings on expenses. The following costs are considered:

Direct Labor:

If any of the 3 solutions will change the workers needed at GDC (either reduce or increase the headcount), then there will be some change on the direct labor cost.

The current hourly pay (including benefits) for a GDC worker is $20.

Support Labor:

If specific working hours for internal/external engineers are required to do the implementation, such cost will be regarded as support labor cost.

The hourly pay (including benefits) for a Waters' IT engineer is $60.

Corrugate:

Waters buys corrugate boxes from a specific supplier and can get unlimited free FedEx packaging supplies. Table 2 shows the details of the 2018 GDC box usage and cost for domestic outbound.

Table 2. 2018 GDC box usage and cost for domestic outbound

Box Name	**Annual Quantity**	**$/carton**	**Total Spend**
J12	27,300	0.32	$ 8,736.00
J14	24,000	0.42	$ 10,080.00
J18	12,750	0.79	$ 10,072.50
J22	10,950	1.02	$ 11,169.00
J64W	13,500	1.293	$ 17,455.50
Square box	14,750	0.65	$ 9,587.50
Small Column	2,200	0.48	$ 1,056.00
Large Column	4,100	0.74	$ 3,034.00
MD262020	3,600	10.21	$ 36,756.00
FedEx Small Box	14,400	Free	Free
FedEx Medium Box	14,850	Free	Free
FedEx Large Box	12,000	Free	Free

The total corrugate cost in 2018 is $107,946.50. Based on the box dimensions in Table 1 and the box usage here, the total corrugate usage can be calculated as 905,515 square feet. Since it is very hard to determine the specific box price, which varies with the purchase quantity and different suppliers, the later corrugate cost calculation will be based on the total area (except for the free FedEx packaging).

Void material:

GDC currently uses air pads to fill the empty spaces within all the packages to protect the products. The cost of such air pads is directly related to the void volume. Therefore, as the air percentage will be reduced for all three scenarios, there will be some savings in the void material. The current annual spending for the void material is about $30,000.

Freight:

The saving on freight cost will be generated by reducing the billable weight for the outbound deliveries. Hence, the saving opportunities only apply to the deliveries that were charged by volume (dimensional weight).

It is assumed that all the deliveries which were charged by actual weight will still be charged by the actual weight after the introduction of new packaging options. Therefore, there will be no change on the billable weight, as well as no freight cost saving for such deliveries.

Since FedEx carried about 98% of GDC's domestic shipments (including Canada), the freight cost calculation and comparison will be only based on the FedEx USA and Canada deliveries.

Delivery	Bill_Vol	Real Vol (Total)	Air %	Actual_Wt (Sum)	Bill_Wt (Sum)	Recipient_Countr	Service	Zone	Freight	Disc	Disc %	Fuel	Sp Hdl	Net Charge
89710646	2716	1958.88	27.88%	11	14	USA	3DPM	04	37.54	[redacted]	[redacted]	0.59	0	[redacted]
89710651	1358	629.5774408	53.64%	6	7	USA	3DPM	08	45.17	[redacted]	[redacted]	0.71	0	[redacted]
89710659	1552	573.48	63.05%	4	8	USA	3DPM	06	39.84	[redacted]	[redacted]	0.63	0	[redacted]
89710660	1358	298.6112796	78.01%	3	7	USA	3DPM	08	45.17	[redacted]	[redacted]	0.71	0	[redacted]
89710671	776	345.96	55.42%	3	4	USA	3DPM	08	34	[redacted]	[redacted]	0.53	0	[redacted]
89710678	1746	707.0531548	59.50%	4	9	USA	1DAM	02	40.51	[redacted]	[redacted]	0.47	0	[redacted]
89710693	9312	4096.105679	56.01%	35.6	48	USA	DOMGRND	03	15.68	[redacted]	[redacted]	0.4	0	[redacted]
89710694	776	55.2	92.89%	1.2	4	USA	DOMGRND	04	10.86	[redacted]	[redacted]	0.39	0	[redacted]
89710695	4656	1893.372139	59.33%	20.5	24	USA	DOMGRND	05	19.32	[redacted]	[redacted]	0.49	0	[redacted]
89710697	582	167.4	71.24%	1.1	3	USA	DOMGRND	03	9.48	[redacted]	[redacted]	0.39	0	[redacted]
89710698	970	286.44	70.47%	2.2	5	USA	DOMGRND	03	9.91	[redacted]	[redacted]	0.39	0	[redacted]
89710699	582	139.425	76.04%	0.7	3	USA	DOMGRND	03	9.48	[redacted]	[redacted]	0.39	0	[redacted]
89710702	582	57.04	90.20%	1.1	3	USA	DOMGRND	05	10.68	[redacted]	[redacted]	0.39	0	[redacted]
89710705	970	102.816	89.40%	1	5	USA	DOMGRND	03	9.91	[redacted]	[redacted]	0.39	0	[redacted]
89710706	582	60.543	89.60%	0.6	3	USA	DOMGRND	05	10.68	[redacted]	[redacted]	0.39	0	[redacted]
89710707	582	55.2	90.52%	0.6	3	USA	DOMGRND	05	10.68	[redacted]	[redacted]	0.39	0	[redacted]
89710763	776	230.64	70.28%	1.5	4	USA	DOMGRND	03	9.71	[redacted]	[redacted]	0.39	0	[redacted]
89710767	582	24.1425	95.85%	0.4	3	USA	DOMGRND	03	9.48	[redacted]	[redacted]	0.39	0	[redacted]
89710776	970	297.279	69.35%	2	5	USA	DOMGRND	02	8.92	[redacted]	[redacted]	0.39	0	[redacted]
89710777	582	57.66	90.09%	0.6	3	USA	DOMGRND	05	10.68	[redacted]	[redacted]	0.39	0	[redacted]
89710778	582	172.98	70.28%	1.4	3	USA	DOMGRND	05	10.68	[redacted]	[redacted]	0.39	0	[redacted]
89710780	1940	481.3551734	75.19%	1.9	10	USA	DOMGRND	03	10.96	[redacted]	[redacted]	0.39	0	[redacted]
89710786	582	10.206	98.25%	0.4	3	USA	DOMGRND	04	10.26	[redacted]	[redacted]	0.39	0	[redacted]
89710787	582	106.08	81.77%	0.8	3	USA	DOMGRND	05	10.68	[redacted]	[redacted]	0.39	0	[redacted]
89710789	970	94.86	90.22%	1	5	USA	DOMGRND	04	11.17	[redacted]	[redacted]	0.39	0	[redacted]

Figure 6. 2018 GDC deliveries data

**The detailed numbers of discount and net charges, which are Waters' confidential information, are not shown here.*

As Figure 6 shows, the following categories of information are required as input to do the freight cost calculation:

Delivery Number: the unique record number for every delivery.

Bill volume: the total package volume.

Real volume: the actual aggregated content volume.

Air percentage: the corresponding air percentage within each box.

Actual weight: the actual weight of the shipment (in pounds).

Bill weight: The weight used to calculate freight rates. It is the larger one of the actual weight/ dimensional weight.

Recipient country: for this analysis, there are only USA and Canada.

Service: the specific service type that delivery used. In this analysis, there are only 5 types of service: 4 for domestic -- Priority Overnight(1DAM), Standard Overnight (1DPM), 2 Day (2DPM), Express Saver(3DPM); and 1 for Canada -- International Priority (INTL).

Zone: For USA domestic, there are 8 zones in contiguous US and 4 zones for Hawaii and Alaska; for Canada, there are 2 zones.

Freight: the publish freight rates (before discount) based on FedEx service guide 2018.

Discount: the specific amount of freight discount for every order per Waters' contract.

Disc %: the corresponding freight discount percentage.

Fuel: FedEx charges fuel surcharge to compensate for the oil price fluctuation.

Special Handling fee: this fee applies when special handling is required, including Saturday services, hold at FedEx location and special requirements such as hazardous material or cold-chain transportation.

Net Charge: the after-discount actual charge Waters paid to FedEx. This will be the basis for our analysis.

Saving calculation:

New Package	Volume	New Dim weight	New_Bill_wt	New freight	New net charge	Saving	Saving %
N13	2040	10.51546392	11	31.07	9.884515184	1.93548482	16.37%
N12	1521	7.840206186	8	49.33	15.46422404	-1.244224	-8.75%
N7	576	2.969072165	4	25.82	8.355261044	4.19473896	33.42%
N8	576	2.969072165	3	29.73	9.602014611	4.61798539	32.48%
N5	539	2.778350515	3	29.73	9.422767647	1.27723235	11.94%
N11	1512	7.793814433	8	40	9.327072328	0.11292767	1.20%
N17	4160	21.44329897	36	19.58	9.865331633	-1.8853316	-23.63%
N2	144	0.742268041	2	9.73	7.037937385	0.77206262	9.89%
N13	2040	10.51546392	21	17.22	8.823695652	1.01630435	10.33%
N3	240	1.237113402	2	9.09	7.504746835	0.30525316	3.91%
N7	576	2.969072165	3	9.48	7.488042381	0.32195762	4.12%
N4	240	1.237113402	2	9.09	7.504746835	0.30525316	3.91%
N2	144	0.742268041	2	9.94	7.29588015	0.51411985	6.58%
N8	576	2.969072165	3	9.48	7.488042381	0.32195762	4.12%
N3	240	1.237113402	2	9.94	7.29588015	0.51411985	6.58%
N2	144	0.742268041	1	8.97	6.621966292	1.18803371	15.21%
N3	240	1.237113402	2	9.09	7.336220391	0.47377961	6.07%
N1	128	0.659793814	1	8.36	6.933375527	0.87662447	11.22%
N5	539	2.778350515	3	8.5	7.460627803	0.3493722	4.47%
N2	144	0.742268041	1	8.97	6.621966292	1.18803371	15.21%
N3	240	1.237113402	2	9.94	7.29588015	0.51411985	6.58%
N9	720	3.711340206	4	9.71	6.963740876	0.84625912	10.84%
N1	128	0.659793814	1	8.59	6.602261209	1.20773879	15.46%
N1	128	0.659793814	1	8.97	6.621966292	1.18803371	15.21%
N7	576	2.969072165	3	10.26	7.205505819	0.60449418	7.74%

Figure 7. Freight cost saving calculation

As Figure 7 shows, with the historical data inputs and the new package types that will be adopted, the following data, and finally the projected savings, can be calculated:

New Package: the new package type that will be used by adopting new boxes and other packaging options (envelopes and paks)

Volume: the total volume of the new package

New Dim weight: the new dimensional weight

New Bill weight: the new billable weight. It is the larger one of the actual weight/ new dimensional weight.

New freight: the new corresponding freight rates (before discount) by utilizing new package.

New net charge: the new total net charge for the delivery

Saving: the absolute amount of saving (in US$) for each delivery

Saving%: the corresponding saving percentage for each delivery

With the new packaging, the new dimensional weight of the delivery will be calculated and compared with its actual weight, and thus the new billable weight will be determined. With the new billable weight, as well as the same service type and destination zone, the corresponding new freight rate will be found based on the published rates chart (FedEx service guide). After applying the same discount percentage and add miscellaneous fees, the new net charged will be achieved. Then we can compare the new reduced net charge with the actual charge in 2018 to get the savings and the corresponding saving percentages.

(The python code to extract data from FedEx service guide and calculate the corresponding freight rates is attached in the Appendix.)

Equipment:

Equipment cost includes the ownership cost (either the depreciation of the investment for the bought equipment or the rental/lease expenses) and maintenance cost for the additional new equipment required.

Based on the aforementioned costs, the annual saving and Return on Investment(ROI) could be calculated for each solution for comparison with other Waters' internal projects.

4.2 Implementation

Implementation means turning the project plan into actions and reality. Certain resources are required during such process, and here are three metrics to evaluate the implementation feasibility and difficulty.

Time frame:

The total time between the decision to adopt one solution to the moment the solution becomes functional. The earlier the solution can be functional, the more savings will be generated.

Space:

Space requirement could be another deciding factor based on the feedback from the GDC manager. GDC, which is currently operating close to its capability, has very limited available space around the packing/shipping stations, not to mention the extreme scenarios during End of Quarter. If the required additional space is too large for GDC to accommodate, such solution will become not viable, regardless of the financial performance.

IT resources/support:

Waters functional departments usually get limited IT support due to the finite budget on IT spending and lengthy application processes. Therefore, the IT resources requirement will be another concern for decision making.

4.3 Sustainability

Waters Corporation aspires to protect and enhance the environment. The team chose two specific metrics to quantity the sustainability impacts for all the solutions:

Corrugate usage:

The total area of corrugate used for packaging.

CO2 emission:

For this analysis, the change on CO_2 emission mainly depends on the corrugate usage, while the impact from void material is relatively small and thus negligible. By using Packsize's conversion rate, 1 ton of CO_2 is saved for every 8477.76 square feet of corrugate not used [14]. The reduced shipping volume can also avoid some truckloads, thus reducing CO_2 emission; however, such reduction is hard to quantify and relatively small, so it will not be considered in this analysis.

Chapter 5. Evaluation of Three Solutions:

In this chapter, the evaluation method established in Chapter 4 is utilized to evaluate the three proposed solutions for GDC packing problem.

5.1 Solution 1: Envelope/Pak Adoption

For current Waters GDC domestic operation, there are only 12 standard-size stock boxes that can be chosen to pack the shipping items. Based on the team's observation and historical data, the team found out that there are great saving opportunities for small deliveries: Since the smallest box GDC has is either FedEx Small box or the J12 box, no matter how small the real volume of a order is (even only several pieces of papers or small O-rings), that order will be packed in a box. Sometimes, due to dimension constraints, a single small item (such as a column) may even be packed in a FedEx Medium box, whose dimensional weight is far beyond the actual item weight. Therefore, such limited packaging option caused very high air percentage for the small-volume deliveries and wasted huge amount of money on freight.

After analyzing FedEx charging methods and Waters' specific contact, the team proposed to introduce two new types of packaging: Envelope and Pak.

Figure 8. FedEx Envelope [Source: FedEx]

Figure 9. FedEx Pak [Source: FedEx]

FedEx Envelope:

- Dimensions: 9.5’ * 12.5’
- Maximum weight allowed: 1.5 lbs.
- For documents (Waters can ship other small items in envelope as well, as long as the item inside is not fragile)

FedEx Pak:

- Dimensions: 12’ * 15.5’
- Maximum weight allowed: 5.5 lbs.

Assumptions:

- The maximum usable volume for a FedEx Envelope is about 40 $inch^3$; however, in order to account for dimensional constraints and be conservative, the team decided that:
  For real volume under **30** $inch^3$, we can use an Envelope.
  (However, for the applicable deliveries, only 599 are under 30 $inch^3$. Such small amount (about 2%) could be negligible. For simplicity, in this analysis, we will assume that all applicable small-volume deliveries should go with pak)

- The maximum usable volume for a FedEx Pak is about 350 $inch^3$; Similarly, in order to account for dimensional constraints and be conservative, we decided that:
  For real volume under **280** $inch^3$, we can use Pak.

- Fact: FedEx does not measure dimensions of FedEx Pak. All FedEx Paks are charged by the actual weight, which is equivalent to 0 air percentage.

- The miscellaneous charge (fuel and special handling fees) will not change with different packaging.

Data Selection:

1. #128858 total shipments for GDC outbound in 2018
2. Select FedEx USA and CAN deliveries charged by volume.
3. Exclude hazardous materials/Cold Chain shipments, because these two categories have special requirements during shipment and cannot go within the pak.

4. Filter out negative air % and unknown zone deliveries, since these data are incorrect or incomplete.
5. Filter out Ground service (FedEx Envelope/Pak cannot go ground)
6. Filter out heavy freight services (only 275 deliveries and with large weight), remaining Priority Overnight(1DAM), Standard Overnight (1DPM), 2 Day (2DPM), Express Saver(3DPM), and International Priority (INTL) services.
7. For real volume under 280 $inch^3$ (the usable volume of Pak), there remain 22135 deliveries.
8. Of these 22135 deliveries, 22020 are under 5 pounds (the weight limit for pak). So only these **22020** deliveries are considered.

Financials:

Direct Labor:

There will be no change to the number of workers required for GDC domestic outbound operations. Thus, there will be no saving on direct labor.

Support labor:

Implementing these two new packaging options almost requires no engineering/IT support. Therefore, there will be no support labor cost.

Corrugate:

FedEx Envelopes and FedEx Paks are free; therefore, the corrugate cost will be reduced.

The annual corrugate use will be decreased by 73,124.4 square foot (including both existing FedEx free boxes and normal boxes).

The annual saving on corrugate will be $4,164.6 (only from the normal boxes).

Void material cost:

Based on extrapolation, the annual saving on void material will be about $2,000.

Freight cost:

For the applicable 22020 deliveries, the freight cost savings are shown in Table 3.

Table 3. Solution 1 freight cost saving results

	No. of Deliveries	Saving	2018 Net Charge	Saving %
USA	20635	$34,860	$239,446	14.56%
CAN	1385	$24,676	$70,260	35.12%
Total	22020	$59,536	$309,726	19.22%

Equipment cost:

There is no requirement for new equipment; therefore, the change on equipment cost will be $0.

In conclusion, the total annual saving for Solution 1 will be $65,701. Most of savings are generated by the reduced freight cost, while the reduction of the corrugate use and void material consumption can also bring some benefits.

Implementation:

Time frame:

The estimated implementation time will be 15 days. Due to Waters internal requirement regarding the product quality, some drop tests need to be conducted for the new packaging, and the Picking SOP will be slightly modified.

IT resources/Support:

This solution almost needs no IT support to implement.

Sustainability:

Corrugate Use:

By adopting the FedEx Envelope/Pak, 73,124.4 square foot of corrugate could be saved every year

CO2 emission:

Based on the reduced corrugate usage, the reduction of CO_2 emission would be 9.6 ton per year. However, since the manufacturing process for the Envelope/Pak will still cause some emission, the annual savings in tons of CO_2 will be projected as 4.3.

5.2 Solution 2: Optimal Box Selection Strategy

For GDC domestic line, the current selection of 12 shipping boxes is based on recent-year continuous improvement efforts. However, such selection is still mainly based on human experience and are not globally optimal. Therefore, the team aimed to use modern data science to systematically tailor a new set of standard boxes for GDC, thus reducing air content and generate savings.

Based on the large pool of carton options (>1000) and Waters order/product data, two new sets of standard boxes are selected. The first packaging set contains 11 boxes and the FedEx Pak, which in combined would make up to 12 packaging options that align with current practice. The second set has 20 options (19 boxes and Pak), which is assumed to be the upper limit to adopt in GDC. These two new packaging sets would yield big improvement for Waters, and the detailed optimization algorithm and strategy will be presented in Bowen Zeng's thesis [1]. Solution 2 applies to all GDC domestic outbound shipments.

Solution 2.1 (12 options):

The detailed box selection results are shown in Table 4.

Table 4. Box selection results (set of 12)

Box	Outside Dims (in)		
	L	W	H
FedEx Pak (FedEx Express only)	15	12	
M1	8	8	2
M2	12	6	2
M3	12	10	2
M4	11	7	7
M5	24	6	4
M6	12	10	6
M7	18	12	7
M8	17	12	10
M9	20	12	12
M10	26	20	8
M11	26	16	16

According to Zeng's results [1], excluding the deliveries that would be shipped in Pak, the air percentage for the remaining deliveries would drop from 60% to 43 % by adopting the new boxes.

Financials:

Direct labor:

There will be no change to the number of worker required for GDC domestic outbound operations. Thus, there will be no saving on direct labor.

Support Labor:

It is estimated that 320 working hours of Waters IT engineers are needed in order to finish the programming and implementation. Therefore, the support labor cost will be a one-time cost of $20,000.

Corrugate:

Based on the analysis results, the corrugate use per box will be reduced by 12.7%. The annual corrugate use will be decreased by 153,964 square foot, and the annual saving on corrugate will be $ $2,325. (There is huge reduction for the corrugate use but financial saving is not that much. The reason is: there will be no more free FedEx boxes in use except Pak, and Waters need to pay for all the new boxes.)

Void material:

For the applicable charged by volume deliveries, the air percentage would be reduced from 60% to 43%.The new average box volume will become (1-60%)/(1-43%)=70.2% of the original box volume, and thus 29.8% of the original box volume would be reduced, and the new void volume would be (60-29.8)/60=50.3% of the original void volume.

By including the deliveries that are shipped in Pak and charged by actual weight into account, the total saving on void material will be $9,500 per year.

Freight:

Based on the detailed calculation, the annual freight cost saving will be $83072.06.

Equipment:

There will be no new equipment required, therefore there is no extra expense.

In conclusion, the first-year saving for Solution 2.1 will be $74,897. Most of savings are generated by the reduced freight cost, while the reduction of the corrugate use and void material consumption can also bring some benefits. In addition, there is a one-time implementation cost (support labor). From Year 2 onwards, the annual saving will be $94,897.

Implementation:

Time frame:

It is estimated that 90 days are need to conduct the implementation for solution 2.1: 1 month for programming (improve and finalize the code), and 2 months for integration with current SAP/WMS systems.

Space:

No additional space required.

IT resources/Support:

320 working hours.

Sustainability:

Corrugate Use:

153,964 square foot of corrugate could be saved annually.

CO_2 emission:

The CO_2 emission will be reduced by 13.86 ton annually due to the pure saving on corrugate.

Solution 2.2 (20 options):

The detailed box selection results are shown in Table 5.

Table 5. Box selection results (set of 20)

Box	Outside Dims (in)		
	L	W	H
FedEx Pak (FedEx Express only)	15	12	
N1	8	8	2
N2	12	6	2
N3	12	5	4
N4	12	10	2
N5	11	7	7
N6	15	12	3
N7	18	16	2
N8	24	6	4
N9	12	10	6
N10	20	12	3
N11	18	12	7
N12	13	13	9
N13	17	12	10
N14	26	20	4
N15	20	12	12
N16	18	16	10
N17	26	20	8
N18	26	15	12
N19	26	16	16

According to Zeng's results [1], excluding the deliveries that would be shipped in Pak, the air percentage for the remaining deliveries would drop from 60% to 39 % by adopting the new boxes.

Financials:

Direct labor:

There will be no change to the number of worker required for GDC domestic outbound operations. Thus, there will be no saving on direct labor.

Support Labor:

Similar to solution 2.1, the one-time support labor cost will be 20,000.

Corrugate:

Based on the analysis results, the corrugate use per box will be reduced by 18.6%. Then the annual corrugate use will be decreased by 191,519.4 square foot and the annual saving on corrugate will be $7,017.

Void material:

For the applicable charged by volume deliveries, the air percentage would be reduced from 60% to 39%. Then the new void volume would be 42.7% of the original void volume. By taking the deliveries that are shipped in Pak and charged by actual weight into account, the total saving on void material will be $10,500 per year.

Freight:

Based on the detailed calculation, the annual freight cost saving will be $115848.13

Equipment:

There will be no additional equipment required, thus no change on equipment cost.

In conclusion, the first-year saving for Solution 2.2 will be $113,365. Most of savings are generated by the reduced freight cost, while the reduction of the corrugate use and void material consumption can also bring some benefits. In addition, there is a one-time implementation cost (support labor). From Year 2 onwards, the annual saving will be $133,365.

Implementation:

The implementation difficulty and resources needed for solution 2.2 will be exactly the same as solution 2.1.

Sustainability:

Corrugate Use:

191,519 square foot of corrugate could be saved per year by adopting this solution.

CO2 emission:

The corresponding annual reduction of CO2 emission would be 18.29 ton.

5.3 Solution 3: Automated Box Maker Implementation

Theoretically, the optimal solution to solve the packing problem is to keep unlimited options of stock box to choose. Thus, every order can have a box that exactly matches its dimensions. Nonetheless, it is impossible to stock and use that much different boxes in real practice.

However, in recent years, thanks to the development of big data technology and warehouse digitalization, a new solution, called "on demand packaging", emerged and can achieve the equivalent results as keeping unlimited stock boxes. On demand packaging is a sustainable concept that utilizes custom box-making to replace box inventories. The automated box maker can make right-sized boxes for every order (both single and multiple item orders), and thus minimize the waste.

Waters has reached out with one leading on-demand packaging system provider– Packsize, regarding the implementation of the automated box maker. Therefore, Solution 3 was proposed by Packsize per Waters' requirements.

Figure 10. Packsize Custom Box Maker [Source: Packsize]

Solution 3 applies to all GDC domestic outbound shipments. According to Packsize's results, more than 3000 kinds of customized boxes with different dimensions would be made based on GDC 2018 data, and the air percentage can be reduced from more than 60% to 18% [14].

Financials:

Direct labor:

There will be no change to the number of worker required for GDC domestic outbound operations. Thus, there will be no saving on direct labor.

Support Labor:

200 working hours from Waters IT engineers and 40 hours from Packsize's software engineer are required one time to do the solution integration. So the support labor cost will be one-time $19,000 ($12,000 internal, $7000 for Packsize).

Corrugate:

The total corrugate use will be decreased to 606080.76 square foot, and the reduction will be 299434.57 square foot. Based on Waters' current spending and Packsize's charge, the annual cost saving from corrugate will be $9,891.

Void material:

Based on the reduction of the void volume, there will be $25,200 saving from void material per year.

Freight cost:

The total freight costing saving is projected to be $210,783 per year based on current contract/rates.

Equipment cost:

Packsize will provide (and still own) the box maker equipment to its customer, and Waters needs to pay the annual subscription fee, which is $25,080 for GDC, to use the equipment and software. The box maker equipment installation cost is estimated to be $8,970.

In addition, some new equipment, including new conveyors, trays and air pipes, need to be purchased for the box maker system. The total cost is estimated to be $12,000, and the depreciation period is 5 year. So, the first-year equipment cost would be 25080+8970+12000/5=$36,450. The annual equipment cost since Year 2 would be 25080+12000/5=$27,480.

In conclusion, the first-year saving for Solution 3 will be $190,424. Most of savings are generated by the reduced freight cost, while the reduction of the corrugate use and void material consumption can also bring some benefits. In addition, there is a one-time implementation cost, and additional equipment costs. From Year 2 onwards, the annual saving will be $218,394.

Implementation:

Time frame:

It is estimated that 180 days are needed to conduct the implementation for box maker: the data preparation/integration with current SAP/WMS systems will take relatively long time, and extra time will be required for training and transition at GDC.

Space:

The detailed floor plan after the implementation of box maker systems is shown as Figure 11, and 150 square foot floor space is needed. More details are presented in Harsono's thesis [2].

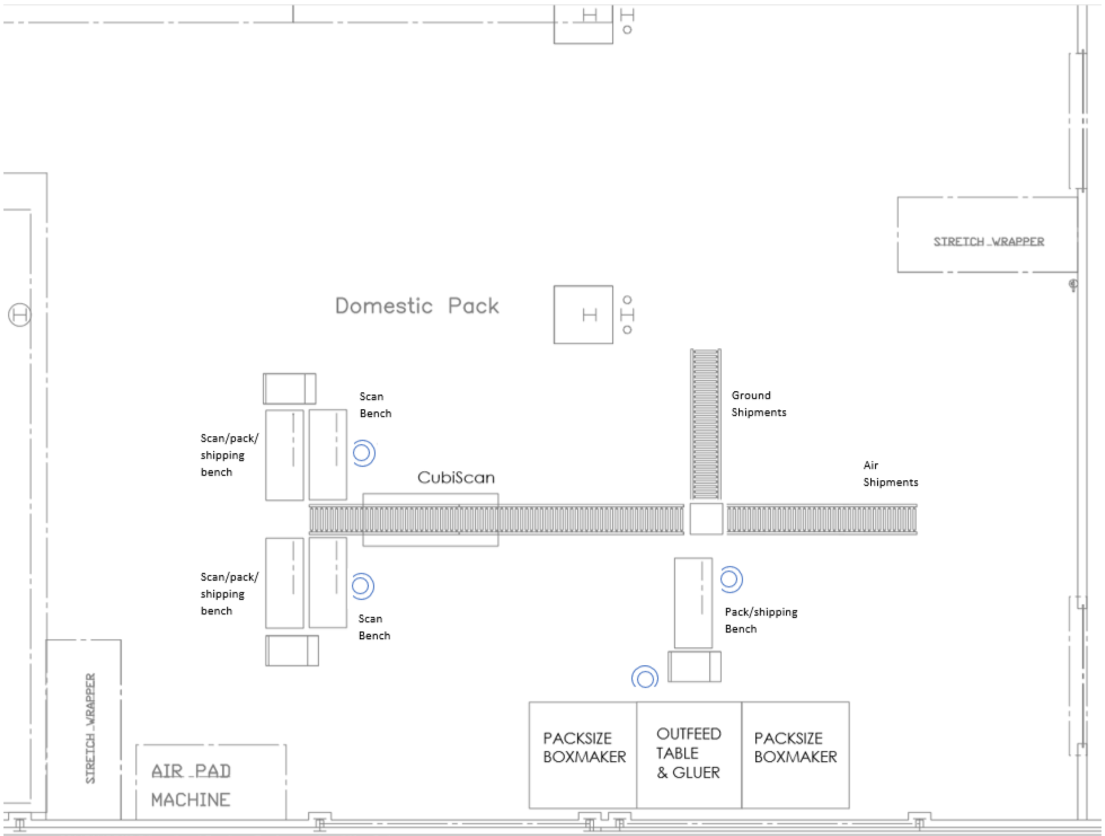

Figure 11. Proposed GDC floor plan with integrated box maker system

IT resources/Support:

200 work hours for Waters IT department.

Sustainability:

Corrugate Use:

299434.57 square foot of corrugate could be saved per year.

CO_2 emission

There will be 35.32 tons CO_2 emission prevented per year.

Chapter 6. Results and Discussion

This chapter summaries the evaluation results from the three perspectives: financial, implementation and sustainability. The proposed solutions are compared, and the recommendations to Waters are made.

6.1 Financial

Table 6. Financial returns of proposed solutions

	Solution 1	Solution 2.1	Solution 2.2	Solution 3
Direct labor ($/yr)	$ -	$ -	$ -	$ -
Support labor (one-time cost)	$ -	$ (20,000)	$ (20,000)	$ (19,000)
Corrugate ($/yr)	$ 4,165	$ 2,325	$ 7,017	$ 9,891
Void material ($/yr)	$ 2,000	$ 9,500	$ 10,500	$ 25,200
Freight ($/yr)	$ 59,536	$ 83,072	$ 115,848	$ 210,783
Equipment * ($/yr)	$ -	$ -	$ -	$ (36,450)
First-year saving	$ 65,701	$ 74,897	$ 113,365	$ 190,424
Investment	$ -	$ 20,000	$ 20,000	$ 65,050
ROI	N/A	374.49%	566.83%	292.73%
Annual saving since Year 2	$ 65,701	$ 94,897	$ 133,365	$ 218,394

**For Solution 3, The equipment cost for first year is $36,450, while from year 2 onwards it will become $27,480 per year.*

Since no solution will affect the number of workers required at GDC, there will be no saving from direct labor. Solution 2.1/2.2 and 3 require hundreds of work hour for the internal/external engineers to implement; thus, there will be some one-time expenses on support labor. All four solutions can reduce the corrugate and void material cost, as well as freight cost: Solution 3 will have the largest saving on these categories due to the smallest air percentage remaining after implementation. For equipment, only Solution 3 requires extra expenses.

Based on all the costs and savings, the corresponding annual savings and ROI for all solutions are calculated. The ROI is calculated as the first-year saving divided by the investment (to be conservative. In addition, since Solution 1 almost needs no investment, the ROI will be extremely high and thus not calculated here). For the absolute saving, Solution 3 has the highest return, Solution 1 has the lowest return, while solution 2.1 and 2.2 are in between. The ROI of every solution is more than 200%, which is way above Waters' internal project ROI threshold. Therefore, in conclusion, from financial perspective, all the solutions are quite promising.

6.2 Implementation

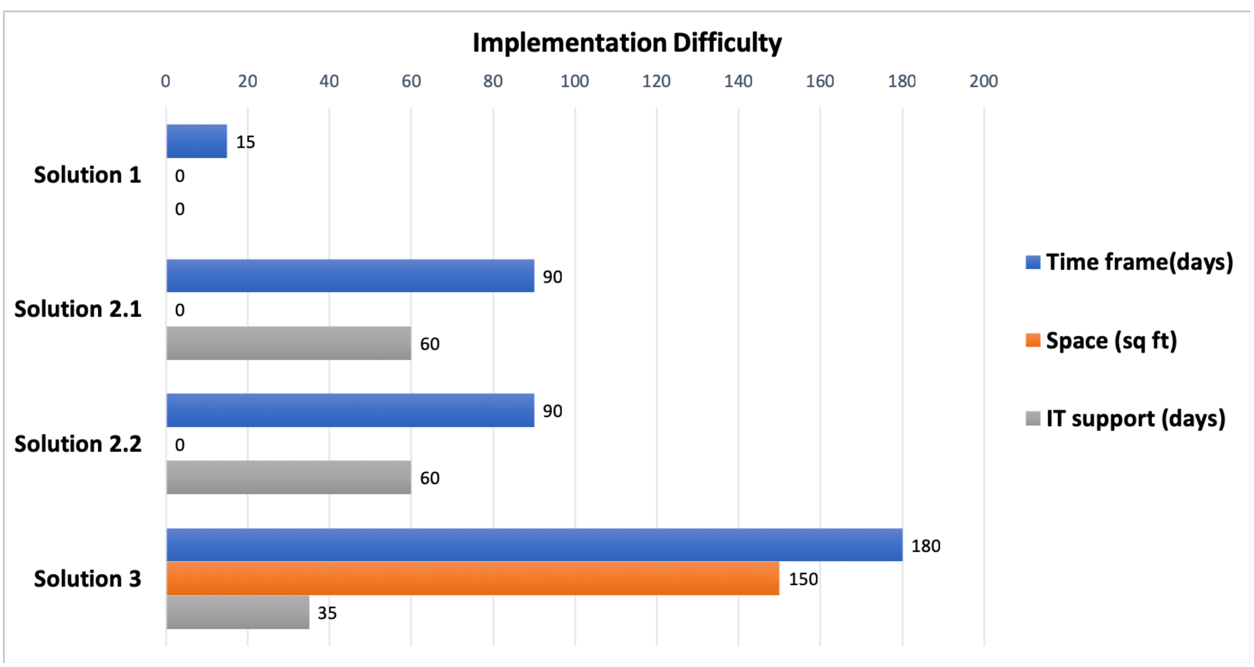

Figure 12. Comparison of implementation difficulty of proposed solutions

As Figure 12 shows, the implementation difficulty and resources requirements are ascending from Solution 1 to Solution 3. Solution 1 is the easiest to implement since there will be no change on the software system/process flow. Solution 2.1 and 2.2 requires a lot of work for programming and system integration, but no additional space is required at GDC. Solution 3 is the hardest to implement, since it requires new equipment installation, process flow modification, system integration and employee training before becoming fully functional.

6.3 Sustainability

Table 7. Sustainability impacts of proposed solutions

	Solution 1	Solution 2.1	Solution 2.2	Solution 3
Corrugate saving (square ft per year)	73,124	153,864	191,519	299,435
CO2 emission reduced (tons per year)	4.30	13.86	18.29	35.32

All the solutions have positive impacts on sustainability, which is one of the company goals Waters emphasizes. As Table 7 shows, Solution 1 has relatively smaller saving on both corrugate use and CO_2 emission, since the applicable deliveries are small. Solution 2.1/2.2 have bigger impacts because the savings are generated from most of the GDC domestic deliveries. Solution 3 has the highest sustainability benefit because every custom box will actively use less corrugated than the stock size box.

6.4 Recommendations

Based on all the analysis from section 6.1 to 6.3, the team offered recommendations to Waters regarding the adoption of the proposed projects. Figure 13 shows the decision-making matrix the team utilized to compare three solutions.

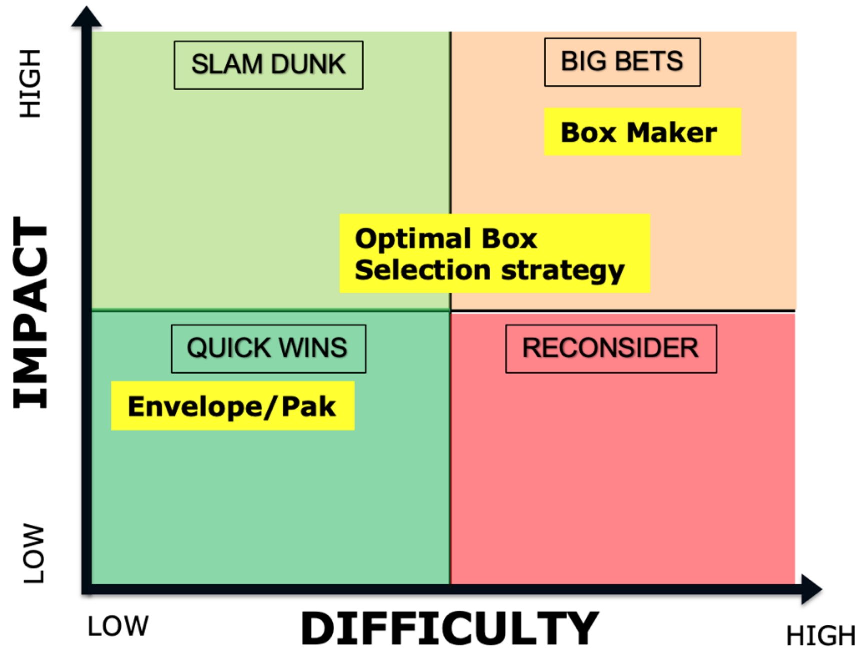

Figure 13. Decision-making matrix

As Figure 13 shows, the Envelope/Pak adoption (Solution 1) is very easy to implement and can generate certain benefits, and thus it is highly recommended. The box maker (Solution 3) can generate the largest savings, but also has the highest difficulty to adopt. The optimal box selection strategy (Solution 2) falls in between, with a decent return and relatively high implementation difficulty. It is important to note that Solution 2 is built upon Solution 1, since the Pak will become one of the new packaging options. Therefore, if Solution 1 were already implemented, there would be limited additional savings by further adopting Solution 2.

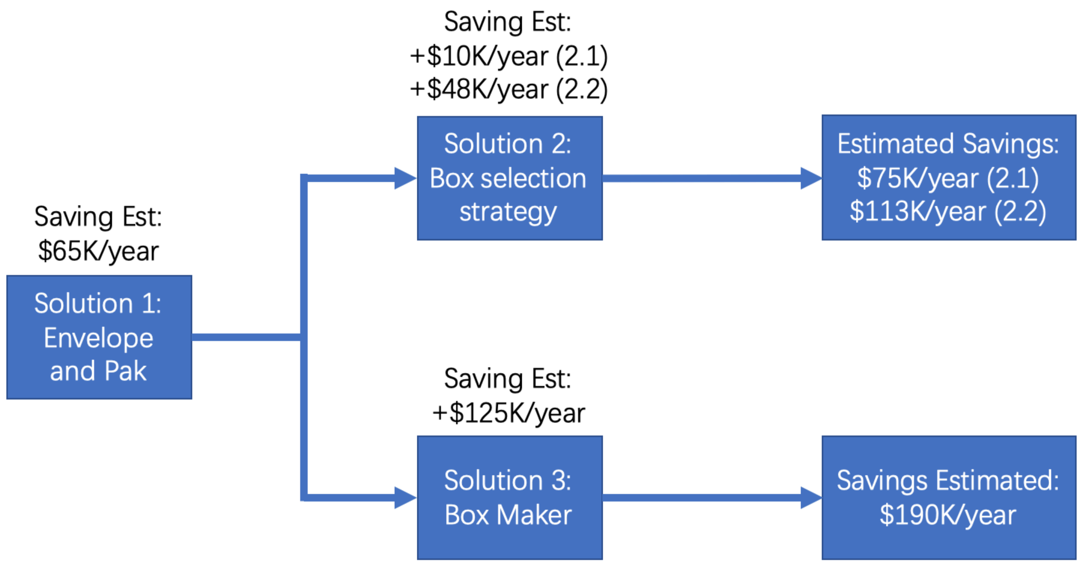

Figure 14. Recommended road map

Figure 14 shows the recommended road map to Waters. The team suggests to first introduce envelopes/Paks (Solution 1) to the GDC domestic line. This requires little to no investment, creates minimal impact on current operations, and can generate immediate savings. From there, two paths can be taken. One path is to implement the optimal box selection strategy (Solution 2), which requires initial IT support but also creates relatively little change to current packing operations. The other path is to implement the box maker (Solution 3). This requires the most time and money invested, but would result in much more savings. It would not make sense to implement both Solution 2 and Solution 3, because the former is based on stock size boxes, which would have very limited use once the majority of boxes were custom made using the box maker. Therefore, the team recommends GDC to select either Solution 2 or Solution 3 to invest in, depending on the financial/sustainability target and the resources availability.

Chapter 7. Conclusion and Future Work

With a span of several months, the MIT team analyzed Waters GDC's packing problem, established the baseline, proposed and evaluated three solutions.

All these projects will benefit Waters by:1. Reduce freight costs, thus translating to savings that hit the bottom line. 2. Reduce cardboard and void material waste, which promotes sustainable packaging and lowers Waters carbon footprint.

Based on all the evaluation in previous chapters, a progressive road map was proposed to solve the GDC packing problem: the envelope/pak adoption for Phase 1, and the optimal box selection strategy or the automated box maker implementation for Phase 2.

In addition, there are some future work that is recommended.

From solution adoption perspective:

For envelope/pak adoption, since the primary objective of packing is to ensure adequate protection of the finished goods, a pilot project may need to be conducted first to test the results and gather feedback from internal and external customers. For the optimal box selection strategy, the program needs to be finished and further improved to incorporate all possible scenarios such as hazardous material/cold chain shipments. For the automated box maker implementation, the new process flow/floor layout needs to be approved to meet the operation and quality requirements.

If any of the solutions is proved to be successful after the implementation at GDC, such solution can be extended to ADC and EDC to generate bigger savings and sustainability impacts.

From data perspective:

During this project, collecting more supporting data and maintaining a robust database are shown to be of critical importance. Currently the volume information for more than 10,000 deliveries that are charged by dimensional weight cannot be recovered due to missing data; the potential freight cost savings for these deliveries were not captured in the previous analysis. Therefore, it is suggested to measure the dimensions of the remaining several thousand SKUs to complete the product information dataset. Furthermore, with the recently purchased scanner, the actual dimensions for all the outbound shipments can be captured to improve the data quality.

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Appendix

PDF data extraction code:

```
import csv
import pdfplumber

path = 'input.pdf'
pdf = pdfplumber.open(path)

for page in pdf.pages:
    for table in page.extract_tables():
        for row in table:
            print(row)
            if len(row) == 8:
                result = []
                try:
                    for i in range(1, len(row)):
                        result.append(row[i].replace("$","").replace(" ","").replace("lbs.","").replace("lb.",""))
                except Exception as e:
                    break
                with open("result.csv", "a", newline='', encoding = 'utf-8') as csv_file:
                    writer = csv.writer(csv_file, delimiter=',')
                    writer.writerow(result)
            elif len(row == 5):
                result = []
                try:
                    for i in range(1, len(row)):
                        result.append(row[i].replace("$","").replace(" ","").replace("lbs.","").replace("lb.",""))
                except Exception as e:
                    break
                with open("result1.csv", "a", newline='', encoding = 'utf-8') as csv_file:
                    writer = csv.writer(csv_file, delimiter=',')
                    writer.writerow(result)
            elif len(row) == 9:
                result = []
                try:
                    for i in range(1, len(row)):
                        result.append(row[i].replace("$","").replace(" ","").replace("lbs.","").replace("lb.",""))
                except Exception as e:
                    break
                with open("result2.csv", "a", newline='', encoding = 'utf-8') as csv_file:
                    writer = csv.writer(csv_file, delimiter=',')
                    writer.writerow(result)
pdf.close()
```

Freight rates calculation code:

```
import csv
import pandas as pd

print("Read data....")
data = pd.read_excel("input.xlsx")
Delivery = data.Delivery.tolist()
Recipient_Country = data.Recipient_Country.tolist()
Service = data.Service.tolist()
Zone = data.Zone.tolist()
New_Bill_Wt = data.New_Bill_wt.tolist()
print("Read data completed")

for i in range(len(Delivery)):
    delivery  = Delivery[i]
    country = str(Recipient_Country[i])
    zone = str(Zone[i])
    service = str(Service[i])
    wt = New_Bill_Wt[i]
    print(delivery, country, zone, service, wt)
    if country.find("USA") > -1 and service.find("DOMGRND") > -1:
        print("*1")
        ground = pd.read_excel("Ground.xlsx", header=None)
        price = ground.iloc[int(wt), int(zone)]
    elif country.find("USA") > -1 and service.find("DOMGRND") < 0:
        print("*2")
        us = pd.read_excel("US"+zone.replace("0","")+".xlsx", header=None)
        if service.find("3DPM") > -1:
            price = us.iloc[int(wt), 6]
        elif service.find("1DAM") > -1:
            price = us.iloc[int(wt), 2]
        elif service.find("1DPM") > -1:
            price = us.iloc[int(wt), 3]
        elif service.find("2DPM") > -1:
            price = us.iloc[int(wt), 5]
    elif country.find("CAN") > -1:
        print("*3")
        can = pd.read_excel("CAN.xlsx", header=None)
        if zone.find("A") > -1:
            price = can.iloc[int(wt)-1, 2]
        elif zone.find("B") > -1:
            price = can.iloc[int(wt)-1, 1]
    result = []
    result.append("'"+str(delivery))
    result.append(price)
    with open("result.csv", "a", newline='', encoding = 'utf-8') as csv_file:
        writer = csv.writer(csv_file, delimiter=',')
        writer.writerow(result)
```