Operational Analysis of an Inventory Location Optimization Algorithm and RFID Implementation in a Distribution Center

by

Rushil Batra

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Signature of Author: .... Signature redacted

Department of Mechanical Engineering
August 10, 2018

Certified by: .... Signature redacted ....

David E. Hardt
Ralph E. and Eloise F. Cross Professor of Mechanical Engineering
Thesis Supervisor

Accepted by: .... Signature redacted ....

Rohan Abeyaratne
Quentin Berg Professor of Mechanics
Chairman, Committee for Graduate Students

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ABSTRACT

This thesis presents a strategic roadmap laid out for Waters Corporation, an analytical laboratory instrument company, and explores various avenues for digitalization, automation, optimization and standardization throughout its value chain. It then focuses on operational analysis of two pilot process improvement projects at their Global Distribution Center (GDC).

Sub-optimal inventory placement caused by randomized assignment of primary storage locations is one of the key challenges faced by GDC. This often leads to inefficiencies in the form of unfulfilled orders as well as additional time and effort expended by material handlers. To cater to this problem, the first project revolves around the development of an inventory location optimization algorithm by taking into consideration the order frequency for a particular product and its distance from the shipping area. This work develops a mathematical formulation for assigning discrete storage location costs as an input for the algorithm by incorporating the nuances of current operating procedures. Preliminary estimates point toward savings of around 5% in walking time.

While the aforementioned algorithm improves efficiency for put-away and retrieval of products, GDC requires better technology to track inventory and tackle the challenge effectively. Radio Frequency Identification (RFID) is an Automatic Identification (Auto-ID) technology popular for reading multiple tags at once and not requiring line of sight and. Its implementation was selected as the second pilot project for its ability to better manage inventory, reduce dock-to-stock time, improve put-away and shipping accuracy thereby directly impacting rate and quality of order fulfillment. The estimates suggest a reduction of over 20% in receiving time and 80% in time taken for inventory cycle counts besides drastic improvement in process accuracy.

This work analyses the impact of both projects on the existing business processes by assessing the as-is state and proposing a future state after full-scale implementation. RFID has seen limited implementation in the industry owing to complexity in estimating the added value. The suitability of RFID application for inventory management in GDC is demonstrated through a cost-benefit analysis and Net Present Value (NPV). While there are significant costs associated with the technology, the range of applications and benefits derived strengthen the case for its implementation.

Thesis Supervisor: David E. Hardt
Title: Ralph E. and Eloise F. Cross Professor of Mechanical Engineering

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ABBREVIATIONS

AAGR	Average Annual Growth Rate
Auto-ID	Automatic Identification
DFMA	Design for Manufacture and Assembly
EPC	Electronic Product Code
HPLC	High-performance Liquid Chromatography
NIOSH	National Institute for Occupational Safety and Health
GDC	Global Distribution Center
GR	Goods Received
NIL	Not-in-Location
NPV	Net Present Value
OEE	Overall Equipment Efficiency
PL	Packing List
PLC	Programmable Logic Controller
PLM	Product Lifecycle Management
IM	Inventory Management (System)
RFID	Radio Frequency Identification
ROI	Return on Investment
SKU	Stock Keeping Unit
SOP	Standard Operating Procedure
TO	Transfer Order
TRF	Transport Request Form
UPLC	Ultra-performance Liquid Chromatography
WMS	Warehouse Management System

CHAPTER 1

INTRODUCTION

This section introduces the project's overall problem statement and enlists the objectives for the period. It then covers the task division methodology for the MIT team and concludes with a structure for this document.

1.1 Problem Statement

Traditionally at the Waters' Global Distribution Center (GDC), products are counted manually while performing various warehouse operations such as receiving, order picking, inventory cycle counts, and shipping. It was observed that this physical check of inventory, scanning, and verification accounted for a large proportion of material handlers' time and often led to inaccurate system inventory data. Moreover, after recent drastic changes in the overall layout, it was observed that the storage locations for incoming products were randomly assigned. This resulted in frequently shipped items often being placed away from packing stations. This implied that the pickers had to repeatedly walk longer distances and clock additional work hours for ensuring order fulfillment.

1.2 Objective

The primary objective of this work is to lay out a strategic roadmap for Waters Corporation by carefully assessing the present state and benchmarking it against the industry standards and latest technology trends. The focus is on identifying opportunities for minimizing the picking and put-away errors, optimizing inventory location and handling processes in the warehouse, by means of operational analysis. This thesis aims to highlight the gaps in the existing business processes at Waters. In addition, this work establishes the need and implementation plan for inventory location optimization algorithm and RFID deployment at GDC. The other objectives taken into consideration while defining the solution approach and strategic roadmap are to minimize the throughput time of an order, maximize the use of labor, maximize the accessibility to all items and reduce the order non-fulfillment rate (due to picking errors).

In order to operate efficiently, the inventory handling process should be robustly designed and optimally controlled, keeping in view the implications on business. While there is abundant information on the physics & applications of RFID, there is very limited literature on whether the business should deploy RFID from a financial standpoint and the effective deployment of the principles. This project seeks to fill this gap by serving as a template for organizations looking to introduce RFID in their warehouses by providing an extensive study through assessment of technological feasibility and economic viability.

1.3 Task Division

This section discusses the role and responsibilities of the three members of the team.

1.3.1 Strategic Roadmap

The team developed the strategic roadmap and deliberated on fundamental themes to carve out multiple projects for Waters. Individual projects were developed by individual members of the team and those proposals appear separately in each thesis.

1.3.2 Pilot Projects

The team developed and implemented two pilot projects, a Warehouse RFID-based Dock Door System, and Inventory Relocation. With two projects and three members, the team took a dedicated/floater approach toward allocating its resources. Hochsztein participated and contributed during the general planning and research phase of the RFID project, but was otherwise dedicated exclusively to the Inventory Relocation project [1]. Likewise, Harlalka participated in the ideation and planning phase of the Inventory Relocation project but was otherwise dedicated exclusively to the RFID Project [2]. The author of this thesis was engaged directly in both projects and conducted research, operational analysis, and testing in service of both objectives. This hybrid approach between direct collaboration and task division was crucial to the success of both projects within the time constraints of the shortened project timeline.

1.4 Thesis Structure

The thesis begins with a description of the project objectives (Chapter 1) which is followed by a brief introduction to Waters (Chapter 2). It then presents the strategic roadmap and details certain process improvement initiatives (Chapter 3). The following chapters explain the methodology and basic technology for the selected pilot project ideas in detail (Chapter 4 & Chapter 5). The impact of the selected projects on business processes, a major factor influencing decision-making, is then studied (Chapter 6). In addition, this work ultimately quantifies this impact in the form of a cost-benefit analysis for RFID implementation (Chapter 7). To summarize the key takeaways, this document concludes with the results of the projects and recommended action plan for Waters (Chapter 8).

CHAPTER 2

BACKGROUND

This section introduces Waters Corporation, the host of this thesis project and the primary subject of the corporate and technical analyses. It details the history of the partnership between Waters and MIT. The chapter also introduces Waters' manufacturing business unit, its Massachusetts based distribution center, and the main elements of its technology and product lines.

2.1 Waters Corporation: Corporate Profile

Founded in 1958 by James Waters, Waters Corporation is a $2.2 billion publicly traded corporation with its headquarters in Milford, Massachusetts. The company is a leader in complementary analytical technologies such as mass spectroscopy, liquid chromatography, rheometry and microcalorimetry with a presence in over 100 countries [3][4][4].

The company boasts of an advanced design division, sprawling manufacturing facilities and service network focused on ultra-performance liquid chromatography (UPLC), high-performance liquid chromatography (HPLC), chromatography columns and chemistry products, mass spectrometry (MS) systems, thermal analysis and rheometry instruments. Waters employs over 7200 people worldwide. The company has segregated its operations into two separate divisions: Waters Division and TA Instruments [4].

The Waters Division is responsible for design, development, and production of UPLC, HPLC and MS instruments, and consumables which are used in a broad range of industries to measure the chemical, physical and biological composition of materials. Their products are primarily used by pharmaceutical, life science, biochemical, industrial, academic and government organizations. Meanwhile, TA Instruments is responsible for the thermal analysis, rheometry and microcalorimetry instruments which are used for determining the applicability of various chemical substances used in industrial, consumer goods and healthcare products [4].

2.2 Waters – MIT Alliance

Incorporated in 2013, Waters – MIT Alliance has led to multiple projects in areas ranging from Research & Development to Manufacturing to Operations to Supply Chain. Every academic year, a team of student consultants from the Master of Engineering in Advanced Manufacturing & Design program at MIT comes in to augment various teams at Waters realize their strategic goals and at times, help them set a vision for the future.

The projects have resulted in patent-worthy scientific implementations and have made it possible to bring fresh innovative ideas into the scientific legacy existing at Waters. The company benefits from the out-of-the-box thinking and an outsider's perspective on their challenges. In addition to the student team, a faculty member provides the necessary subject matter expertise required to take these ideas forward. Meanwhile, the students develop systemic thinking by getting a holistic view of the business and gaining unparalleled industry experience.

2.3 Waters Advanced Manufacturing Center

Located in Milford, MA, the Waters Advanced Manufacturing Center is a state-of-the-art manufacturing facility which houses the Advanced Instrument Assembly & Accessory Kitting Operations area, a Class 10000 clean room and the Global Machining Center [5].

The Advanced Instrument Assembly & Accessory Kitting Operations area is responsible for assembling the standalone kits and the HPLC instruments. The 8,500 sq. ft. clean room produces optics, microvalves and critical parts for Waters products [5].

The Global Machining Center is responsible for manufacturing various components like columns and valves which are critical to the performance of Waters instruments for distribution worldwide. Around 85% of manufacturing is outsourced to contract manufacturers; however, high-precision components and parts for New Product Development (NPD) are manufactured in this facility. The process flow in the factory is primarily job-shop in nature with different areas corresponding to turning and milling operations. The valve cell and the column area are exceptions for the existent flow is product based [5].

2.4 Global Distribution Center (GDC)

Waters' worldwide distribution is centralized in three primary distribution centers across the world, the Asian Distribution Center (ADC) in Singapore, the European Distribution Center

(EDC) in the Netherlands, and the Global Distribution Center (GDC) in Franklin, Massachusetts. GDC handles most of Water's outbound shipments, sending over 1500 lines per day both directly to customers and to other distribution centers as well.

In October 2017, Waters moved its Global Distribution Center into its current home in Franklin, MA. GDC is currently at a facility with 56,000 square feet of space outfitted with various types of storage, ranging from high bay areas, to standard shelving, to refrigerator and freezer locations in order to maintain over 11,000 distinct stock keeping units in over 20,000 separate storage locations. GDC has two separate loading docks and employs the traditional "flow-through" warehouse model. While GDC has dedicated staff for receiving, international and domestic picking, and international and domestic packing, many of its experienced material handlers are cross-trained to enable flexibility when confronting different order patterns and daily, quarterly, and seasonal trends.

2.5 Waters Products

This section introduces the products which form the most significant part of product line-up for Waters.

2.5.1 Liquid Chromatography Instruments

Liquid Chromatography (LC) is a technique to separate a substance/material into its constituents by using a pressurized liquid solvent. The most significant markets for LC instruments are the life sciences and pharmaceutical industries which require the technique to identify new drugs, test the purity of certain pharmaceuticals and diagnose diseases. Waters manufactures highly customizable LC instruments for the end user. There are various configurations and degrees of automation which the customer can choose from, starting with component configured systems for research and teaching applications to fully automatic systems which can provide much higher throughputs in industrial settings [6].

In 2004, Waters introduced a novel technology called the Ultra-performance Liquid Chromatography (UPLC). This technology enabled the use of very small but uniform sized particles as a packing material for its columns. These packed columns when used with the *Acquity* UPLC system helped the customers separate the materials more reliably and achieve the separations in a faster time frame. These systems are Waters' current workhorses in the LC instrument segment [6].

2.5.2 Mass Spectroscopy Instruments

Mass Spectroscopy (MS) primarily allows users to identify unknown compounds/materials by measuring the weights of the molecules that get converted into ions during the process [6]. In September 1997, Waters transformed itself from a minor player in the MS instrument industry to a leader by acquiring MicroMass Ltd. based in Manchester, England. MS is frequently used with other analytical techniques like LC or gas chromatography for drug testing, nutritional safety testing and environmental testing procedures [6].

2.5.3 Consumables

For LC, the primary consumables are columns, which are essentially steel tubes packed with the separation media [6]. These columns have a much shorter life cycle than instruments and are typically replaced at regular intervals. The packing material for the columns is typically made from Silica or Polymeric resins. During the liquid chromatography process, the sample is introduced into the column at a high pressure and its subsequent interaction with powder initiates the separation [6].

CHAPTER 3

STRATEGIC ROADMAP

This section details the strategic roadmap that was researched and developed during the exploration phase of the 2018 Waters - MIT Alliance project. While the complete roadmap was submitted to Waters in a unified document, the proposed projects are listed below to help understand the significance of the roadmap, themes and some of the ideas.

3.1 Need

The major markets served by Waters Corporation include pharmaceutical, food, and materials. However, the majority of revenue (over 50%) is derived from the pharmaceutical industry slated to grow at 6% for the next few years [7]. This requires the company to ramp up production volumes amidst increasing cost pressures from the market to continue to beat benchmark indices. The scenario in the industry is changing rapidly owing to the high-growth markets in Asia, lingering fears of protectionism and the economic conditions in Europe. Waters requires a strategic overhaul to provide them the necessary edge and make their value chain agile enough to respond to any event effectively.

Traditionally, Waters has led the industry owing to its high-quality instrument portfolio that has resonated with the customers spanning from the pharmaceutical industry to the food industry. The competition is now catching up by providing innovative designs with a shorter turnaround time by incorporating feedback from detailed customer studies. For instance, some of the competitors have focused more on enhancing the overall user interface (UI) of their instruments by inclusion of smooth touch-displays whereas most of Waters' instruments have an LCD screen controlled by buttons. With the passage of time, the customer needs have evolved towards UI being a major buying factor in addition to the all-around performance. The design teams should scout for such drifts in customer requirements and work towards adapting the next generation products to the same.

Similarly, Waters should always keep up with the latest trends in technology to lead the industry. For instance, a plethora of applications of Artificial Intelligence (AI) have altered the way the businesses operate. The ever-increasing complexity of the supply chain has long warranted a systemic overhaul to prune inefficiencies and work towards productivity improvements. Given the changing times, the author recommends that the supply chain of the future should be quick to adapt and pivot according to the mood of the market. The latest technological revolution can aid in better capture and utilization of data for effective decision making. However, these technologies are only as good as data input for analysis which makes it all the more important to streamline data collection procedures and use technology there as well. For instance, the use of Automatic Identification (Auto-ID) technologies in conjunction with machine learning and data science can unearth hidden inefficiencies in the supply chain by improving the visibility of product and information flow.

The first set of checkpoints in transition to the organization of the future would be to revisit the business processes and explore use cases of latest technological trends. This should be followed by a detailed technical feasibility as well as economic viability study ensuring that the suggested alterations are in line with the strategic goals. The MIT team during the exploratory phase interacted with different teams at Waters to take the first step in rethinking the way business is conducted and laid the strategic roadmap presented in this chapter. The following sections discuss the importance of certain themes and how they fit into the roadmap and subsequently touches upon each idea in detail.

3.2 Outlook

The purpose of this roadmap is to document the findings of the exploration phase in a way that identifies and directs future projects at Waters Corporation. After considering the observations and points of view of various managers, the MIT team weighed the different goals and pain points to find an overall direction for the next three to ten years.

The team highlighted four overarching themes that encompass the direction that Waters seems to want to move toward as well as twelve specific high-value projects that fit into those themes and address some of Waters' most crucial needs. Many of these projects are pilot projects envisioned to bring new approaches, thought processes, and technology into Waters' field of vision in order to drive and inform other possibilities for growth and improvement.

As this roadmap is designed to illuminate future projects, it can potentially serve as a menu for teams of interns or MIT M.Eng. teams to select projects. Guided by the leadership team at Waters, two of the projects, Inventory Management using RFID and Inventory Relocation were selected as pilots for this year's team.

3.3 Themes

The strategic roadmap is centered around four central themes: Optimization, Automation, Digitalization, and Standardization. These have been identified as key areas for improvement across all business areas.

3.3.1 Optimization

Perhaps the simplest objective is for Waters to optimize aspects of its processes. For a very long time, Waters has relied on its industry-leading products and quality to ensure consistent consumption, profitability, and growth. As most of Waters' products sell at extremely high margins, it has been very easy for the company to sit comfortably atop the market and sustain its high level of success.

However, a recent shift in the mindset of Waters' management is in favor of working to improve process flows and efficiencies to increase product quality and reduce direct and indirect costs. It is extremely important for Waters to optimize whatever it can so that it is better equipped to keep pace with its competitors in this age of continuously evolving technology and markets.

3.3.2 Digitalization

Large corporations like Waters face challenges in sufficiently collecting, storing, maintaining, and utilizing the massive amount of data that describe their day-to-day processes. Business specific data is crucial for decision-makers to carve out the competitive strategy and streamline operations. Managers across all of Waters' business units need to be able to monitor the activity and availability of their resources, machines, and materials, and the task of handling all of these concerns becomes increasingly difficult as the company grows.

On one hand, this theme involves an effort to collect more digital data from various parts of the company. And it is equally important that the data collected using conventional methods be ideal for digital processing and use. On the other hand, Waters is already collecting tremendous amounts of information in many of its business units. Some effort from the teams is necessary to find uses for data that is already collected and continue to find ways to make the information profitable.

3.3.3 Automation

Currently, Waters' experiences tremendous waste through manual tasks. From repetitive physical tasks like box erection to tedious computer tasks like data entry and manual analytics, thousands of man-hours are spent doing tasks that don't necessarily require the attention of human staff members. While it is not the intention of the corporation to downsize its staff and lay off its workers, Waters still has room to grow by enabling its workers to spend more time on value-adding activities. Machines have the power to augment the ability of humans and allow them to perform more effectively.

3.3.4 Standardization

The final theme is focused on unifying aspects of Waters' business. As with many corporations, the larger Waters' grows, the more difficult it becomes to ensure that output results of work in many business areas is sufficiently homogeneous.

It was decided that effective standardization would be ensured if it's included in the upstream processes like product design. Teams responsible for design are often so pressed by their release deadlines that individual parts of the teams end up diverging in direction from other parts. Without time to realign the entire teams, the resulting work ends up with aspects from many different perspectives that do not have common features. Having processes, protocols, and component designs that do not share any portions results in increased work for staff and customers who have to deal with those protocols, as well as larger families of parts and documents to support the wide variety of entities. It is therefore proposed that making concentrated, team-wide initiatives to introduce strategic standardizations to homogenize the output of the business units will bring great value to the corporation.

3.4 Proposals: Summary

In service of the roadmap and its themes, twelve project proposals were prepared, four of which appear in this thesis, with the rest distributed between Hochsztein's & Harlalka's work [1] [2]. The MIT team brainstormed multiple ideas across the central themes and met with the key stakeholders in different departments to learn about their problems in more detail. It is believed that streamlining the existing business processes would be the first step in this roadmap.

The ideas pertaining to process improvement were grouped under the Optimization theme, in which four main ideas were considered: inventory relocation within DC, distribution network redesign, redefining shelf life to reduce scrap and determining optimal lot sizes. The team believes that an algorithm for optimal location of the inventory in warehouse could help GDC reduce its costs. Similarly, after learning that Waters' current distribution network involves significant back and forth shipping, the team believes that there could be an opportunity to optimize the current network, especially given the fact that freight costs Waters $40 million dollars each year. A meeting with the demand planning team resulted in the generation of the other project ideas based on their recommendations. One of their suggestions involved evaluating the potential of lengthening the expiration periods for certain products while the other sought to determine the optimal lot sizing structure by analyzing customer behavior and balancing trade-off with manufacturing costs. It is believed that these ideas can be augmented by better quality data which can be analyzed to unearth inefficiencies.

Digitalization of some of their processes would prove essential for getting access to high fidelity data. This theme encompassed four main ideas: data-driven manufacturing, digitalization pilots for manufacturing and assembly, inventory tracking using RFID, and IoT-based HPLC system architecture. During the MIT team's interview with the manufacturing team, it was learned that many machines in the shop floor were "MTConnect ready" referring to the common data protocol shared by these machine tools. By leveraging the capability of MTConnect, the team believes that a dashboard representing the real-time activity on the shop floor could be created for the shop manager, thus saving him time to inspect shop operations physically. During the team's visit to the shop floor, it was also learned that certain valuable shop floor metrics were being calculated manually. The team suggested shifting to digital methods of measurement and recommended the Digital Factory Kit offered by Tulip as a possibility. The visit to GDC, where the team observed the painstaking process of scanning individual items, convinced them of the potential of using RFID for inventory tracking. Similarly, learning about the intricacies in capturing consumer data led the team to propose the idea of introducing an IoT-based HPLC System Architecture. In addition to better data, it's required to augment the workforce with the necessary machines to improve productivity.

To ensure that humans only work on value-adding activities, certain parts of the processes need to be automated. Within this broad theme of Automation, the team put forward two ideas: box erection technologies and assistive technologies for material handlers in GDC. A specific implementation in this theme would benefit the manufacturing floor. The team discovered that the lack of communication between TrackWise & SAP necessitated manual checks for inventory levels of raw material for LC columns. Automating the raw material as part of the larger theme of automation could help shorten the effective lead time. In a similar manner, automated box erection technology could help reduce the time required for the material handler to package and ship orders. It's also known that these improvements can only be sustained in the long term if the processes are standardized.

Within the Standardization theme, two main ideas were proposed: design standardization and modular design of HPLC system architecture. The design standardization idea focused on reducing inconsistency in product architecture that leads to greater assembly and service times. Meanwhile, the modular design aspect focused on creating a common rack architecture for LC equipment that would allow for independent disassembly of the individual modules.

The strategic roadmap listing all the ideas for improving the existing business processes under the specific themes, are given below in Figure 3-1.

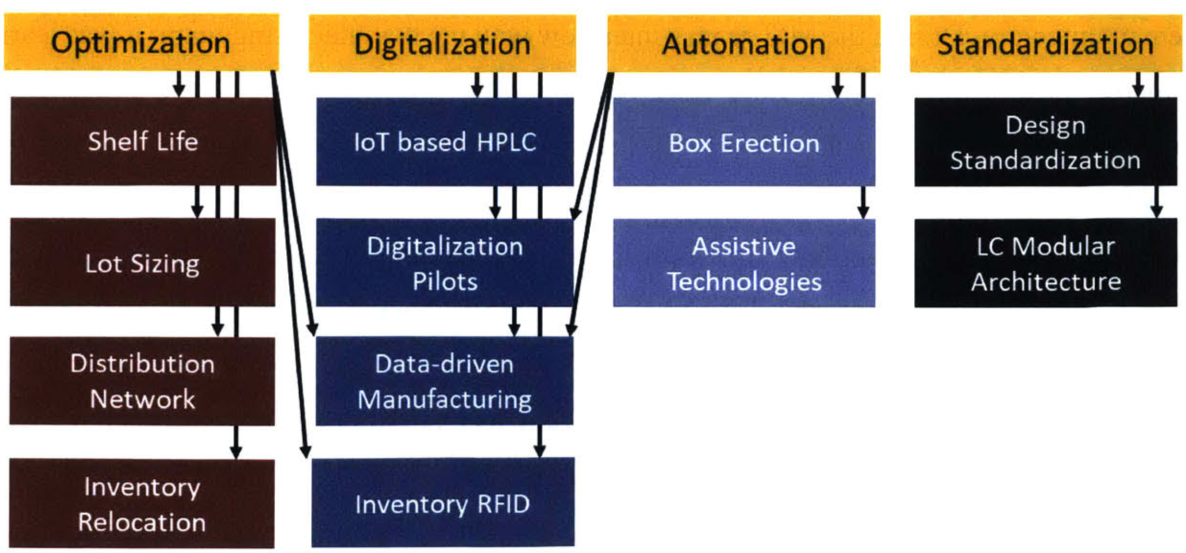


Figure 3-1. Schematic of the Strategic Roadmap

3.5 Proposals: Description

Based on the assessment of the current processes and focus areas at Waters, twelve project proposals were identified and organized under four themes which form the spine of the overall strategic roadmap (Figure 3-1). It is recommended that the team at Waters considers the themes to be flexible and scout for more improvement areas within the business and broaden the scope while tackling the existing problem areas in depth. In the following sections, a few of the proposals highlighted above have been explained in detail. More information on the rest of the ideas can be found in Hochsztein's and Harlalka's work [1] [2].

3.5.1 Data-driven Manufacturing

During the exploratory phase at Waters, the team visited the manufacturing lines at the Global Machining Center. These lines were equipped with state-of-the-art machines working in conjunction to create a highly diverse mix of products – ranging from chromatography columns to valves. When the team tried to gather machine utilization and order backlog data for the shop floor, significant order buildup was observed with no machine utilization data being recorded. In addition to that, the data entry in terms of processing time was entirely manual with machining metrics being updated with a time delay. This required the managers to visit the shop floor for assessing the performance of the different manufacturing cells.

Overall Equipment Effectiveness (OEE) is an all-encompassing productivity measure that incorporates availability, performance, and quality of a manufacturing operation. It is essentially a single number which considers both planned and unplanned stoppage, processing time and defects.

Equation 3-1. Overall Equipment Effectiveness

$$OEE = Availability * Performance * Quality$$

Recently, there have been efforts at Waters to measure OEE and define a methodology to benchmark it against industry standards. Although a step in the right direction, manual data collection is not only time consuming but erroneous as well.

On investigating the machine capabilities on the shop floor, the team came across a significant number of machines already outputting sensor data in their native transmission protocols. In addition to that, some of the machines were capable of converting that data into a common protocol (MTConnect) for the ease of analytics. This seemed to be a huge opportunity in the direction of automated data collection and analysis. Extending this further, the data collected could be used to create digital dashboards updated with real-time data at the click of a button.

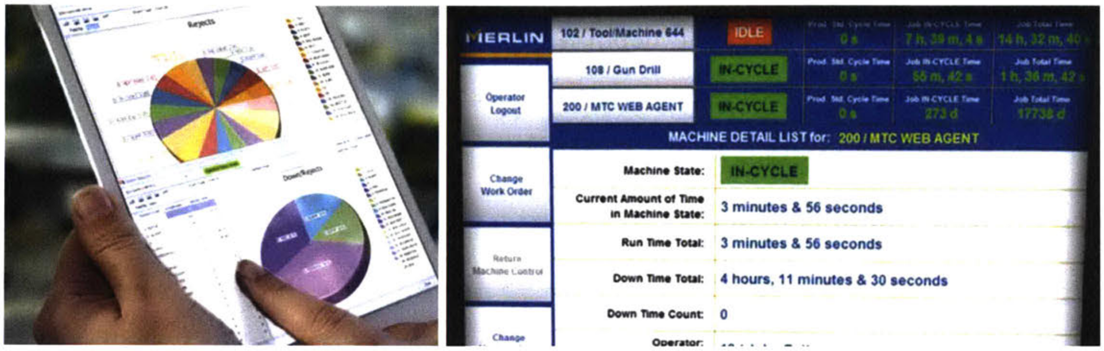


Figure 3-2. Memex Products (Left: Merlin Digital Dashboard; Right: Merlin Operator Portal) [8]

The team conducted meetings with third-party vendors like FactoryWiz, Memex, and ShopViz, who develop proprietary software that could be used to interact with the machines' native protocol and MTConnect (Figure 3-2). In addition to this, it was also noted that there are specific Programmable Logic Controllers (PLC) available off-the-shelf which could be used to gather data from older machines not equipped with the data gathering technology. This could potentially gather data from the machine control signals and then output it in the required protocol. Waters Manufacturing Team stressed on lower reliability and utilization rates for the older machines, in their case automated data collection could make the processes more transparent and help identify hidden opportunities in their operations. The benefits of using something as adaptive as MTConnect and helping the company transition to the latest Industry 4.0 standards seems like a great opportunity. However, these software packages are sold on a per machine basis, ranging anywhere from \$2500 to \$4000. This, in turn, necessitates a careful consideration of the costs involved and the derived benefits from the technology.

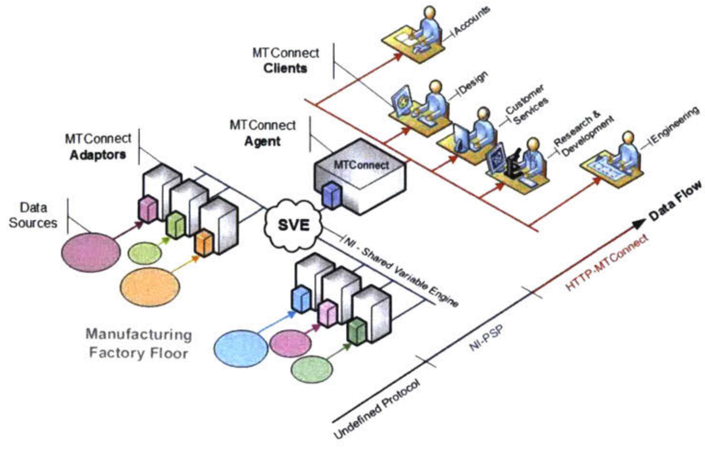


Figure 3-3. Schematic of an MTConnect enabled shop floor [9]

Next Steps: A pilot project could be developed for assessing the potential of the technology for MTConnect ready machine tools (like DMG Mori in the turning area) (Figure 3-3) to gather and display data automatically. The pilot would incur minimal costs due to the free software tools available for converting the output (CSV files) into suitable metrics and graphics. This project could prove the application of technology and assess the importance of the data being gathered which could then be further scaled with the third-party software available. With the pilot in mind, the team also connected with the MTConnect Institute which is a not-for-profit standards development organization for the MTConnect standard. The conversations with the Managing Director of the institute were fruitful and they were interested in technically supporting the pilot study at Waters followed by research opportunities at MIT.

3.5.2 Digitalization Pilots for Manufacturing & Assembly

Waters has always led the learning curve for the industry in terms of instrument technology, the company now needs to inculcate the same thought process within its operations team. The latest technological revolution, Industry 4.0, can prove a game-changer by involving cyber-physical systems which share data with each other and humans. During interactions with stakeholders across various departments, the MIT team realized the need for digitalization and automation in various processes. In addition to this, there were problems pertaining to ineffective communication between various systems existing within the organization.

It was revealed during the interviews with the manufacturing team that in addition to the lack of OEE benchmarks for the shop floor, there is no employee specific data available. Other industries have harnessed this data to incentivize productivity improvement. This seemed to be a great opportunity in terms of process improvement. If data was being collected automatically with meaningful metrics conveyed, the managers could adapt their decisions for optimizing the operations at Waters. Similarly, it was observed that the operators were required to pack a high variety of kits in the kitting area. The assembly area required the operators to work on different SKUs with lengthy work instructions which were not visual. All these issues suggested that there was a need to digitalize a part of these operations to improve visibility and drive productivity. However, the new systems being envisioned should require minimal training for development and maintenance.

While scouting for solutions, the team found out that there exist solutions which could be used for conducting pilot studies in all these areas before proceeding towards a systemic overhaul. One such closely studied solution was the Factory Kit by Tulip [10]. The kit contains the essential hardware required to deploy pilot studies for different applications (Figure 3-4). It also comes with the software support which requires the user to only drag and drop buttons, embed them with logic and create interactive applications without any backend software development. Solutions like this could go a long way in making a case for digitalization and the associated process improvement.

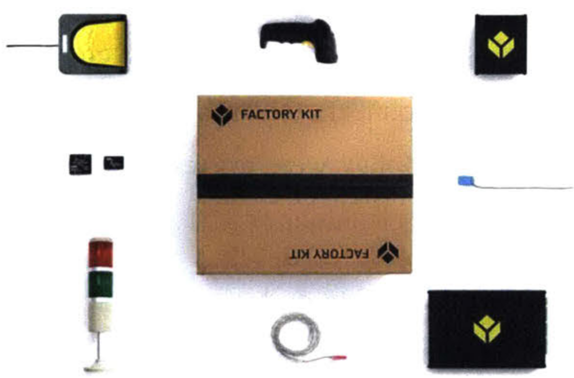


Figure 3-4. Components of the Factory Kit created by Tulip [10]

Next Steps: The team has already conducted meetings with the team at Tulip to understand the potential use cases and the kits applicability at Waters. In addition to this, the team arranged a brief presentation for the manufacturing team at Waters to understand the same. In future, it's recommended that the potential pilot areas be identified for digitalization using the factory kit followed by rigorous testing. If found applicable, the full-fledged software platform from Tulip or other solutions from various third-party providers could then be scaled up for application across the organization.

On assessing the industry best practices, it was noted that it's considered beneficial to have a separate process improvement team within the operations team that continually works towards incremental changes in productivity. The author recommends instituting a team that possesses cross-operational expertise and works towards making these digitalization pilots suited to various operations.

Automated Raw Material Ordering: One of the recommended digitalization and automation pilots would be to alter the way raw material for columns is handled in the manufacturing facility. The team was made aware that the lead time on most of the material is around 200 days and surprisingly during the visit, the safety stock levels were low. This was attributed to the unnatural number of rejections of the incoming stock. Adding to it, the quality system (TrackWise) and the SAP didn't communicate to each other rendering the procurement team helpless about the actual quantity of raw stock available for production of columns. The system could only be updated if there were manual inputs into the system pertaining to the status of the incoming stock. The team recommends that a plugin should be developed, or a middleware software be tested to bridge the gap and ensure effective communication between teams.

3.5.3 Assistive Technologies for Material Handlers

Global Distribution Center (GDC) in Franklin, MA is one of the three major distribution centers for Waters Corporation. It is responsible for shipping the end-product produced in Milford, MA and other products originating from various vendors or Waters subsidiaries. The company has recently shifted from a small warehouse in the Milford campus to a much larger space in Franklin. Upon observing the operations within the warehouse, the team noted that most of the work in terms of receiving, put-away, picking, and shipping was manual thereby exposing the material handlers to the risk of injury. Most of the material handlers in the GDC are highly experienced but this aggravates the risk of injury due to the higher average age.

It was also observed that the material handlers were not following the best practices in terms of posture while performing these tasks. For instance, research recommends that the spine should maintain its natural arch and the maximum body weight should rest knees while bending whereas inherently humans tend to bend by transferring weight on their back. The suggested posture resembles that of a weightlifter who bends his knees to lift heavy loads (Figure 3-5)[11]. As per the team's observation, the loads carried by the material handlers although not excessive could lead to chronic back pain due to repeated lifting.

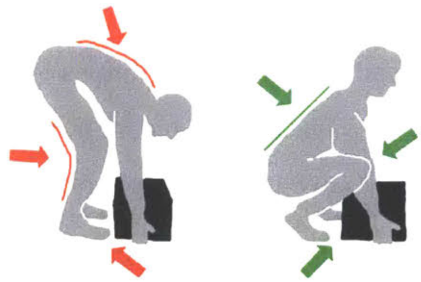


Figure 3-5. Incorrect and Correct Lifting Posture [12]

This warrants the use of assistive technologies like exoskeletons to help material handlers correct their posture and potentially reduce the load on the lower back by 40%. Broadly, exoskeletons can be of two types – active and passive. Active exoskeletons utilize various sensors and actuators powered by batteries to support humans. They are more expensive and possess the ability to handle greater loads. On the other hand, passive exoskeletons aren't powered but utilize springs for weight re-distribution and energy capture to support humans (Figure 3-6). They are less expensive and have a smoother adoption curve.

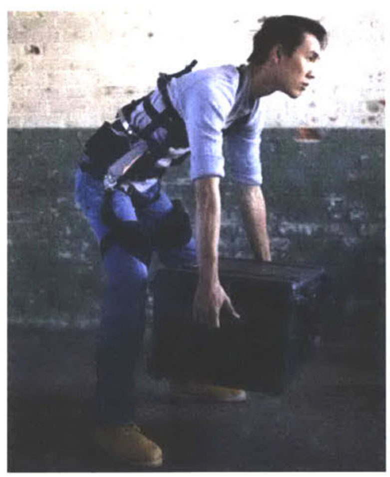


Figure 3-6. BackX: A commercial exoskeleton designed by SuitX [13]

Next Steps: To assess the need for assistive technologies, a detailed ergonomic study in the GDC is recommended. Some of the methods generally used are the NIOSH lifting equations which quantify the risk to the handler (calculated from lifting index) on the basis of the weight carried and its loading conditions [14]. This could help identify the specific risk and form the basis of either conducting a posture training session for all material handlers or order suitable exoskeletons for different jobs in the warehouse. The health benefits of such a study could be a boon for Waters personnel and could be extended to other areas within the company with similar working conditions. Although challenging to estimate, the economic benefits for such steps could result from decreased insurance costs to the company and better productivity of the workforce.

3.5.4 Design Standardization

Design standardization holds the key to lower manufacturing costs, ease of assembly and easier serviceability. The meetings with the Research & Development team at Waters unearthed an incoherent approach to design of products which could be attributed to different teams concurrently working on various modules for the same product. The performance of the product is world-class but the inconsistencies in design are apparent from the cosmetic parts like the outer casing of the unit. For instance, in one of the UPLC instruments, it was observed that the design of the doors for all individual modules was different (Figure 3-7). Surprisingly, it was not just the design, but the mechanical system used for the purpose was different as well. It was also noted that the fastener families used in a variety of modules were different.

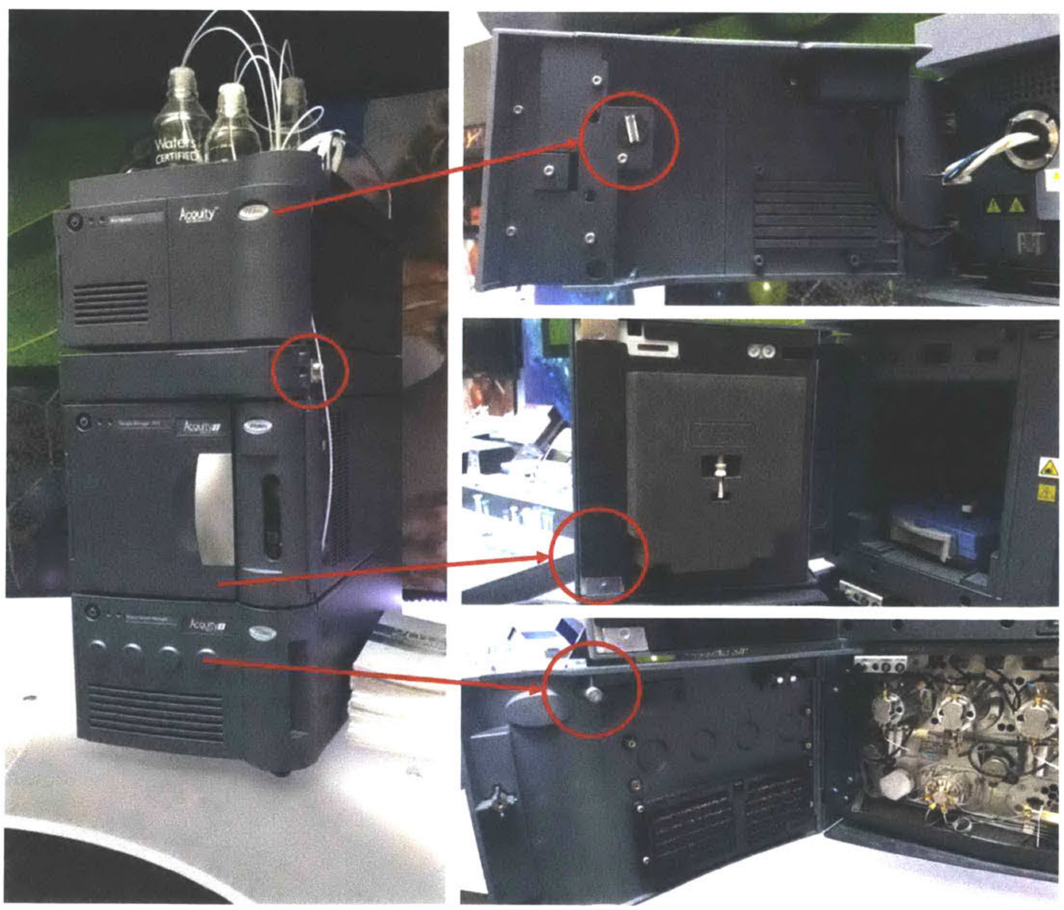


Figure 3-7. Waters Acquity UPLC (Left: Instrument; Right: Different door mechanisms)

The complexity in finding the solution arises from the fact that the design expertise required for designing different modules lies with different teams. The author recommends that the company institute a set of guidelines that would be followed by the design teams across Waters. This could be formulated by bringing stakeholders from different teams on the same page in terms of domain-specific requirements and creating the guidelines keeping all of those into consideration. Given the complexity involved in communicating design requirements effectively, Product Lifecycle Management (PLM) systems could transform the existent communication channels between various teams and contain attribute related information pertaining to material and processes that eases both the design and manufacturing stages. If manufacturing teams were included in the initial phases, it could potentially reduce the number of design or performance compromises in later stages of product development. An example could be the incorporation of feedback from downstream teams for optimization of tolerances on manufactured parts based on both performance and production costs.

There are several benefits that could arise out of such an approach. It could potentially reduce the time-to-market for products by streamlining the design process and reducing the iterations to achieve the desired product state. Responding to the current needs of the market in a shorter time frame can prove to be a game changer in the analytical instrument industry. More importantly, standardization can reduce costs of production by leveraging economies of scale in the procurement of standard parts, lower inventory levels throughout the supply chain and shorten assembly times. Uniformity in design also enhances the usability and serviceability of the product which could translate to better customer satisfaction levels in the future.

Next Steps: There have been previous attempts at Waters to standardize and modify designs keeping the DFMA considerations in mind. It's necessary that no such effort to ensure standardization impedes product performance. So, it's recommended that more such efforts should be encouraged at the company level so that the experts who are aware of the design rationale take decisions pertaining to ease of manufacturing. Additionally, the Waters team could institute a set of design guidelines with preferred mechanisms listed for every scenario either with a PLM software or manually.

CHAPTER 4

INVENTORY LOCATION OPTIMIZATION

This section introduces the inventory location optimization algorithm and details the current state of operations for order-picking in the Global Distribution Center (GDC). It then describes the methodology and limitations of the storage location cost assignment procedure which is a critical input for the algorithm. It concludes with a mathematical formulation of the procedure in the form of an MS Excel-based tool.

4.1 Project Overview

The Global Distribution Center (GDC) shifted from its location in the Milford campus to a stand-alone warehouse in Franklin, MA around a year ago. However, the storage location for various SKUs was kept unchanged even after the drastic changes in the overall layout for the 56,000 sq. ft. space. Given the huge area, delivering over 1500 lines every day requires the pickers to walk miles across the facility.

There have been no attempts to optimize the locations of various SKUs within the DC before or after the shift. After researching this problem, it became clear that while the GDC staff do their best to make sure to place incoming material intelligently, computationally-driven recommendations would improve on their decisions and save them the time spent making those decisions. Three key areas were highlighted as ways an automatic software tool could be used by distribution center managers and personnel to improve productivity:

- **Total Relocation:** A relocation of all SKUs currently in a particular section of the warehouse (or the entire warehouse at once). This goal involves creating a report that will list the new location of every SKU and estimate the resulting improvement to the warehouse's picking speed.
- **Replace x:** A tool that allows the manager to request recommendations for inventory relocation procedures that involve the relocation of x SKUs within a particular section. This goal is intended to give control over how extensive a particular relocation effort should be, as it will often be the case that a manager desires to improve the picking speed

but does not have sufficient time and resources to relocate every SKU in the section. This too will create a report listing the new layout and the estimated improvement, as well as a list of actual moves required.

- **Recommended Put-Away:** A tool that recommends storage locations for every SKU present in an incoming shipment.

With all three goals, it is crucial that they be implemented as recommendations, where each particular SKU suggestion can be considered by a human and then ignored if it is believed that there is a reason to disregard the suggestion. Especially at the initial implementation of this system, when there will be many instances of information available to the software tool being incomplete, many of the recommendations will need to be recognized by a human as not meaningful (i.e. if the system has no information on the size of an SKU and then recommends placing it in a location where it clearly will not fit, a human familiar with the materials needs to be able to disregard the recommendation).

As it is necessary to test an inventory relocation system to properly determine its benefits, it was decided that the implementation cannot involve excessive spending. For this reason, the algorithm was to be developed from scratch and tailored directly to the GDC. By doing so, any costs associated with purchasing and/or applying commercial solutions (should any exist) to the GDC could be avoided. As such, the need to validate the inventory relocation in terms of return on investment can be avoided as the implementation requires no capital expenditure.

In addition to the requirement that the algorithm produces relevant and mathematically sound solutions, the tool needs to interface easily with existing Waters systems and people. Specifically, it must be able to grab whatever information it needs from the databases, and the output results need to be readable and manipulatable by staff members that have basic backgrounds in using computers (text files, emails, Microsoft Excel tables) but not in coding environments.

4.2 Task Division

Hochsztein's work explores the actual process of developing the logic behind the algorithm and programming the tool in its entirety [1]. The work also contains the integration of the tool with the process and IT infrastructure at Waters. This thesis contains the detailed process and rationale behind cost assignment for various storage locations.

4.3 Cost Assignment

The aforementioned algorithm for inventory relocation utilizes a number of datasets to determine the best location. One of the major datasets that affects the performance of the algorithm is the associated location cost for determining the best locations for SKU placement. A novel approach to create a map of the warehouse with the associated location cost was devised.

4.3.1 State of Operations

It was important to observe the picking and put-away operations within the warehouse to effectively understand the difficulty associated with keeping and then procuring a part for an order. The warehouse can be divided into regions based on the storage location type or the type of product stored:

- **High Bay Aisles:** Pallet racks which house large volume products (attributed either to larger unit volume or larger quantity) (Figure 4-1).
- **Shelving Aisles:** Regular shelves which house most of the consumables and frequently shipped parts.
- **Hazard Room:** A contained room which houses hazardous products in the warehouse (located near shelving aisles) being equipped with emergency systems.

In addition to this, there is designated floor space for cross-docking high volume products and a section of freezers which house temperature-controlled products. It should be noted that most of the SKUs are picked from shelving aisle region whereas the rest are picked from the high bay areas. The pickers utilize different modes of transport based on the SKU and the designated storage location. This stems from their experience of working within the GDC and having an idea of the form factor for various SKUs.

Figure 4-1. Different levels in high bay area

- **Shelving Aisles and Level 1 & Level 2 of High Bay Area:** On observing the operations, it was noted that the pickers either use carts or walk for picking multiple orders at the same time. They try to pick all lines contained within multiple orders for SKUs placed in the shelving aisles. The same procedure is followed for picking parts from Level 2 in the high bays. Although the SOP is slightly different for Level 1, it has been assumed that they walk to these locations as well.
- **Level 3 & above of High Bay Area:** For large volume SKUs placed in high bay areas, the picker uses a pallet truck to reach the location and then gets the reach truck to bring down the required quantity, place it in the pallet truck, park the reach truck back in its designated home and proceed to the packing stations.
- **Other Areas:** The storage location called "Floor" stores large volume instruments that are palletized at the origin itself, so they are accessed by the pickers using pallet truck. Freezers and Hazard Room are accessed on foot with a cart.

4.3.2 Methodology

Scope of the project: It was determined that the pilot implementation of the developed inventory relocation algorithm would be most efficiently applied to the high bay area in the first phase for the following reasons. Firstly, the algorithm required credible information on the volumes of various SKUs for optimal placement in an area and, this data was easily available for large instruments and some other products for the high bay area. Secondly, it was observed that the volumetric capacity for each storage location was highly variable in the shelving aisles as compared to the high-bay area. Hence, the cost assignment procedure covers the operations within the high bay area only.

The literature available on the subject suggests that picking is the most critical warehousing operation given its direct relation to the rate of order fulfillment. For this purpose, it was decided that the location cost of each storage location would be directly proportional to the time it would take the picker to pick an SKU from that particular location. This, in turn, means that the objective function of the algorithm would be to minimize the total time spent picking. Multiple time studies (Table 4-1) were conducted to estimate the walking speed of a picker walking around the aisles with a cart, on a pallet truck and the time it took to reach different levels in the high bay area.

Table 4-1. Time Study for Picking operation in high bay area

Activity	Speed/Time
Walking with cart	3.8 ft/s
Driving Reach Truck	7.8 ft/s
Driving Forklift	7.8 ft/s
Driving Pallet Truck	7.8 ft/s
Reaching Level 1 (and return)	8 seconds
Reaching Level 2 (and return)	0 seconds
Reaching Level 3 (and return)	40 seconds
Additional Time (for each subsequent level)	8 seconds

The basic methodology for cost assignment revolved around utilization of distances of various storage locations from the packaging and shipping area to estimate the time required for covering these distances given the mode of transport. In addition to this, to penalize the upper levels in pallet racks, a time penalty would be added based on the level and the specific location of concern.

4.3.3 Key Assumptions

It is important to optimally tackle the scope and granularity of a problem in its initial phases. The scope of cost assignment was limited to the high bay area but variability in day-to-day operations made the determination of optimal granularity a complex task. Some simplifying assumptions have been made during the process of creating this cost assignment structure. The future phases of implementation could focus on tackling some of these assumptions thereby enhancing the inventory relocation algorithm's performance.

- **Receiving trips can be ignored:** Since picking is the most critical operation within the warehouse and the ultimate objective of the algorithm is to reduce the time spent walking, the cost assignment procedure ignores the cost of put-away in a certain location. It can be observed from the layout of the warehouse that receiving cost of movement would increase if products were to be placed closer to packaging. However, the assumption is reasonable given the frequency of the operation - while products are received in large volumes requiring fewer trips, they are picked in much smaller quantities increasing the picking frequency by a greater factor.

- **Picking is independent of SKU:** In order to simplify the solution to the problem pertaining to cost assignment, it has been assumed that the picking operation is independent of the SKU being picked. For instance, it assumes that the picker would always pick a product from Level 2 by hand because it's at the eye level. The solution also assumes that everything on Level 1 and Level 3 & above is palletized and would require either a reach truck, a pallet truck or a forklift to be picked. However, the assumption is reasonable given the uniformity of SKU placement in the high bay area. It was observed that more than 80% of picking from Level 2 is carried out with a cart.
- **Orders are not picked in batches:** Exclusion of this assumption would increase the complexity of cost assignment by a power of two. It is known that some orders are not picked in batches but considering batch picking would not just alter cost assignment, it would drastically change the skeleton of the algorithm itself. It would then require the storage location cost to also be dependent on the distance from all other locations because the picker would proceed from one location to the other without returning to packing stations. The team expects the algorithm to still perform optimally because placing frequently picked items closer to packing stations would enhance productivity, irrespective of it being batch picked. It is important to note that the magnitude of improvement as determined from the algorithm would actually be less in reality due to batch picking.
- **Vehicles are always available:** It has been considered that the necessary vehicles for picking a particular product are always available. The future improvements could include a factor for vehicle availability based on empirical observations.
- **No bias in choosing between similar vehicle:** There are multiple vehicles available within the GDC with separate designated home locations. During the interviews with material handlers, it was revealed that choice of the vehicle was independent of the storage location but entirely dependent on availability and personal bias of the picker. So, it has been reasonably assumed these vehicles would be used equally.

4.3.4 Procedure

In order to define the cost of each storage location in the high bay area, it was necessary to determine the distance of each location to the packing stations. It was decided to get these distances and the costs in an orderly manner by devising a mathematical scheme.

In Figure 4-2,

- Node 1 : Packing stations
- Node 2 : High bay area (starting point)
- Vehicle Home 1 : Forklift/reach truck parking
- Vehicle Home 2 : Forklift/reach truck parking
- Storage Location : Variable point for which cost needs to be calculated
- Variable Distance : Represented by X/Y for distance estimation from fixed points
- Model Constant : Represented by K for inter-node distances and other fixed distances in the layout

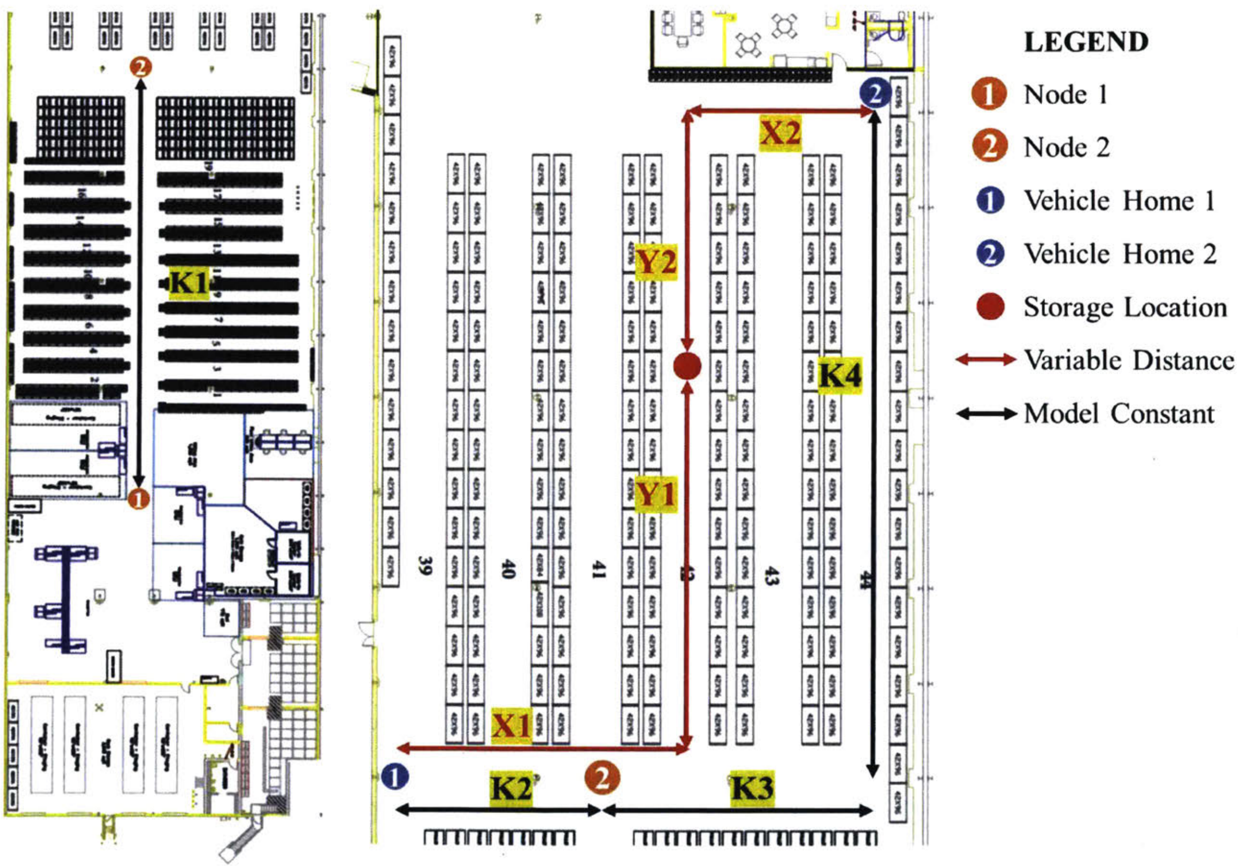


Figure 4-2. GDC Floor Plan labeled with Variables for Cost Assignment

It can be noted from Figure 4-2 that, X2 and Y2 are essentially derived from X1 and Y1 whose values can be calculated by using model constants.

Equation 4-1. X2 in terms of X1

$$X2 = K2 + K3 - X1$$

Equation 4-2. Y2 in terms of Y1

$$Y2 = K4 - Y1$$

An MS Excel spreadsheet containing all the storage locations in high bay area was used to calculate X1 and Y1 for each location. Then, the factor (L(Z)) accounting for the multiple levels of storage – each with a different time penalty – was included to compute a comprehensive cost function. Some more variables need to be defined for encapsulating the problem in a mathematical form.

- L(Z) : Time penalty for Level in bays
- V_T : Average speed of pallet truck, reach truck and fork lift
- V_W : Average speed of walking
- C1 : Proportion of time Vehicle 1 is used
- C2 : Proportion of time Vehicle 2 is used

Using the above constants and variables, the cost of an arbitrary storage location within GDC's high-bay area would still be dependent on the level as that alters the mode of transport and hence the distance traveled as defined above.

For Level 1,

Equation 4-3. Storage Location Cost: Level 1

$$Cost = \frac{[2K1 + 2|X1 - K2| + 2Y1]}{V_W} + L(Z)$$

This is because of the assumption that the picker would always walk to pick a product from Level 1 and L(Z) = 8 (ergonomic cost for bending) in this case.

For Level 2,

Equation 4-4. Storage Location Cost: Level 2

$$Cost = \frac{[2K1 + 2|X1 - K2| + 2Y1]}{V_W} + L(Z)$$

This is because of the assumption that the picker would always use a pallet truck which doesn't possess a home to pick a product from Level 2 and L(Z) = 0 in this case.

For Level 3 and above,

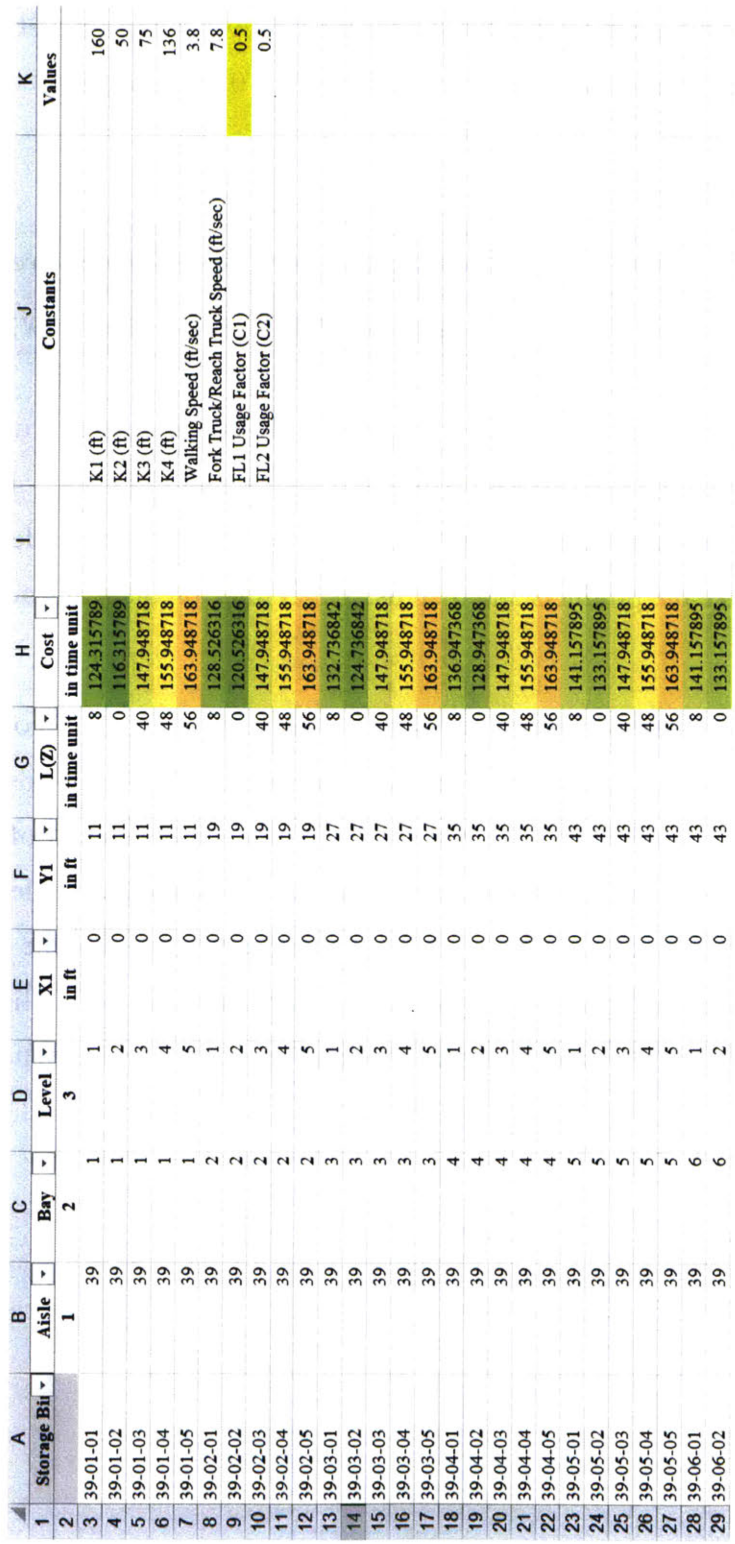
Equation 4-5. Storage Location Cost: Level 3 and above

$$Cost = \frac{[C1(2K1 + 2K2 + 2X1 + 2Y1) + C2(2K1 + 2K3 + 2K4 + 2X2 + 2Y2)]}{V_T} + L(Z)$$

This is because of the assumption that the picker would always use a reach truck or a forklift which possess a home to pick a product from Level 3 and above, and L(Z) = 40, 48, 56... in this case. This also assumes that the picker uses a pallet truck to travel to the node and then use reach truck/forklift to retrieve the products and then use pallet track on the way back as well.

4.3.5 Results

The above formulae were used to estimate the storage location cost and an MS Excel spreadsheet (Figure 4-3) was created. The resulting storage location costs assume the SOP (described in 4.3.1) is followed and the picking operation is independent of SKU. The rationale behind using MS Excel was to ease the use and modification of the tool as deemed necessary with time by the team at Waters. During the knowledge transfer presentation, the current methodology and procedure for cost assignment were explained to the team at Waters. In line with expectations, it was found that the storage locations closer to the packing stations were better to place frequently shipped products.



Storage Bi	Aisle	Bay	Level	X1	Y1	L(Z)	Cost
	1	2	3	in ft	in ft	in time unit	in time unit
39-01-01	39	1	1	0	11	8	124.315789
39-01-02	39	1	2	0	11	0	116.315789
39-01-03	39	1	3	0	11	40	147.948718
39-01-04	39	1	4	0	11	48	155.948718
39-01-05	39	1	5	0	11	56	163.948718
39-02-01	39	2	1	0	19	8	128.526316
39-02-02	39	2	2	0	19	0	120.526316
39-02-03	39	2	3	0	19	40	147.948718
39-02-04	39	2	4	0	19	48	155.948718
39-02-05	39	2	5	0	19	56	163.948718
39-03-01	39	3	1	0	27	8	132.736842
39-03-02	39	3	2	0	27	0	124.736842
39-03-03	39	3	3	0	27	40	147.948718
39-03-04	39	3	4	0	27	48	155.948718
39-03-05	39	3	5	0	27	56	163.948718
39-04-01	39	4	1	0	35	8	136.947368
39-04-02	39	4	2	0	35	0	128.947368
39-04-03	39	4	3	0	35	40	147.948718
39-04-04	39	4	4	0	35	48	155.948718
39-04-05	39	4	5	0	35	56	163.948718
39-05-01	39	5	1	0	43	8	141.157895
39-05-02	39	5	2	0	43	0	133.157895
39-05-03	39	5	3	0	43	40	147.948718
39-05-04	39	5	4	0	43	48	155.948718
39-05-05	39	5	5	0	43	56	163.948718
39-06-01	39	6	1	0	43	8	141.157895
39-06-02	39	6	2	0	43	0	133.157895

Constants	Values
K1 (ft)	160
K2 (ft)	50
K3 (ft)	75
K4 (ft)	136
Walking Speed (ft/sec)	3.8
Fork Truck/Reach Truck Speed (ft/sec)	7.8
FL1 Usage Factor (C1)	0.5
FL2 Usage Factor (C2)	0.5

Figure 4-3. Screenshot of MS Excel-based Cost Assignment Tool

CHAPTER 5

RFID FOR INVENTORY MANAGEMENT

This section introduces the RFID implementation project at the Global Distribution Center (GDC). It includes a technical primer for better understanding of the RFID terminology used in subsequent sections. The chapter concludes with a literature review relevant to the business processes at Waters to understand the common use cases of the technology.

5.1 Project Overview

Radio Frequency Identification (RFID) is an Auto-ID technology (like barcode) used to identify physical products and trace them digitally. While there is a plethora of information on the physics of RFID, there is limited literature covering the systematic deployment of the technology in business organizations. Understanding the behavior of radio-frequency waves, assessing the site for electromagnetic interference and, determining the optimal tag location and orientation are all vital factors which significantly affect the success of any RFID deployment.

This project seeks to fill this gap by serving as a template for organizations looking to introduce RFID in their warehouses. The pilot at GDC outlines a systematic RFID implementation procedure; however, Waters and other organizations can use it as a starting point to direct similar initiatives across other facilities and create value throughout. The project was initiated with comprehensive site assessment, an important step which involved measuring the strength of Ambient Electromagnetic Noise (AEN) within the premises of GDC and conducting a Path Loss Contour Mapping of the Interrogation Zones [15]. Following the site assessment, a pilot system was designed around a specific SKU–chromatography columns–with an objective to get well versed with the technological nuances.

Complementing the technological feasibility assessment, a business case was prepared to prove the economic viability of RFID at Waters. It included a comprehensive study of the current business processes; the proposed future state using RFID and estimates of the Net Present Value (NPV) as a part of the cost-benefit analysis.

5.2 Task Division

Harlalka's work revolves around the technical feasibility aspect of RFID implementation in GDC [2]. A proof of technology assessment is included in his work which helps the reader understand the various considerations before adoption. This thesis builds upon the use cases listed by him and how they could be applied to GDC. It also explores how RFID implementation could improve various business processes and provides a cost-benefit analysis to support an RFID implementation strategy at Waters Corporation.

5.3 Technical Primer on RFID

5.3.1 Introduction

In June 2003, Walmart announced that it would require its suppliers to put RFID tags on every case and pallet. RFID technology was still in nascent stages in terms of implementation and the helpless suppliers were caught unaware [15]. This period coincided with the spike in research interest in Auto-ID technologies, which ultimately declined a few years later when industry realized that RFID wasn't the panacea they were looking forward to. It only sparked up again a few years ago due to the development of Internet of Things (IoT) and other smart systems.

Essentially, as mentioned earlier as well, RFID is an Auto-ID technology (like barcode) used to identify physical products and trace them digitally. Earlier, introduction of barcode revolutionized business processes by transitioning data collection from manually recorded data to simple scans at the click of a button. The industry expected similar results from RFID implementation only to realize that the technology is not as ubiquitous, limited by environment and costly to implement. The experts were unable to identify the additional value it could add to the existing barcode-based systems. Now, the times have changed, data accuracy has become more important than a decade ago given the evolution of data science and the cost of RFID implementation has substantially reduced.

5.3.2 Tags

Tags are identification labels which are attached to physical objects to ensure detection. They are composed of an integrated circuit for RF modulation and an antenna for facilitating exchange over RF and form the most important and costly component of the RFID system.

Tags can be active, passive or semi-passive. Active tags possess a battery which is used to power the signal transmission process to the reader. The power source enables the tag to communicate at longer ranges by either constantly beaconing or broadcasting in response to reader communication [15]. These tags are more expensive and have the ability to carry much more information locally as well. On the other hand, a passive tag derives its power from the electromagnetic field created by the reader to respond to its queries [15]. They are employed in large numbers in retail for their cost-effective implementation and longer service life. A hybrid of the two, semi-passive tags require internal power to run the integrated circuit but still derive power from EM field for communication [15].

In addition to the above classification, tags can be classified on the basis of the frequency range they communicate in – LF (Low Frequency), HF (High Frequency) and UHF (Ultra High Frequency). Both range and power requirement increase with the increase in the frequency band. Another important categorization is based on their read-write capability dividing them into different classes. For instance, Class 0 corresponds to a read-only tag whereas Class 1 corresponds to Write Once, Read Many (WORM) tag.

5.3.3 Reader

The reader generates the signals which are ultimately broadcasted by antenna in the RFID system. It is essentially a transceiver and is often dubbed as the "brain" of the system. It also controls the range of the signal by establishing communication at a preset frequency. Upon moving into the reader's established field, the tag responds with another signal which is interpreted by the reader to decipher the information encoded on the tag.

5.3.4 Antenna

The antenna is the hardware component responsible for the signal broadcast to an interrogation zone and then receiving backscatter from the tag. The reader communicates with the tag via antenna. Nowadays, there are reader-antenna combinations available which work together as a single unit to both create and broadcast the RF signal. They are available in varied shapes and sizes and can emit the signal continuously when tagged items are present on a regular basis or be activated based on a trigger by optical, pressure or some other kind of sensor [15].

5.3.5 Software

There are many layers to RFID communication in terms of software. Firstly, it is the middleware which lies between the backend system utilizing RFID data and the reader. It is required to convert reader output into a specific application format. The middleware is usually reader-dependent should be efficiently programmed to ensure faster data transmission and recording. Second comes the organizational product management software which utilizes the middleware to perform internal system transactions corresponding to RFID reads. In addition to this, there can be separate encoding software being used for printing and encoding RFID labels in-house and many other plug-ins and tools built on top of these basic software packages.

5.3.6 EPC

Electronic Product Code (EPC) is an item-specific code that is embedded in the RFID tag to individually identify the item. When an RFID reader reads a tag, it actually reads this 32 to 256-bit number which is linked to a central database with all the requisite information. It can facilitate the tracking of a product throughout its lifecycle by acting as a unique identifier [15]. This also translates into better system security since the system is as secure as the database storing the information. So, being able to read a number wouldn't matter if it doesn't have the ability to point to the right database. The development of these databases necessitates that EPC follows a universal numbering scheme accepted by the majority. EPCglobal is the organization responsible for standardization and management of EPC protocol.

5.4 Literature Review on Implementation

There has been considerable research on the development and implementation of RFID in various industries ranging from retail to manufacturing to healthcare. However, this section focuses on the literature available for RFID implementation primarily relevant to the processes at Waters.

Walmart's decision to make RFID tagging mandatory for its top 100 suppliers can be dubbed as a crucial milestone in the history of RFID implementation. Hardgrave et al. tried to quantify the associated effect of this decision [16]. It was concluded that out-of-stocks reduced by 21% due to RFID by studying a group of stores with and without RFID for a period. It rightfully acknowledges the various reasons behind out-of-stocks in retail–store ordering, store forecasting, shelf replenishment, etc.–and cites that RFID can almost eliminate the shelf replenishment aspect.

Apart from retail, there have been many studies which exhibit improvement in overall warehousing operations using RFID. Wang et al. studied the implementation of RFID-based digital WMS in the tobacco industry to replace manual decisions for placement and retrieval of stock [17]. In this case, RFID tags were attached only at the pallet level rather than product level to be used to create a digital shelf map for visualization of inventory, receiving and shipping, these applications resulted in an increase of inventory accuracy from 80% to 99%. This was achieved with an overall read-rate of 98% on pallet tags. Chow et al. designed an RFID case-based resource management system the implementation of which resulted in improved shipping order accuracy of 7% through a pilot study [18]. Another study conducted in the petroleum development industry pointed to more efficient stock evaluation for inventory management and enhanced operational efficiency [19].

Adding more value to the benefits of RFID in inventory management, some of the other use cases for RFID in the industry involve accurate tracking and tracing of the product throughout its value chain. A track & trace application at Johnson Controls helped the company visualize over 800,000 returnable containers in real-time [20]. The company struggled to gather information in the past with repeated phone calls and emails. The archaic system was replaced by smart dock doors and handheld scanners for tracing the movement of their goods throughout the supply chain with a read-rate of over 99%. In an interesting scenario depicting an implementation of RFID in the field, Gillette decided to implement case-level tagging for a new product launch in 2006. Due to the added visibility of inventory, the company reported that it could respond to sales trends better and the launch was immensely successful with centralized monitoring [21]. Another relevant use-case for Waters could be to use RFID for tracing their instruments throughout the lifecycle. For instance, Michelin Tires started adding RFID tags to their commercial truck tires. The tags were used to relay product usage statistics to the company and ultimately provide more efficient troubleshooting and service to the customers [22]. It helped the company gain a competitive advantage by leading the industry innovation cycle in this aspect.

CHAPTER 6

IMPACT ON BUSINESS PROCESSES

The combination of Inventory Relocation Tool and RFID for Inventory Management can potentially bring about sweeping changes in the existing business processes at Waters. This section outlines the current state of the processes and the proposed future state with the capability to handle the shipments more efficiently. For the RFID implementation, the section assumes that all the incoming products have already been tagged before entering the GDC. It is necessary, however, to note that tagging (as mentioned in 7.4.1) is a critical hurdle towards implementation which needs to be planned carefully.

6.1 Receiving

Pre-receipt and receiving are important processes within the warehouse which need to ensure that the right product is received in the right condition at the right time. GDC handles shipments based on their content and point of origin in slightly different ways. The process flow diagram clearly documents the procedure followed (Figure 6-1).

6.1.1 Present State

6.1.1.1 Receiving Ireland/MicroMass Shipment

The pre-receipt procedure involves the creation of Packing List (PL) in SAP followed by notification of US import team. The shipment is then received at GDC in a palletized form. In the staging area, the shipment is physically broken down into its various sub-components based on the packing list. The process is tedious and involves placement of all SKUs on a cart in an orderly manner. This step is followed by physical verification or, in other words, assessment of condition of the goods received and counting them manually. Post-verification, the goods are usually segregated into two distinct categories – shortage and safety stock. The goods corresponding to shortage are prioritized for put-away. This is followed by multiple SAP transactions to update receipt of goods into the facility.

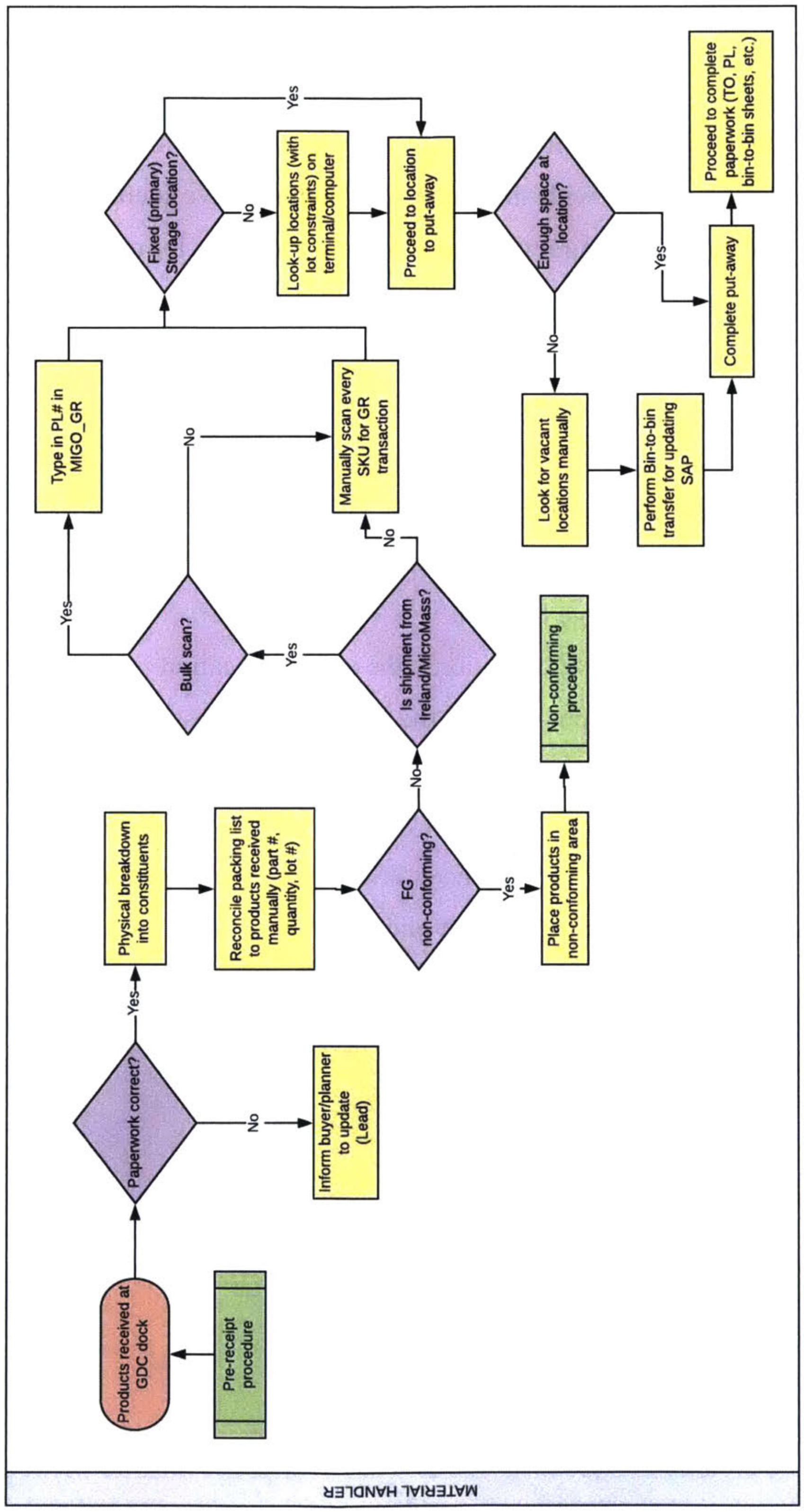


Figure 6-1. Process Flow Diagram: Receiving

Serial/Lot Controlled: Only some of the goods being received in the facility possess a unique identification code. They're said to be serial or lot-controlled depending on the type of the SKU. Instruments possess a unique serial number along with the identification of the part type (part number). On the other hand, columns are lot-controlled and are identified by lot number along with the part number. Products with the same part number have identical packaging. So, it is essential for ensuring picking accuracy that products of the same lot number aren't stored in the same location.

Fixed Storage Location vs. Default Storage Location: The majority of the goods being received in this kind of shipment don't possess a fixed storage location within the warehouse. They possess what is known as the "default" storage location. This implies that the material handler must look up for the vacant storage locations in the system before put-away or waste time looking for empty spaces during put-away. The handler also must keep in the mind the lot-controlled nature of the products to decide the storage location.

Upon considering the above conditions, the storage location is decided before the cart is taken for put-away. In receiving, put-away is the lengthiest process which takes most of the time and effort of the material handler (Figure 6-2 & Figure 6-3). Due to the introduction of the Z_MIGO_01, the bulk scanning transaction for SAP, as a part of process improvement activity in the GDC, the time spent on paperwork reduced drastically. The system could bulk scan i.e. scan the packing list and receive all the products at once.

Figure 6-2. Ireland Shipment in staging area before physical breakdown

Figure 6-3. Constituents of Ireland Shipment segregated into shortage/safety stock carts

Time Study: There have been earlier attempts at Waters to study the time taken by different processing steps for the receipt of Ireland shipment. The team collected more data and studied it to understand the time taken by different steps (Table 6-1).

Table 6-1. Step-wise distribution of time for Ireland/MicroMass Shipments

Activity	Time Elapsed (%)
Physical Breakdown	20
Physical Check	17
Transact GR	6
Match GR to PL	3
Look up Locations	14
Put-away	41
Paperwork	0

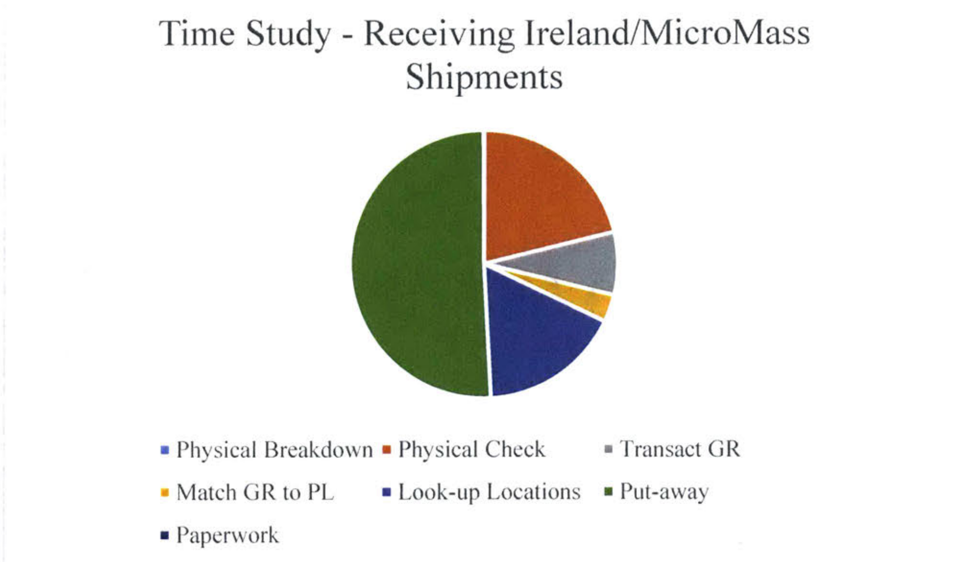


Figure 6-4. Step-wise distribution of time for Ireland/MicroMass Shipments

It can be noted from Figure 6-4 that physical check, looking up locations, SAP transactions (transact GR) and matching Goods Received (GR) it to the Packing List (PL) take up around 39% of the total time spent in receiving the shipment. The time required for put-away can't be reduced but the auxiliary steps can be made more efficient through digitalization and automation.

6.1.1.2 Receiving Milford Manufacturing/Vendor/Taunton Shipment

A notably different receiving process from the above category, these shipments contain a wide variety of products originating from multiple vendors and points of origin.

The pre-receipt procedure involves the creation of PLs in SAP followed by notification of US import team. The shipment is then received at the GDC. Here, the shipment which is usually in cartons is physically broken down into its various sub-components based on the packing list. The process is tedious and involves placement of all SKUs on a cart in an orderly manner. This step is followed by physical verification or assessment of condition of the goods received and counting them manually. Post-verification, the material handler scans the paperwork with the incoming shipment to generate the Transport Purchase Orders (PO) for internal movement. Most of the products in this category have a fixed storage location (indicated on transport PO) eliminating the need for look-up. After arranging everything on a cart and attaching the respective transport POs, the material handler proceeds towards the respective storage locations to put everything away.

It should be noted that counting everything manually and scanning the label multiple times for different pieces of information is time consuming. The jobs observed by the team required the handler to scan the same label three times i.e. for part number, quantity and serial number.

Time Study: The time-wise distribution of various processing steps involved in receiving the other shipments was studied to understand the scope for automation (Table 6-2, Figure 6-5).

Table 6-2. Step-wise distribution of time for Other Shipments

Activity	Time Elapsed (%)
Physical Breakdown	11
Physical Check	13
Scanning	10
Paperwork (Transport PO)	4
Put-away	61

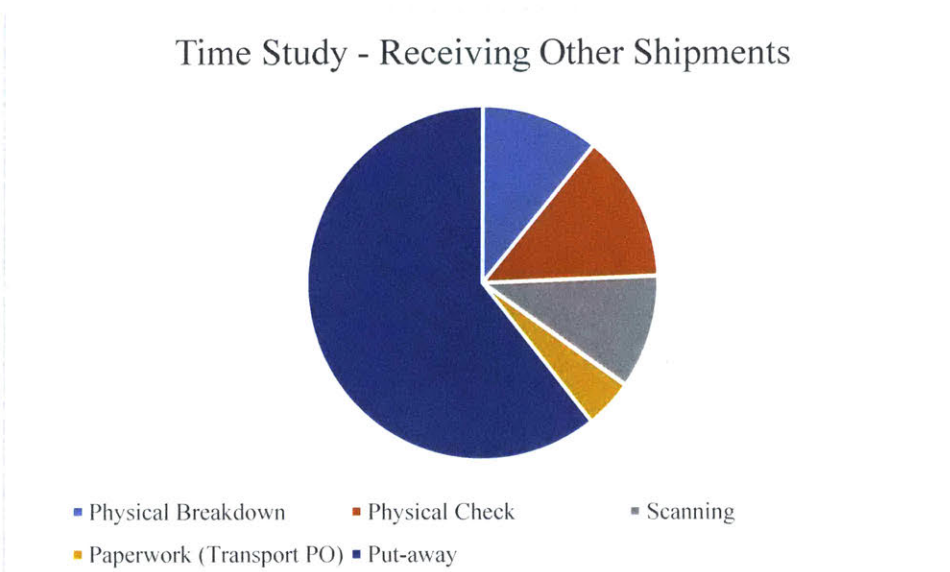


Figure 6-5. Step-wise distribution of time for Other Shipments

It can be noted that physical check, scanning and handling the paperwork if put together take up around 27% of the total spent time in receiving the shipment (Figure 6-6). While put-away and physical breakdown are the most time-consuming, they're necessary as well. On the other hand, the other steps that support put-away and should be looked at critically for improving the overall efficiency.

Figure 6-6. Constituents of a shipment from the Milford Manufacturing Plant placed on a cart

6.1.2 Proposed Future State

Using the Inventory Relocation Algorithm in conjunction with RFID could potentially lead to huge time savings for the receiving process. As mentioned earlier in section 4.3 and Hochsztein's work [1], the inventory relocation algorithm takes into account the order frequency, volume, and storage location cost to determine optimal placement, so if implemented across all SKUs, it could potentially eliminate the need to look-up storage locations while receiving the products in the dock. This could lead to a time saving of over 14% for shipments with default storage locations as evident from Table 6-1.

The proposed RFID system would comprise a dock-door portal in the receiving area which could be used to bulk scan all the incoming products during staging and while placing them on the cart. This would remove the need to manually count every single SKU being received. Instead, the team would focus on checking for damages and then simply pass the cart with products arranged through the dock door. If in addition to each product, the RFID tags are stuck to the pallet or the carton as well, the system could automatically identify and check for constituents when passed through the dock door. This would further reduce handling the paperwork in future and need to manually verify from the packing lists. Both applications have already been tested during the pilot study conducted, the results of which were favorable [2]. However, it can only be considered feasible after conducting the feasibility study for all SKUs, the team has only tested these use cases for columns only.

It is critical to note that the read rates close to 99% are imperative to the success of such a system. Studies in the past have shown that it is considerably difficult to bulk scan the products while they are in a pallet or a large carton with boxes in different orientations. The team suggests that Waters must plan the RFID implementation in phases, starting with their own subsidiaries and units in the beginning. For the receiving area, GDC could implement a similar system as to the one proved technically feasible in the pilot [2]. The system would have the capability of scanning every tagged product placed on the cart with the read rate close to 99% as evident from the pilot study. It's necessary to ensure that the tag orientation is in line with the work instructions for the technology.

After scanning the received items and receiving them in the system, the material handlers would have handheld scanners directing them towards various locations for put-away. This implies that there would be no paperwork involved during all these transactions. The handheld scanners would not only provide the storage location but would also be used to confirm placement. This would aid in improving the inventory accuracy during placement and reduce the number of Not-in-Location (NIL) products within the warehouse.

The author estimates that using all these technologies in perfect conjunction could lead to improved process efficiency and huge time savings. For instance, over half the time elapsed during the physical check is spent on manually counting every SKU to match with the packing list. Therefore, for receiving the Ireland/MicroMass Shipment, GDC could save about 21% of time spent in receiving by removing the need to manually count or perform transactions manually. This a conservative estimate of the time saved during physical check (only 12% has been considered from the 17%, the author believes the number could increase with the passage of time). Similarly, for receiving all other shipments, there would be no need to scan or attach transport POs to each SKU or even manually count them. It can be roughly estimated that 23% of time spent in receiving the other shipments can be potentially saved. Researchers have cited much greater reduction in receiving times for case studies at Gillette, this is still a conservative estimate of the possible benefit [23].

6.2 Picking

While receiving is an important warehouse operation, managers consider picking to be the most important for its direct impact on order fulfillment rate and accuracy. Order picking refers to removal (or retrieval) of products from their designated storage locations in accordance with customer orders.

6.2.1 Present State

This process is segregated in GDC by shipment destination (international and domestic) as described in Figure 6-7. The teams help each other based on delivery targets for the day and the backlog, and cross-training is not an issue since the operation for both the categories is the essentially the same. It begins with the respective international or domestic lead "dropping orders" and generating a Transfer Order which is handed to the picker. The Transfer Order contains the details pertaining to the specific SKU (part number and lot number/serial number) that need to be fulfilled in that order with the associated quantity and storage location within the warehouse listed.

The picker then plans a route, selects a mode of transport dependent on the SKU and the storage location listed and proceeds (more details can be found in section 4.3.1). In most cases, the picker finds the right product in the right quantity at the listed location and places it on his/her cart/pallet truck. If the picker is unable to retrieve the listed items, the discrepancy is reported to the inventory analyst who follows with an investigation at his end. Then, based on its destination, the cart/pallet truck is moved to respective pack station to complete packaging and shipping. The order is packed by the same or different material handler before being shipped depending on the number of people in the area.

It should be noted that smaller orders – which also happen to be more in volume – are dropped and picked in batches to avoid the time lost in traveling to and forth between the packing stations and aisles. Another interesting observation that deviated from the standard operating procedure (SOP) involved different pickers picking multiple orders and placing them on the same cart and then just one picker taking it to the packing stations while others continue working on a different set of orders and cart. These deviations from SOP add to the productivity but make accurate process representation difficult.

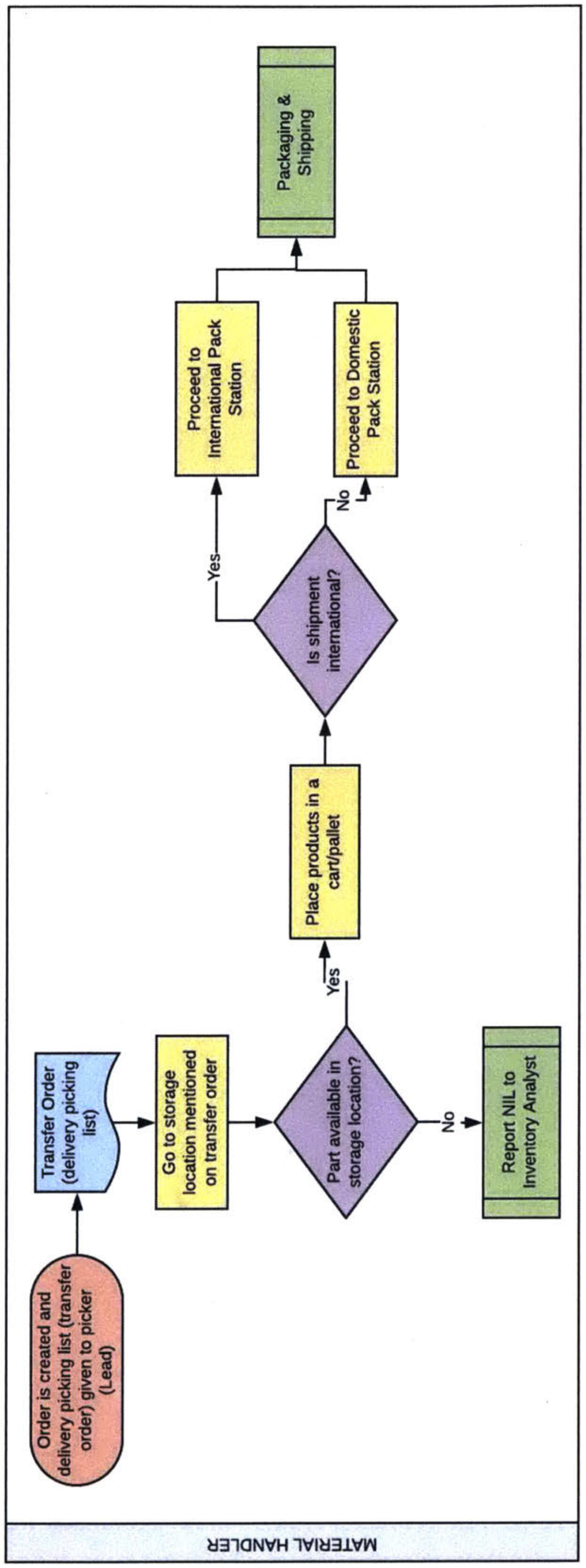


Figure 6-7. Process Flow Diagram: Picking

Time Study: To discern the time-wise distribution of various processing steps involved in picking, packaging, and shipping, the team collected the data and studied it (Table 6-3, Figure 6-8). It was important to group picking, packaging, and shipping together to align with the available data for overtime (OT) and regular hours. This data was exclusively collected for smaller orders being packed for both international and domestic sections. When it's required to prepare consolidated pallets for international shipment, the proportion of box erection & product placement time would increase substantially.

Table 6-3. Step-wise distribution of time for Picking, Packaging & Shipping

Activity	Time Elapsed (%)
Drop Order	1
Plan Route	3
Pick	41
Pick-Verify in SAP	3
Box Erection & Product Placement	51
Paperwork	3

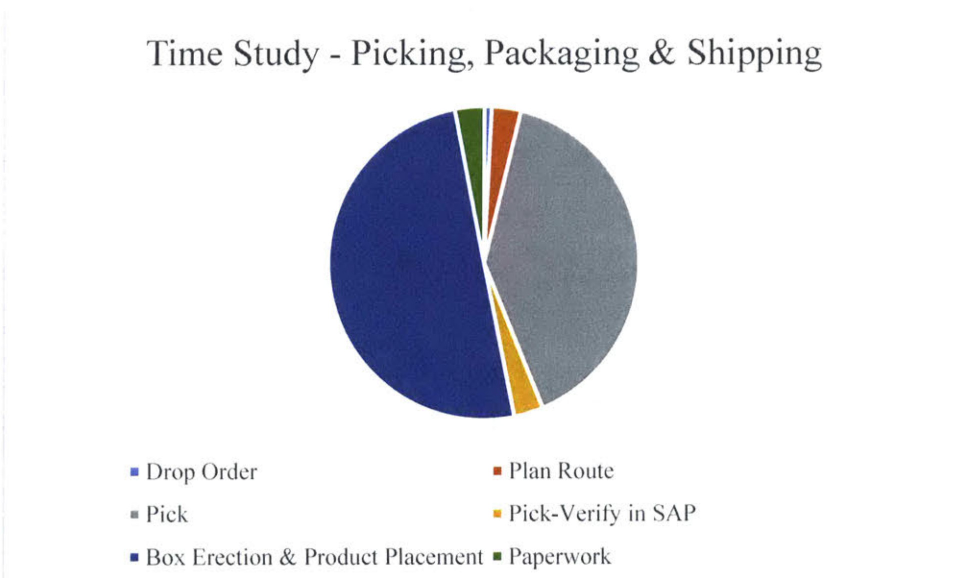


Figure 6-8. Step-wise distribution of time for Picking, Packaging & Shipping

6.2.2 Proposed Future State

It was observed that picking as a process was largely void of inefficiencies. The material handlers worked tirelessly towards picking lines with the speed of ~ 1.5 lines/min. This implies that implementation of RFID would not necessarily improve the process efficiency. However, if the pickers are equipped with handheld scanners instead of transfer orders, the automated system could guide them to the storage location and verify the SKU picked on the spot. This could lead to improved picking accuracies for the process.

As per the time study estimates, the actual walking (pick) time contributes about 41% of the total time spent in the process. The inventory relocation algorithm by the virtue of smarter placement of frequently shipped items would require the pickers to walk less to fulfill these orders. From the preliminary calculations concluded in Hochsztein's work [1], the team estimates that it would lead to a reduction of 5% in walking time, thereby enhancing the productivity.

6.3 Packaging & Shipping

Packaging & Shipping is the final processing step within the warehouse which is required to be completed after the products have been correctly picked. This step involves packing the order in a carton, labeling it with the customer address and passing it to the carrier (Figure 6-9). The step is critical to ensure order accuracy and acts as a checkpoint where orders get differentiated based on their destination and other constraints. There is no distinction between picking mechanism for hazardous substances, pallets, instruments or products in freezers. However, each of them requires a slightly different procedure in terms of packaging and shipping.

6.3.1 Present State

Currently, there are nine packing stations in GDC. Out of these, five are primarily used for international shipments and four of them are used for domestic shipments. The picker brings a cart organized by different orders with their transfer orders placed beneath the products to one of these stations based on the destination. The material handler responsible for packaging then scans Transfer Order Number, followed by each SKU, and ultimately scans the quantity by manually counting or based on the ordered quantity and then packs them into a carton. This process is termed as Pick-Verify in SAP (Figure 6-10).

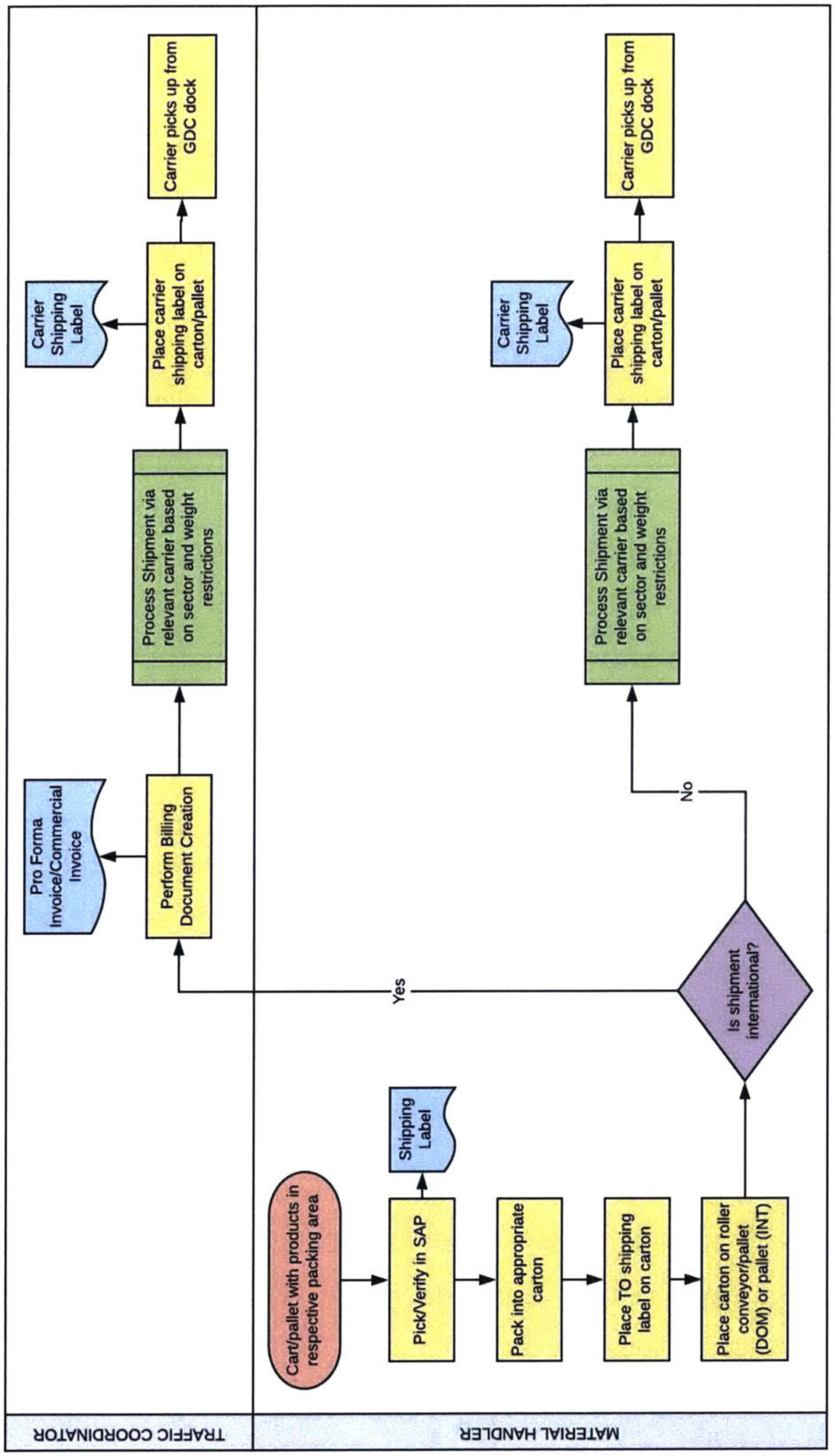


Figure 6-9. Process Flow Diagram: Packaging & Shipping

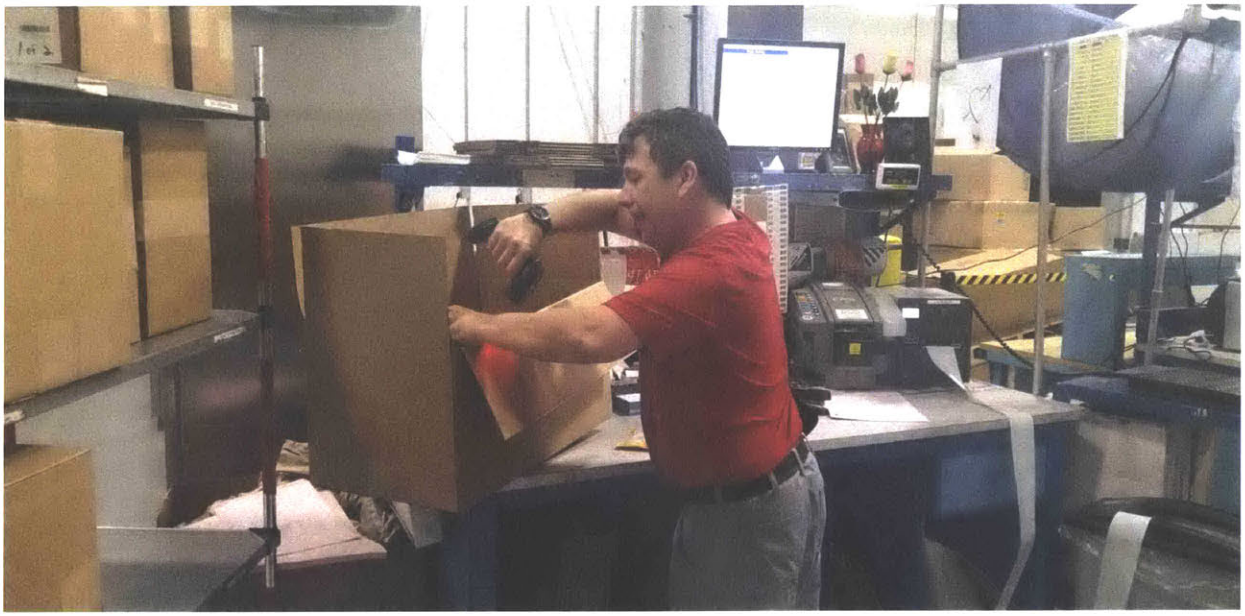


Figure 6-10. Packaging an order in GDC

The material handler responsible for packaging does not manually count or verify if each SKU is actually the same or is it different in the same external box. It should be noted that in this process, the picker is responsible for picking the correct SKU in the right quantity. There's no other error-proofing mechanism instilled in the system to check the same.

From the time study of the process (Table 6-3), it can be observed packing orders into cartons takes most of the time. This is because box erection is entirely manual and there are times when one doesn't pick the right carton in the first go. The packer is responsible for sticking the shipping label onto the carton to ready it for the next step.

There are essentially three shipping stations on the warehouse floor. Sealed cartons from the previous step are brought here, their shipping labels are scanned, and appropriate carrier labels and documents are stuck to the carton. Material handlers usually handle this aspect as well for domestic shipments, but international shipments require intervention by traffic coordinators who handle this aspect to ascertain adherence to compliance.

6.3.2 Proposed Future State

Using RFID, the accuracy of the incoming material is ensured using the dock door portal in the receiving section. However, the system would be incomplete if the loop is not closed to ensure perfection. For this purpose, it is recommended that shipping labels enabled with RFID be used instead of the normal shipping labels. The system would then directly embed the Transfer Order data into the shipping label tag. Currently, GDC uses a conveyor where cartons with shipping label are placed (Figure 6-11).

Figure 6-11. Conveyor for domestic shipments between packing stations & shipping stations

An RFID portal can be installed on such a conveyor to scan each carton exiting GDC. In this case, the shipping label would already contain the specific order details and scans would confirm if the carton possesses the products in the right quantity. Such a system could indicate to the user any discrepancy. Researchers have shown that the shipment accuracy in one of the pilot applications rose from 92% to 99% [18]. The team believes that its implementation would result in improving order accuracy and reducing incorrect shipments by 70%. The pilot study described in Harlalka's work [2] involved testing of tag readability when enclosed in a pallet with success. So, a similar dock door portal can be installed for pallets where hierarchized tags on both pallets and individual products would ensure that only the right product exits in the GDC in the right quantity.

6.4 Inventory Cycle Count

GDC carries around $45 million worth of inventory as estimated from the latest monthly report. Although the transactions for both receiving and shipping are recorded digitally to update inventory automatically, like most other organizations, the team at GDC counts their inventory manually as well (Figure 6-12).

6.4.1 Present State

Currently, the inventory analyst schedules cycle counts for the entire month by assigning a range of storage locations for each day. This list containing the particulars of SKUs is passed on to the section lead who assigns a team member to the task in the second shift after all the orders have been picked. This team member goes to each storage location assigned for the day and manually counts each SKU listed. He/She is also responsible for checking if the product is damaged or not. All non-conforming goods have a separate procedure for detailed inspection. It should be noted that the list doesn't contain information on the quantity recorded in the IM system.

The completed list with information on quantity available in a storage location is matched by the inventory analyst the next day. If any discrepancies are listed, they are thoroughly investigated by manually re-counting. Then, changes are made to the system inventory to reflect the updated status and the transaction is recorded on a cycle count adjustment sheet. Seemingly non-complex, this process requires a material handler to spend over 45 minutes every day counting the SKUs. Moreover, in its present state, the manual counting has a direct impact on inventory accuracy in the system. According to the SOP established, Waters verifies the inventory at each storage location just once a year.

Inventory Shrinkage: Inventory shrinkage can be defined as excess inventory as recorded in the system which doesn't physically exist in the warehouse. There can be many reasons behind the shrinkage ranging from process errors to theft (internal & external) to spoilage to deception [24]. It has been noted that in GDC, the primary reason for inventory shrinkage could be process error. For instance, picking more than customer order requirement and receiving less than the prescribed quantity without updating can cause system inventory mismatch. It should also be noted that while there are many SKUs which are not found during these cycle counts, there are many products which are found but are non-existent in system inventory. Table 6-4 exhibits the value of inventory lost and found over 2016, 2017 and 2018 (Q1 & Q2).

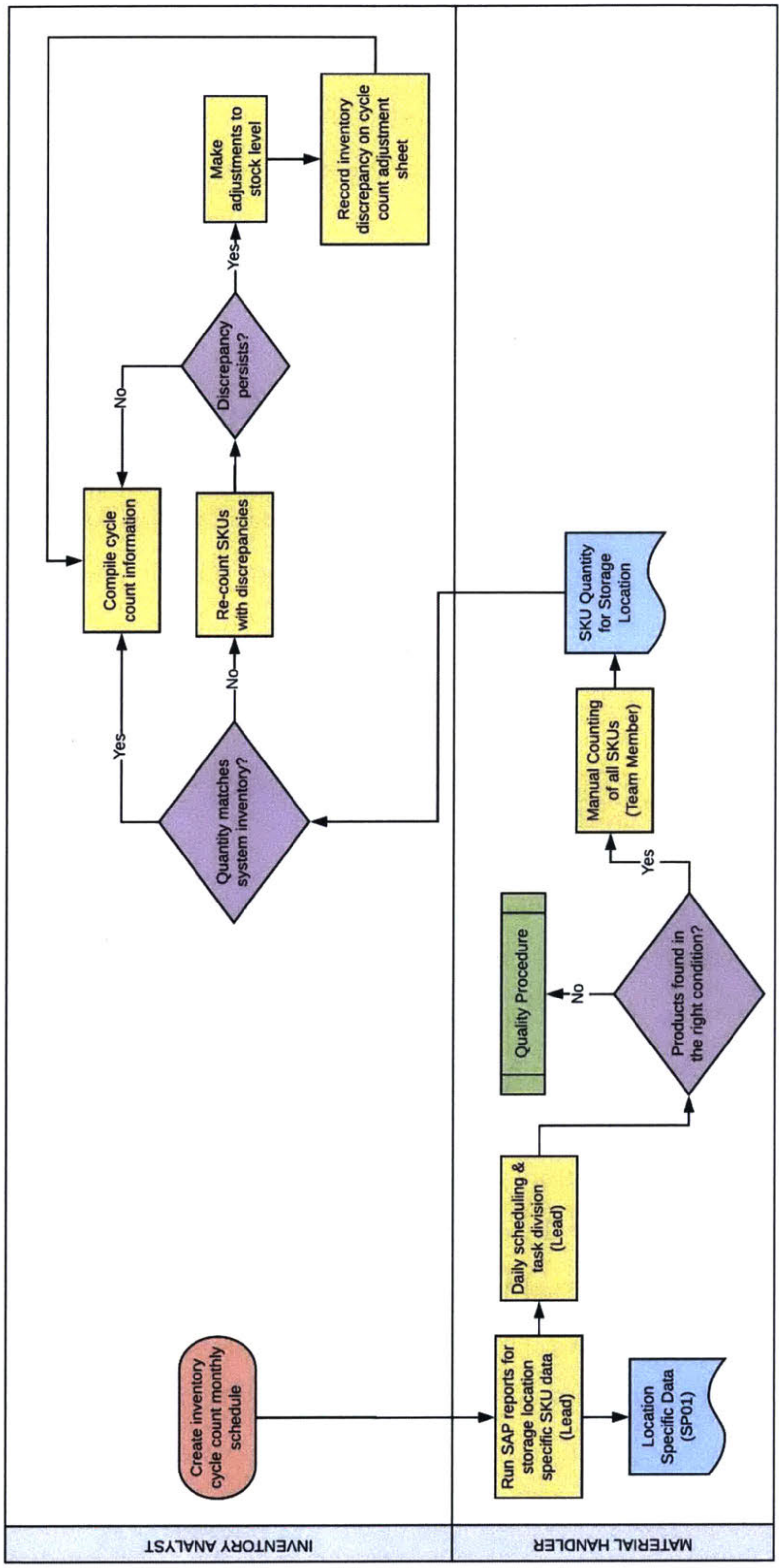


Figure 6-12. Process Flow Diagram: Inventory Cycle Count

Table 6-4. Results of Inventory Cycle Counts

Time Period	Inventory Lost	Inventory Found	Net
2016	$36,019.29	$26,271.17	$9,748.12
2017	$72,668.83	$23,116.44	$49,552.39
2018 (Q1 & Q2)	$39,401.83	$30,621.99	$8,779.84

It could be argued that if there is substantial inventory lost then a lot of products are found during these cycle counts as well. However, both point to the inaccuracy of the system records pertaining to the products that should exist within the GDC and process improvements should focus on reduction in both inventory lost as well as found. An important point to note from the financial perspective is that the inventory lost matters more to GDC given that its value is debited from the account.

6.4.2 Proposed Future State

As described earlier for the individual warehouse processes of receiving, picking, packaging & shipping, RFID could greatly improve the accuracy and efficiency. In shipping, similar results could be achieved by introducing multiple checkpoints for outbound shipment (dock door portals and scanning of each item). And similarly, if receivers are assisted by hand-held scanners during put-away and dock door portals for counting the incoming shipment, the accuracy would greatly improve there as well. Upon implementation of RFID, most companies have achieved read rates close to 100% [20]. With such high read rates, it's possible that the errors in receiving and the ones due to over-picking would reduce substantially. Other research points to an increase in inventory accuracy from 80% to 99% using RFID based DWMS [17]. It is known that the inventory accuracy at Waters is close to 99% but gains can still be realized by using the technology. So, now that each incoming and outgoing shipment would be read, it can be estimated that this could lead to a reduction of 70% in the inventory lost to unknown reasons each year. It should be noted that this number is an estimate based on the improvements from the current operating procedure and could, in fact, vary between 60 – 80%. A sensitivity analysis conducted in section 7.7 considers three separate scenarios to account for the variability.

In addition to this, full-scale RFID implementation could aid faster and more frequent inventory cycle counts improving overall productivity. Firstly, the material handlers responsible for cycle counts could be assisted by hand-held scanners with accurate information for the current inventory status and automatically verifying the part availability using RFID signals. This could reduce the time spent on cycle counts by at least 80% given the manual labor expended in the process. Secondly, the overall cycle count process could be largely automated by installing readers and antennas on warehouse equipment like carts and forklifts that keep moving within the warehouse and updating the inventory status in real-time [2]. Such systems don't require manual intervention and alert users if discrepancies are found and can greatly enhance the frequency of counts as well.

6.5 Resolution of NILs/FILs

NIL(s) or Not-in-Location(s) can be defined as the products which were not found in their designated storage locations by pickers for fulfilling customer orders. A lengthy investigation is carried out by the inventory analyst to categorize them and identify the root-cause. On similar lines is the FIL or found-in-location, the products which are found in storage locations different from that in system inventory.

6.5.1 Present State

As described earlier in picking (6.2), the order is dropped, and pickers proceed to the designated storage location listed on the Transfer Order. If they are unable to find a product on the list, it's noted on an internal NIL form and submitted to the inventory analyst. The inventory analyst receives many such requests in a day and checks system inventory before proceeding to the location. SAP also contains the details pertaining to the time stamps for part transactions in the inventory system. This helps in verifying if the desired part was recently received or not. The analyst then proceeds to the storage location. If the part is available but the picker was unable to identify it, the NIL is termed as a "picker" error. If the part is actually not available in the location, the analyst confirms the receipt with the receiving team. If the part has been received but not put-away yet or is found in a different storage location than what is listed on the system, the NIL is termed as a "receiving" error. In both these cases, the part is handed over to the material handler after retrieval by the inventory analyst. A chart describing the contribution of all these errors to the total NILs is given in Figure 6-13.

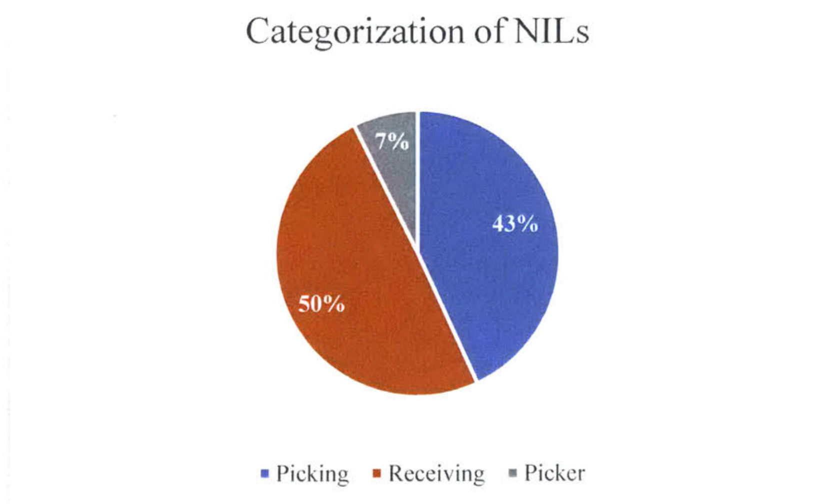


Figure 6-13. Error Categorization for NILs in 2018 (Q1 & Q2)

In every other scenario, when the product can't be traced within the warehouse and its unavailability is confirmed, the NIL is termed as a "picking" error. If it's a lot-specific part, and lot replacement is possible, then the order is re-dropped with the new lot and completed. If it's not a lot-specific part, then constraints on partial order fulfillment are checked and partial orders are shipped if possible. If none of these avenues are favorable, the inventory analyst cancels the order leading to revenue losses for the company (Table 6-5). It could be argued that FILs also exist within GDC and their value could be greater as compared to that of NILs. However, lost orders are a far more serious concern because it is a loss in revenue and overall customer satisfaction which could have been potentially earned had the system been perfect. The procedure for resolution of NILs is described in Figure 6-14.

Table 6-5. Value of Lost Orders due to NILs

Month	NILs
January	$30,401.37
February	$31,921.43
March	$26,621.63
April	$21,034.02
May	$22,437.18
June	$12,901.75
Total	**$145,317.38**

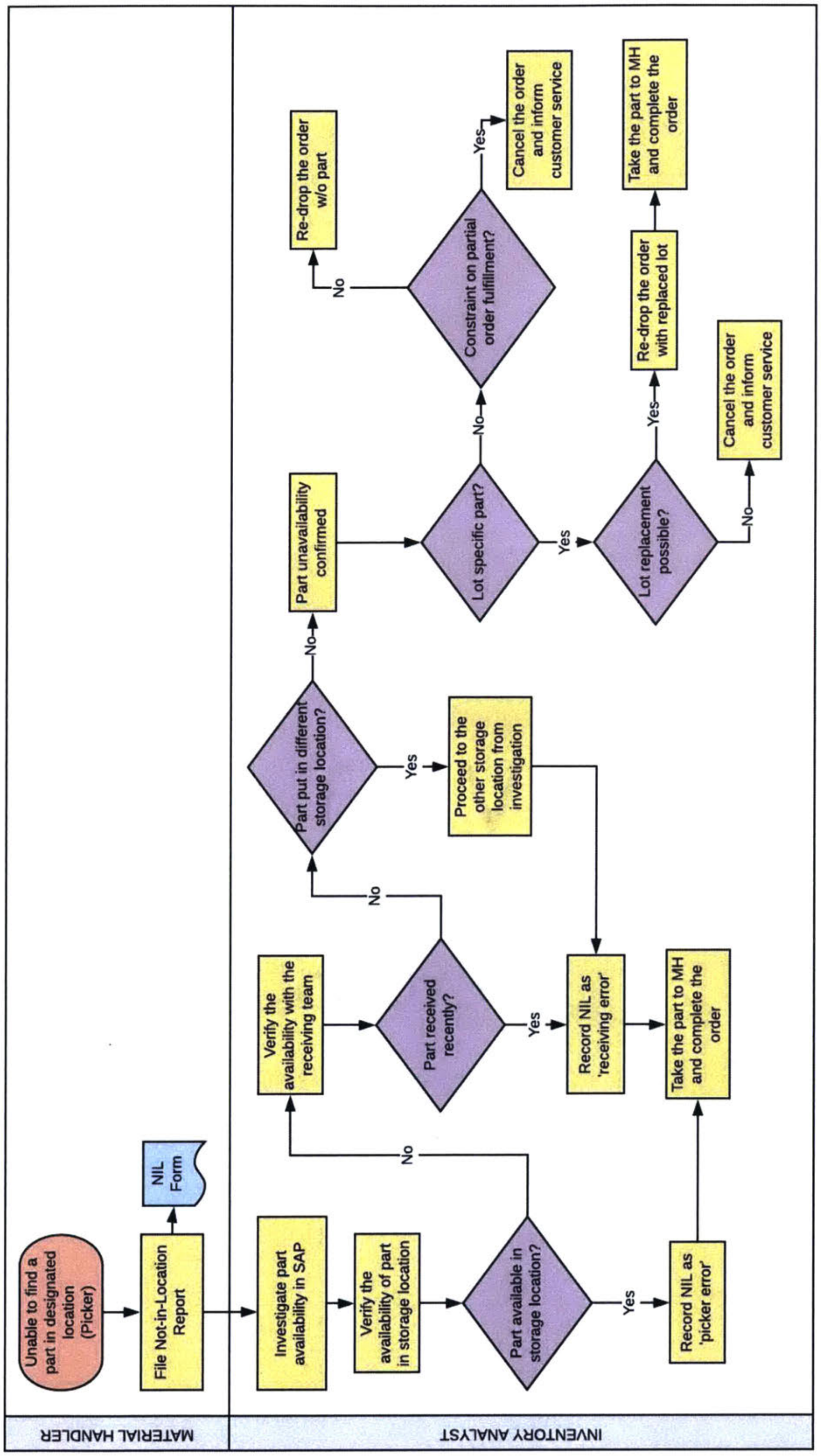


Figure 6-14. Process Flow Diagram: Resolution of NILs/FILs

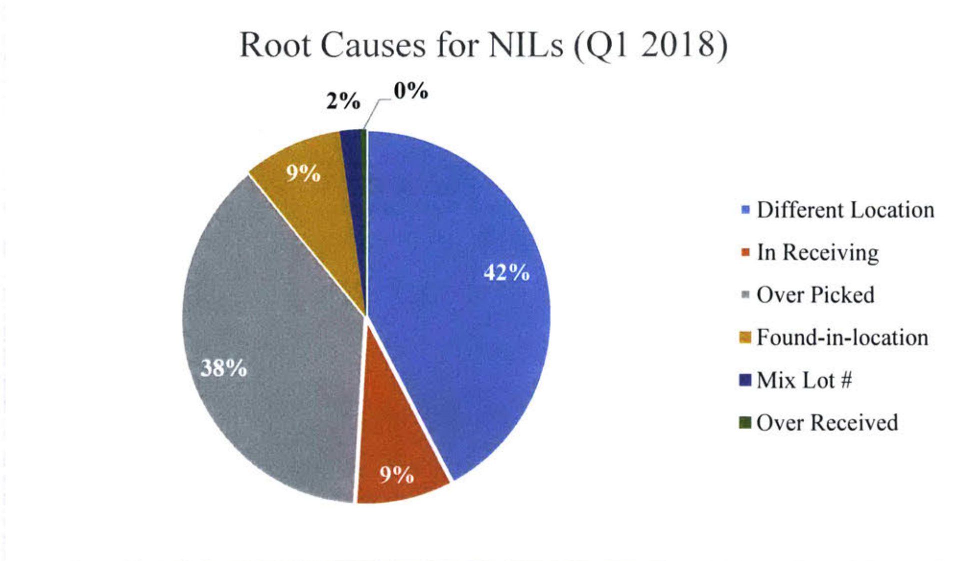


Figure 6-15. Root Causes for NILs

6.5.2 Proposed Future State

In order to estimate the potential reduction in NILs after RFID implementation, it is important to understand the root-cause behind NILs. The first major reason is receiving – either the receivers have recently received the item and it is still in the staging area or have put it away at the wrong location. RFID implementation can reduce these errors by automating the counting step and assisting material handlers during put-away to ensure accurate inventory locations. A similar application, in the tobacco industry, reduced misplacement errors from over 15% to under 2% [17]. After receiving, most of the NILs are attributed to errors in picking. Although it's termed as "picking", it can be attributed to both over-picking and under-receiving. Dock door portals on shipping stations and automating the pick-verify process would act as checkpoints, not allowing incorrect shipments to exit GDC. So, even if pickers make an error, it would be rectified before the order leaves GDC. RFID applications have cited read rates close to 100% [20].

An optimal estimate for reduction in both receiving error and picking error would be around 70%. The effect of these reductions in errors can be used to calculate the estimated reduction in total NILs, by calculating the weighted mean, based on their individual contributions to the total NILs (Figure 6-13 & Figure 6-15). The estimated reduction hence calculated is about 65%. However, during discussions with the team at Waters, it was made clear that the majority of these items not found would be re-ordered. So, based on the discussion with Waters, it is believed that the potential additional revenue due to reduction in "picking" NILs would only be around

30%. It should be noted that this number is an estimate and could, in fact, vary between 20 – 40%. A sensitivity analysis conducted in section 7.7 considers three separate scenarios to account for the variability.

It is also suggested that the receiving transaction be broken down into two separate transactions: one for goods received (GR) and the other for put-away. Currently, the single GR transaction leads the system into believing that the part is already available in system inventory even if it isn't put-away yet. This is a pain for the inventory analyst and the picker who files NIL form. This suggestion can also be implemented without adopting RFID in GDC and it could potentially save a lot of time for the inventory analyst who spends around 25 minutes investigating into each NIL. During separate interviews with the Business Technology (BT) team, inventory analyst and receiving lead, this proposal was discussed, and considered a favorable modification.

6.6 Handling Incorrect Shipments

Out of the many performance measures of a warehouse, order accuracy is perhaps one of the most important ones. The added cost of returns and re-shipment along with misinformation on inventory make the process of handling incorrect shipments a tedious one.

6.6.1 Present State

The process starts with the customer reporting an error. If the customer is external, this information is conveyed via Customer Service to the GDC. If the shipment was sent to a Waters subsidiary, the information is directly conveyed to the GDC. It should be noted that the process is slightly different for handling domestic and international shipments as given in the process flow diagrams below (Figure 6-16 & Figure 6-17). The inventory analyst is responsible for verifying if the customer-stated discrepancy matches the system inventory status. If it's found true, the shipment was either short-shipped or over-shipped. A Transport Request Form (TRF) is generated to ship the shortage to the customer. In case of international shipments, the export administrator audits this TRF before shipment and investigates for compliance requirements.

In the case of an over-shipment, it's verified if the customer desires to keep the excess quantity or the different product. In the case of international customers (usually ADC and EDC), there are almost no cases of return of a product and the other subsidiary keeps the stock and generates either a Stock Transport Order (STO) or a Purchase Order (PO), so that the system inventory could be updated to confirm the shipment. The export administrator keeps track of the whole process and updates the GTS shipment and US Census data manually. It's mandatory for the company to report any changes in order to comply with customs regulations beyond a certain shipment amount. The export administrator spends about 40 minutes for rectifying each incorrect shipment. In the case of domestic customers, the interview with inventory analyst revealed that they are usually inclined towards returning the excess. The cost of this return must be borne by GDC and all arrangements pertaining to the shipment are made to its account. Finally, when the returned shipment is received in GDC, it undergoes a preliminary quality check by the inventory analyst followed by a detailed quality procedure if required. To better understand the magnitude of problem, Table 6-6 includes the total number of international incorrect shipments.

Table 6-6. International Incorrect Shipments

Month	International Incorrect Shipments
January	100
February	57
March	70
April	53
May	12
June	28
Total International Incorrect Shipments	**320**

6.6.2 Proposed Future State

The author believes that upon introduction on multiple checkpoints for a shipment before exiting (6.3.2), the number of incorrect shipments would reduce substantially. The primary reason for incorrect shipments can be attributed to picking error as there is no error-proofing mechanism built into the system. If a picker picks the wrong quantity, the pick-verify process in shipping isn't adequately robust to identify the inaccuracy. As explained earlier in detail, the recent applications of RFID have proven the technology to have very high read rates which could potentially identify mis-picks at the shipping station itself. Researchers have shown that the shipment accuracy in one of the pilot applications rose from 92% to 99% [18]. It should be acknowledged that the shipment accuracy at Waters is close to 99% already. From the literature available, a direct reduction in terms of incorrect shipments can't be computed. However, it is believed that the technology could reduce errors by 70% and save time for inventory analysts, export administrators and material handlers. It should be noted that this number is an estimate and could, in fact, vary between 60 – 80%. A sensitivity analysis conducted in section 7.7 considers three separate scenarios to account for the variability.

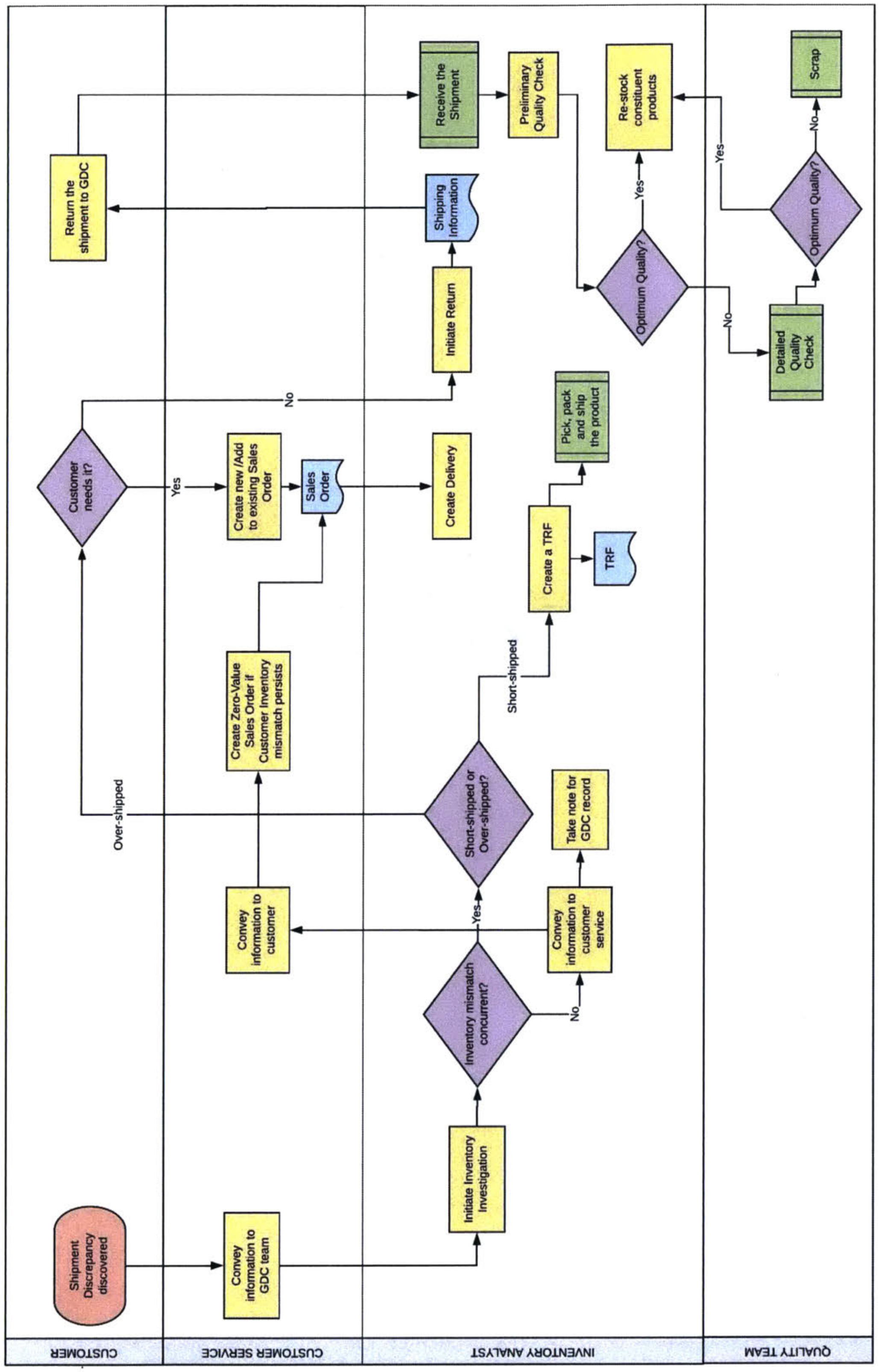


Figure 6-16. Process Flow Diagram: Handling Incorrect Shipments (Domestic)

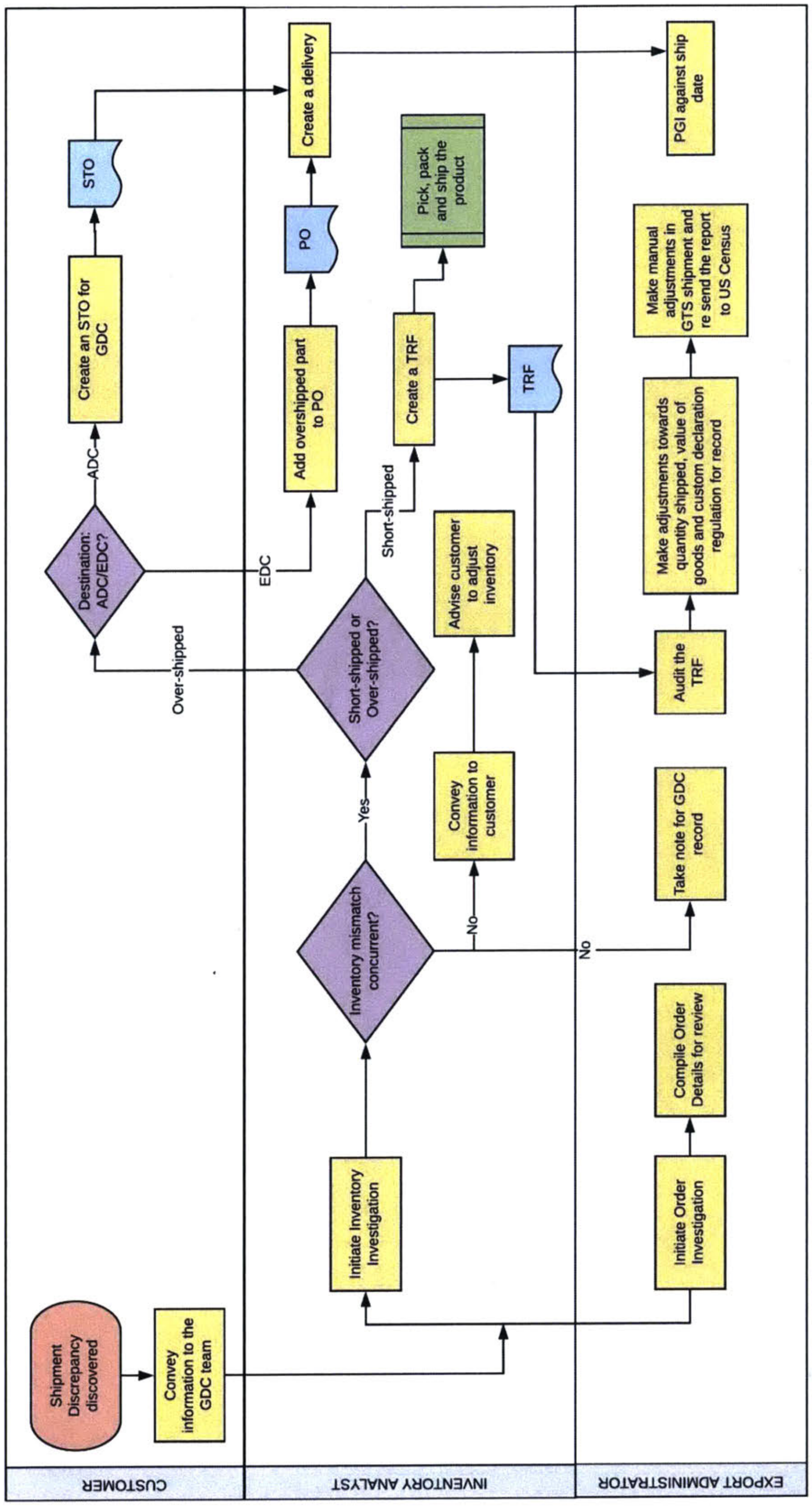


Figure 6-17. Process Flow Diagram: Handling Incorrect Shipments (International)

6.7 Summary of Full-scale Implementation Use Cases

Warehouse Operation	Proposed Future State
Receiving	• Dock Door Portals for bulk scanning reduce receiving time by over 20% • Handheld Readers assisting put-away reduce placement errors • Inventory Location Optimization Algorithm automatically determines storage locations diminishing the need to look up "default" locations
Picking	• Inventory Location Optimization Algorithm reduces the overall walking time by 5% thereby increasing the rate of order fulfillment
Packaging & Shipping	• RFID enabled printers encode and print shipping labels to ensure tag hierarchy and improve tracking • Handheld Readers assist at packing stations to automate pick-verify in SAP without manually scanning every SKU • Separate Dock Door Portals for domestic shipments, international shipments and pallets scan each outgoing shipment to reduce shipping inaccuracy
Inventory Cycle Counts	• Handheld Readers assist material handlers during cycle counts removing the need to count manually • Reader-antenna bundles mounted on forklifts and carts automatically verify system inventory during day-to-day usage

CHAPTER 7

COST-BENEFIT ANALYSIS FOR RFID IMPLEMENTATION

Adoption of any technology requires a supportive business case that enlists the potential benefits, transition costs, and implementation issues. Incorporating RFID into the supply chain at Waters Corporation is no different. This chapter presents a preliminary cost-benefit analysis of RFID implementation within GDC. It could serve as the first step towards detailed studies at Waters before the final implementation roadmap is drafted. It takes into account the execution strategies defined in the previous chapter to calculate the Net Present Value (NPV).

7.1 Methodology

Defining the model used for cost-benefit analysis is an important consideration given the vast number of such models. They can be grouped into three major categories: a) conventional models, b) uncertainty based models, c) decision-making models [25]. Decision-making models use tools like Analytical Process Hierarchy to justify RFID implementation but have been rarely used. Uncertainty based models utilize Markov chain models and simulation but pose difficulty owing to collection of data [25]. There have been simplistic applications for these to determine the ROI using a crystal ball add-in in MS Excel [26]. The crystal ball add-in distributed by Oracle can be used to handle uncertainty in analysis and compute the expected value for multiple scenarios. Lastly, the conventional models use Net Present Value (NPV) and break-even analysis to determine if RFID is worth the investment. Often cited as simplistic, a conventional model could serve the basic need in case of Waters and has therefore been used here.

The company is looking to understand if RFID implementation could transform their business processes and if yes, to what extent. This section contains detailed costs, economic and strategic benefits, and potential issues to equip future Waters team with a base case. It should be noted that the economic benefits listed below assume that all incoming products have been tagged at the item level before being received in GDC, more information on tagging can be found in 7.4.1.

7.2 Quantitative Benefits

7.2.1 Model Constants

Annual Seasonal Factor: Complete data for most of the activities was available for only Q1 and Q2 of 2018. However, to have the costs and benefits on the same page and scale the benefits to a year, an annual seasonal factor was introduced into the analysis. This factor was calculated based on the past data (2015, 2016 and 2017) for the ratio between the deliveries each year to the deliveries in the first two quarters. The value of this annual season factor on an average can be estimated to be 2.

Average Annual Growth Rate (AAGR): To estimate the growth in benefits over the next 5 years for NPV, which were assumed to be linearly dependent on the volume of business (lines delivered), AAGR was assumed as 5% based on industry trends.

7.2.2 Activity-wise Cost Reduction

As described in detail in Chapter 6, RFID has the potential to automate and vastly impact the business processes. It is projected that the implementation would lead to savings primarily in labor costs for most of the warehouse activities and some other costs as described below.

Receiving: As described in section 6.1.2, for receiving the cost reduction stems from the fact that RFID implementation would not require the team to scan or count manually. This would lead to time savings of over 20% in receiving which would translate to savings in labor costs (Table 7-1).

Table 7-1. Benefits: Cost Reduction (Receiving)

Receiving	
Material Handlers	5
Working Hours per Day (hr)	7.33
Total Working Days (Q1 & Q2)	125
Total Regular Working Hours in Receiving (hr)	4581.25
Total OT Hours in Receiving (Q1 & Q2) (hr)	983.5
Total Hours in Receiving	**5564.75**
Total Lines Received	56727
Total Lines from Ireland/MicroMass	16977
Total Lines from Other Shipments	39750
Total Hours spent on Ireland/MicroMass	1665.39
Total Hours spent on Other Shipments	3899.36

Estimated Time Savings in Ireland/MicroMass	21%
Estimated Time Savings in Other Shipments	23%
Total Estimated Time Saved	**1246.58**
Average Material Handler hourly wage (Regular)	$20.00
Average Material Handler hourly wage (OT)	$30.00
Total Estimated Cost Savings in Receiving (Q1 & Q2)	$34,766.69
Annual Seasonal Factor	2
Total Estimated Cost Savings in Receiving (Annual)	**$69,533.39**

Picking: As described in section 6.2.2, the proposed RFID implementation would not have an impact on picking operation and thus, would not save any direct labor costs in that operation (Table 7-2). However, improving the put-away and shipping accuracy would lead to indirect time savings for pickers as well.

Table 7-2. Benefits: Cost Reduction (Picking)

Picking	
Total Estimated Cost Savings in Picking (Annual)	**$0.00**

Packaging & Shipping: As described in section 6.3.2, time savings in packaging and shipping stem from the diminished need to scan SKU manually and automating the pick-verify procedure in SAP (Table 7-3). This 3% saving in time would, in turn, translate to savings in labor costs.

Table 7-3. Benefits: Cost Reduction (Packaging & Shipping)

Packaging & Shipping	
Material Handlers	14
Working Hours per Day (hr)	7.33
Total Working Days (Q1 & Q2)	125
Total Regular Working Hours in Picking, Packaging & Shipping (hr)	12827.5
Total OT Hours in Picking, Packaging & Shipping (Q1 & Q2) (hr)	2071.15
Total Hours in Picking, Packaging & Shipping	**14898.65**
Estimated Distribution of time spent in Scanning of the time in Packaging & Shipping	3%
Total Estimated Time Saved	**446.96**
Average Material Handler hourly wage (Regular)	$20.00
Average Material Handler hourly wage (OT)	$30.00

Total Estimated Cost Savings in Receiving (Q1 & Q2)	$13,408.79
Annual Seasonal Factor	2
Total Estimated Cost Savings in Packaging & Shipping (Annual)	**$26,817.5**

Inventory Cycle Counts: As described in section 6.4.2, RFID would enable the material handler to simply point towards the product to be counted instead of manually counting each part. Additionally, most of the inventory cycle counting procedure would be automated with RFID enabled vehicles in GDC (Table 7-4).

Table 7-4. Benefits: Cost Reduction (Inventory Cycle Counts)

Inventory Cycle Counts	
Total Working Days (Q1 & Q2)	125
Total Time spent by Material Handler per day (hours)	0.75
Total Time spent by Inventory Analyst (hours)	0.33
Total Time spent by Material Handler in Q1 & Q2 (hours)	93.75
Total Time spent by Inventory Analyst (hours)	41.25
Estimated Time Saving	80%
Total Estimated Time Saved (Material Handler)	**75**
Total Estimated Time Saved (Inventory Analyst)	**33**
Average Material Handler hourly wage (Regular)	$20.00
Average Material Handler hourly wage (OT)	$30.00
Average Inventory Analyst hourly wage	$30.00
Total Estimated Cost Savings in Cycle Counts (Q1 & Q2)	$3,240.00
Annual Seasonal Factor	2
Total Estimated Cost Savings in Cycle Counts (Annual)	**$6,480.00**

Resolution of NILs/FILs: As described in section 6.5.2, it is estimated that due to the additional checkpoints in shipping which prevent over-picking and automating the process of receiving, the number of NILs would reduce substantially (Table 7-5). This reduction in NILs could vary between 55 – 75%, the benefits in the table given below consider a realistic scenario with reduction amounting to 65%.

Table 7-5. Benefits: Cost Reduction (Resolution of NILs/FILs)

Resolution of NILs/FILs	
Total NILs (Q1 & Q2)	360
Total Time spent by Material Handler per NIL (hours)	0.08
Total Time spent by Inventory Analyst per NIL (hours)	0.42
Total Time spent by Material Handler in Q1 & Q2 (hours)	30
Total Time spent by Inventory Analyst (hours)	150
Estimated reduction in NILs	65%
Total Estimated Time Saved (Material Handler)	**19.5**
Total Estimated Time Saved (Inventory Analyst)	**97.5**
Average Material Handler hourly wage (Regular)	$20.00
Average Material Handler hourly wage (OT)	$30.00
Average Inventory Analyst hourly wage	$30.00
Total Estimated Cost Savings in Resolution of NILs/FILs (Q1 & Q2)	$3,510.00
Annual Seasonal Factor	2
Total Estimated Cost Savings in Resolution of NILs/FILs (Annual)	**$7,020.00**

Handling Incorrect Shipments: As described earlier in section 6.6.2, it is estimated that due to the additional checkpoints in shipping which prevent over-picking, the number of incorrect shipments would reduce substantially (Table 7-6). This reduction in incorrect shipments could vary between 60 – 80%, the benefits in the table given below consider a realistic scenario with reduction amounting to 70% of time spent in handling incorrect shipments.

Table 7-6. Benefits: Cost Reduction (Handling Incorrect Shipments)

Handling Incorrect Shipments	
Material Handlers	14
Working Hours per Day (hr)	7.33
Total Working Days (Q1 & Q2)	125
Total Regular Working Hours in Picking, Packaging & Shipping (hr)	12827.5
Total OT Hours in Picking, Packaging & Shipping (Q1 & Q2) (hr)	2071.15
Total Hours in Picking, Packaging & Shipping	**14898.65**
Total Lines Delivered	**229492**
Average Time per line (hours)	**0.065**
Total International Incorrect Shipments (Q1 & Q2)	320
Estimated Domestic Incorrect Shipments (Q1 & Q2)	40
Total Time spent by Inventory Analyst per Incorrect Shipment (hours)	0.25

Total Time spent by Export Administrator per Incorrect Shipment (hours)	0.67
Total Time spent by Material Handler per Incorrect Shipment (hours)	0.065
Total Time spent by Inventory Analyst (hours)	80
Total Cost of Shipping (Ireland Shipments)	$310,938.11
Total Lines Shipped (Ireland Shipments)	26695
Average Estimated Cost of Re-shipping per line (International)	**$12**
Total Cost of Shipping (Domestic)	$1,583,455.00
Total Lines Shipped (Domestic)	141010
Average Estimated Cost of Re-shipping per line (Domestic)	**$11**
Estimated reduction in Incorrect Shipments	70%
Total Estimated Time Saved (Inventory Analyst)	**63**
Total Estimated Time Saved (Export Administrator)	**149.33**
Total Estimated Time Saved (Material Handler)	**16.36**
Average Material Handler hourly wage (Regular)	$20.00
Average Material Handler hourly wage (OT)	$30.00
Average Inventory Analyst hourly wage	$30.00
Average Export Administrator hourly wage	$30.00
Total Savings in Shipping Costs	$4,176.47
Total Estimated Cost Savings in Handling Incorrect Shipments (Q1 & Q2) - Labor Only	$6,860.80
Total Estimated Cost Savings in Handling Incorrect Shipments (Q1 & Q2)	$11,037.27
Annual Seasonal Factor	2
Total Estimated Cost Savings in Handling Incorrect Shipments (Annual)	**$22,074.54**

7.2.3 Reduction in Lost Inventory

From the data collected for the lost inventory, it's evident that Waters is losing a significant sum every year. From the modification in business processes and as explained in detail in section 6.4.2, the estimated benefits from the better visibility of inventory and fool-proofing receiving and shipping are given below (Table 7-7). This reduction in lost inventory has been estimated at around 70% for the realistic scenario. However, as per the discussion with Waters team, the reduction can vary from 60 – 80% and requires a sensitivity analysis (in section 7.7) to account for the same.

Table 7-7. Benefits: Reduction in Lost Inventory

Month	Inventory Lost
January	$11,868.51
February	$8,963.04
March	$6,154.72
April	$8,974.68
May	$1,097.20
June	$2,096.62
Total Inventory Lost	**$39,154.77**

Estimated Reduction in Lost Inventory	70%
Annual Seasonal Factor	2

Total Reduction in Lost Inventory	**$54,816.68**

7.2.4 Additional Revenue

Orders are only generated (dropped) when the required products are available in GDC according to the system inventory. If the picker is unable to find a part, a Not-in-Location report is filed. If the product is not found in GDC, the order needs to be canceled subject to certain constraints (in section 6.5.1). This would amount to lost revenue for GDC which could have been avoided with correct inventory information.

Research has proven that RFID improves visibility in inventory and lead to better product availability in retail. It was responsible for almost eradicating the issue of shelf replenishment at Walmart which is directly attributed to inventory visibility [16]. As mentioned in detail earlier in section 6.5.2, it can be concluded that sealing the entry and exit with RFID equipped portals would lead to better control and visibility of inventory leading to reduced revenue losses (Table 7-8). This reduction has been estimated at around 30% for the realistic scenario. However, as per the discussion with Waters team, the reduction can vary from 20 – 40% and requires a sensitivity analysis (in section 7.7) to account for the same.

Table 7-8. Benefits: Additional Revenue due to reduction in "picking" NILs

Month	NILs
January	$30,401.37
February	$31,921.43
March	$26,621.63
April	$21,034.02
May	$22,437.18

June	$12,901.75
Total Value of "picking" NILs (Lost Revenue)	**$145,317.38**

Estimated Additional Revenue due to reduction in "picking" NILs	30%
Annual Seasonal Factor	2

Total Estimated Additional Revenue	**$87,190.43**

7.3 Strategic Benefits

Michael Porter's value chain model would be the most suitable to analyze the impact of RFID implementation on the overall business processes at Waters [27]. The model as described in the literature specifies primary activities such as inbound logistics, operations, outbound logistics, marketing and sales which are supported by leadership, training and technology development [28]. The model identifies that an integrated flow of material and information is the key to value creation. It is believed that RFID implementation would lead to streamlining the communication channels by automating data capture leading to more informed decisions. In addition to that, it can go a long way in providing the necessary visibility and competitive advantage that has the potential to impact not just logistics (the primary function at GDC) but also operations, marketing, and sales.

7.3.1 Competitive Strategy

During the course of research, it was noted that the primary competitors of Waters in the HPLC business had incorporated RFID in their products well before 2016. It is necessary to understand competitor's strategy in a market where product differentiation is the key to future growth.

A major competitor's product includes an RFID tag which stores information on product type, operating pressure, ports and positions as well as the serial number. This identification system was streamlined with the software provided along with the product to give the customer much-needed visibility in the status and operating conditions of the product. An application like this provides direct value to the customer and should be incorporated in the overall strategy for RFID implementation. This would in turn mean that the additional cost of tagging is not a process waste but potentially adds value to the product as from the customer's perspective as well. Moreover, this could aid in providing better data points towards product improvement and servicing by easier identification of root causes of failure. This could result in better responses to customer use cases by the research and development team to quicker turnarounds in the market and boost future sales.

Another major competitor has developed a resource monitor to track and convey performance metrics (number of installations, runs, etc.) for consumables installed in its instruments to the customer. In this case, the data is stored directly on the tag to make it secure and transferable with the product itself. Additionally, the consumable can also alert the customer if installed in an improper manner that could harm the equipment. Adding to the value for the customer, both the competitors have designed asset management utilities that help their large customers track the usage and location of their instruments. This translates to customers having the incentive to buy more instruments from the same company to have all their assets being tracked together.

It is recommended that Waters should analyze the above use cases more closely to identify the added value and if it would play a role in their competitive strategy.

7.3.2 Value-added for Consumers

As described earlier in greater detail, RFID equipped products can help the customers easily manage their assets, track usage and create intuitive performance metrics for evaluating Waters' products. The company leads in instrument performance and making it visible to the consumers would go a long way in establishing strong customer relationships. In addition to this, the company can prepare voluntary customer feedback forms pertaining to usage of certain products ensuring product lifecycle management. Just as anonymous software crash reports are used by software companies to identify bugs in their applications, such usage statistics could improve the product performance over time ultimately leading to higher levels of customer satisfaction.

7.3.3 Performance Management

In legacy systems, most of the data collection is done manually leading to frequent errors and sub-optimal decisions. With a technology like RFID in place, the whole process of data collection for inventory management as well as performance management can be automated resulting in reliable data and better process execution. For instance, a metric like dock-to-stock time is necessary to quantify the performance in the receiving section of a warehouse. For such an application, multiple RFID transactions at each stage of the process become the reliable datapoints the management can use to estimate such metrics. Effective measurement of performance combined with adequate incentives can result in improved process efficiency over time.

7.3.4 Compliance

The major push towards RFID applications, as mentioned earlier, came with Walmart's announcement of making it mandatory for their suppliers tagging their pallets for better management. The way Walmart lead the way for RFID tagging in retail, given the consolidation, the healthcare industry is already transitioning towards tagging all their products for asset management and tracking. Experts believe that large pharmaceutical companies may follow suit to prevent misuse and unintended applications. It is known that Waters' customers are technologically advanced and want to remain at the top of the technology. In future, these customers could alter their requirements and make RFID mandatory or give preference to tagged products. So, the decision to include RFID tags in products would make the long-term strategy future proof.

7.4 Implementation Costs

7.4.1 Tags

Tags are an integral component of any RFID implementation plan. There are multiple decisions ranging from the type of tags to the tagging process that directly affect the implementation. Harlalka's work discusses in detail about the type of tag required and the process behind their application as well [2].

One of the first crucial decisions while designing the RFID system is the level of tagging required. This cost-benefit analysis considers that the products at Waters would be tagged at the item-level instead of the standard retail practice of tagging them at the case/pallet level. Tagging at the case/pallet level is common in retail because RFID adds indirect value to the customer by improving shelf replenishment, adding visibility to inventory and decreasing the in-store theft. It doesn't add direct value for the customer. Meanwhile, pallet-level tagging can help the retail chain reap most of the benefits. However, as mentioned earlier, RFID can potentially provide a strategic advantage to Waters by giving customers the additional feature of asset management. In this scenario, adding tags to item level is better both for the processes and the sales and is thus, a reasonable assumption. Moving forward, the company can experiment with a hybrid approach to tagging – item-level tagging for high-value products and case-level tagging for high-volume low-value products.

The cost of tagging has not been included in this study because GDC is essentially a warehouse. It doesn't play any role towards adding any additional identification to the products shipped. It serves as a buffer between other DCs, manufacturing plants, vendors and Waters' customers. Tagging is a significant overhead that could potentially alter the decision pertaining to implementation. However, GDC receives over 2.3 million products each year and the decision to tag them all at GDC requires much more careful consideration. It is known that the points of origin for various products are required to label them in line with a barcoding scheme followed all over the company. Even the suppliers need to comply with the barcode standards set by Waters. In this scenario, it would be more efficient if the paper labels at the source are replaced with RFID-equipped labels. This solution would only require the sources to switch to RFID-encoder-enabled printers which would enable them to tag the products and encode them with a unique EPC. It would require additional IT infrastructure across the supply chain at Waters to have EPC linked to databases that provide the requisite information at points of scanning but would otherwise not incur any additional labor cost. On the other hand, if material handlers were to tag millions of products received every year in GDC, it would require additional space and labor hours to process. Once tagged at the source, the products can then be traced throughout the supply chain without performing manual transactions. Additionally, this means that the history of the product can be traced even before it enters the doors of GDC which can extract more value at the same cost of tagging.

Given the time frame of the project, it was not possible to realize and quantify the benefits RFID could potentially have over the entire value chain and bundling the entire cost of tagging to GDC's account would have tilted the scales out of technology's favor. The author recommends that the company conduct an all-encompassing study to understand the benefits by taking a holistic view of the supply chain and then distribute the costs of this overhaul.

7.4.2 Hardware

A major non-recurring cost that is highly dependent on the scale of RFID implementation is the hardware. Based on the technology requirements listed in Harlalka's work and the proposed future state for various warehousing operations, a preliminary estimate for hardware costs is given below (Table 7-9) [2]. The cost of purchasing and installing hardware is a significant portion of the total investment in RFID implementation within any facility. It should be noted that the maintenance of hardware is a recurring cost which has been estimated from literature available [15].

Table 7-9. Costs: Hardware

Head	Remarks	Unit Cost	Quantity	Cost
Readers	UHF 4-port Reader			
Receiving	1 Dock Door Portal	$1,600.00	1	$1,600.00
Picking		$1,600.00	0	$0.00
Packaging & Shipping	3 Dock Door Portals	$1,600.00	3	$4,800.00
Others	2 Vehicle Mounted	$1,600.00	2	$3,200.00
Subtotal				$9,600.00
Antenna	Outdoor RFID Antenna (FCC)			
Receiving	1 Dock Door Portal	$130.00	4	$520.00
Picking		$130.00	0	$0.00
Packaging & Shipping	3 Dock Door Portals	$130.00	12	$1,560.00
Others	2 Vehicle Mounted	$130.00	4	$520.00
Subtotal				$2,600.00
Cables	RP-TNC Male to RP-TNC Male (35ft)			
Receiving	1 Dock Door Portal	$110.00	4	$440.00
Picking		$110.00	0	$0.00
Packaging & Shipping	3 Dock Door Portals	$110.00	12	$1,320.00
Others	2 Vehicle Mounted	$110.00	4	$440.00
Subtotal				$2,200.00
Handheld Reader Kits	Circularly Polarized (15ft Read range)			
Receiving	Every material handler	$3,400.00	5	$17,000.00
Picking		$3,400.00	0	$0.00
Packaging & Shipping	Every packing station	$3,400.00	9	$30,600.00
Others	Inventory Analyst for NILs & Cycle Counts	$3,400.00	1	$3,400.00
Subtotal				$51,000.00
Tag				
Mechanical Mounts	Antenna specific			
Receiving	1 Dock Door Portal	$30.00	4	$120.00
Picking		$30.00	0	$0.00

Packaging & Shipping	3 Dock Door Portals	$30.00	12	$360.00
Others	2 Vehicle Mounted	$30.00	4	$120.00
Subtotal				$600.00
RFID Label Printers				
Receiving	Additional labelling for incoming shipment	$3,450.00	1	$3,450.00
Picking		$3,450.00	0	$0.00
Packaging & Shipping	RFID Shipping Labels	$3,450.00	9	$31,050.00
Others		$3,450.00	0	$0.00
Subtotal				$34,500.00
TOTAL HARDWARE				**$100,500.00**
Hardware Maintenance (@10%)				**$10,050.00**

7.4.3 Software

Software is one of the other major non-recurring costs in RFID implementation. It's subject to more variation than hardware and entirely dependent on the needs of the organization and the integration requirements. The estimates given below (Table 7-10) correspond to the various needs identified in Harlalka's work [2]. It should be noted that the selected middleware is available for free but there could be additional cost in developing a .NET based application for use. In addition to that, the WMS Integration Module would be an organization-wide expense and only a part of the total cost of implementation would be borne by GDC, making it difficult to estimate. Maintenance estimates have been taken in accordance with the literature available [15].

Table 7-10. Costs: Software

Head	Remarks	Unit Cost	Quantity	Cost
Middleware	ItemTest (Free + .NET Framework based - Easy Integration)			$20,000.00
WMS Integration Module	Organization-wide expense			$150,000.00
Printer Software	RFID Shipping Labels	$260.00	10	$2,600.00
TOTAL SOFTWARE				**$172,600.00**
Software Maintenance (@15%)				**$25,890.00**

7.4.4 Service

Standard estimates for hardware installation and software integration have been assumed for the cost of service required. These costs are subject to depend on the level of integration ultimately required (Table 7-11). It should be noted that these costs are highly variable and could be curtailed if an Auto-ID module is purchased as a part of the complete WMS. For instance, integration with SAP Auto-ID is seamless as per Harlalka's work [2].

Table 7-11. Costs: Service

Head	Remarks	Unit Cost	Quantity	Cost
Hardware Installation	(@20% Hardware cost)			$20,100.00
Software Integration				$70,000.00
TOTAL SERVICE				**$90,100.00**

7.4.5 Training

Material handlers would need training for adapting to the modifications in their standard operating procedure. The training for helping the staff adapt to new RFID-based systems would be provided by specialized trainers or hardware/software installation companies. Standard estimates for the training time required and the personnel involved have been included to calculate the costs for training (Table 7-12).

Table 7-12. Costs: Training

Head	Remarks	Unit Cost	Quantity	Cost
Labor Training	10 hours for 19 Material Handlers	$20.00	190	$3,800.00
Training Personnel	2 sessions for 10 hours each	$50.00	20	$1,000.00
TOTAL TRAINING				**$4,800.00**

7.4.6 Miscellaneous

One of the major recurring costs in this specific model of implementation would require the replacement of existing shipping labels with RFID enabled labels that contribute to tag hierarchy for shipping and ensure accurate outgoing shipments. The total miscellaneous costs for a year are given below (Table 7-13).

Table 7-13. Costs: Miscellaneous

Head	Remarks	Unit Cost	Quantity	Cost
RFID Shipping Labels	Pack of 500	$75.00	320	$24,000.00
Printer Resin	Pack of 12	$330.00	2	$660.00
TOTAL MISCELLANEOUS				**$24,660.00**

7.5 Cost-benefit Analysis: Summary

Given below is a summary of the specific costs and benefits as listed above (Table 7-14). They have been calculated for the first year by using the data from Q1 and Q2 of 2018 and scaling it up with the annual seasonal factor as mentioned earlier.

Table 7-14. Cost-benefit Summary

COSTS	
Non-Recurring Costs	
Hardware	
Readers	$9,600.00
Antennas	$2,600.00
Cables	$2,200.00
Handheld Reader Kits	$51,000.00
Mechanical Mounts	$600.00
RFID Label Printers	$34,500.00
Total Hardware Cost	**$100,500.00**
Software/IT	
Middleware	$20,000.00
WMS RFID Integration Module	$150,000.00
Printer Software	$2,600.00
Total Software Cost	**$172,600.00**
Service	
Hardware Installation	$20,100.00
Software Integration	$70,000.00
Total Service	**$90,100.00**
Training	
Labor under Training	$3,800.00
Training Personnel	$1,000.00

Total Training	**$4,800.00**
Total Non-Recurring Costs	**$368,000.00**

Recurring Costs	
Miscellaneous	
RFID Shipping Labels	$24,000.00
Printer Resin	$660.00
Total Miscellaneous	**$24,660.00**
Maintenance	
Hardware	$10,050.00
Software	$25,890.00
Total Maintenance	**$35,940.00**
Tags	Organization-wide Expense
Total Recurring Costs	**$60,600.00**

TOTAL ESTIMATED COSTS (Annual)	**$428,600.00**

BENEFITS

Cost Reduction	
Labor Cost	
Receiving	$69,533.39
Picking	$0.00
Packaging & Shipping	$26,817.57
Inventory Cycle Counts	$6,480.00
Resolution of NILs/FILs	$7,020.00
Handling Incorrect Shipments	$13,721.59
Total Savings in Labor Costs	**$123,572.55**
Shipment	
Handling Incorrect Shipments	$8,352.94
Total Savings in Shipment Costs	**$8,352.94**
Total Cost Reduction	**$131,925.49**

Inventory Lost	
Total Reduction in Lost Inventory	**$54,816.68**

Additional Revenue	
Total Estimated Additional Revenue	**$87,190.43**

TOTAL ESTIMATED BENEFITS (Annual)	**$273,932.60**

From the summary of the cost-benefit analysis, it is clear that the total estimated costs outweigh the benefits for the first year. This is because the first year of implementation would require significant investment in infrastructure. To consider the benefits and costs for a longer duration (recommended for such a project), Net Present Value (NPV) needs to be estimated.

7.6 Net Present Value (NPV)

Net present value (NPV) can be defined as the difference between the present value of cash inflows and the present value of cash outflows over a period of time [29]. It is used in capital budgeting for estimating the ROI and the economic viability of a project. It has been cited as the most used tool by financial analysts for its consideration of the time value of money and its ability to provide a single number for comparison against alternatives [30].

Given the full-scale implementation roadmap, the costs and benefits were calculated as above and were used towards NPV estimates for the next 5 years. For the cost reduction, as most of it stems from the volume of deliveries, they have been assumed to be growing with Average Annual Growth Rate (AAGR) of 5% based on industry trends. Non-recurring costs and maintenance costs have been assumed to be constant for the next 5 years and the cost of shipping labels has been assumed to be growing with the assumed AAGR. In addition to it, a standard discount rate of 5% was used in the calculations.

NPV for the project was estimated to be around $680,934.79 pointing towards the fact the benefits of RFID implementation outweigh the costs (Table 7-15). Although, a positive indicator towards the investment, it should be noted that it doesn't include the cost of tagging. It certainly proves that RFID can be a worthy investment for Waters to streamline their business operations and should be considered more closely.

Discount Rate	5.00%
Average Annual Growth Rate	5.00%

Quantitative Analysis	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
BENEFITS						
Cost Reduction	$131,925.49	$138,521.77	$145,447.86	$152,720.25	$160,356.26	$728,971.62
Reduction in Lost Inventory	$54,816.68	$57,557.51	$60,435.39	$63,457.16	$66,630.01	$302,896.75
Additional Revenue	$87,190.43	$91,549.95	$96,127.45	$100,933.82	$105,980.51	$481,782.15
Other	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total Benefits	**$273,932.60**	**$287,629.23**	**$302,010.69**	**$317,111.22**	**$332,966.79**	**$1,513,650.53**
COSTS						
Non-Recurring	$368,000.00	$0.00	$0.00	$0.00	$0.00	$368,000.00
Recurring	$60,600.00	$61,833.00	$63,127.65	$64,487.03	$65,914.38	$315,962.07
Total Costs	**$428,600.00**	**$61,833.00**	**$63,127.65**	**$64,487.03**	**$65,914.38**	$683,962.07
Net Benefit or Cost	**-$154,667.40**	**$225,796.23**	**$238,883.04**	**$252,624.19**	**$267,052.40**	$829,688.46
Present Value of Total Benefits:						$1,304,440.94
Present Value of Total Costs:						$623,506.15
Net Present Value						**$680,934.79**

Table 7-15. Net Present Value (NPV) for RFID Implementation

7.7 Sensitivity Analysis

In the above analysis, a realistic scenario with certain assumptions pertaining to costs, cost savings, additional revenues and reduction in inventory lost have been considered to estimate NPV. However, in line with most of literature, it's known that there is a reasonable level of uncertainty associated with the quantifiable benefits of RFID. This inherent uncertainty warrants a sensitivity analysis of NPV.

There are a number of assumptions in the model which wouldn't be subject to drastic changes, especially the numbers pertaining to cost reduction in warehousing operations. The cost reduction in receiving of over 20% would be attributed to the introduction of bulk scanning in the process (as described in section 6.1.1). Similarly, the time savings in picking (3%) are a direct result of automating the pick-verify transaction in SAP. And as explained earlier, automating the inventory cycle counts by using reader-antenna bundle mounts on forklifts and handheld readers for material handlers would lead to time savings of around 80% of the total time spent on the activity.

It should be noted that there's not enough literature available to derive the estimates for quantifying benefits in Waters' operations directly. The estimates used in this study assume that a full-fledged implementation of the RFID system would be undertaken. This implies that there are RFID portals at both receiving and shipping, in turn, closing the loop for scanning shipments at GDC. An automated RFID-based closed loop inventory management system would certainly increase system inventory accuracy. The estimates also stem from high read rates recorded in pilot implementation at GDC (100% [2]) and other earlier applications of RFID. For one of the estimates, the realistic scenario assumes that the number of Not-in-Location (NIL) products attributed to picking error would reduce by 30% resulting in additional revenue. However, during the knowledge transfer session, the Waters team indicated that these numbers might vary in practice, from 20% to 40%. This uncertainty could be avoided by getting better data pertaining to re-ordering of the parts which were recorded as NILs earlier. Due to unavailability of high-resolution data, it couldn't be estimated with certainty. Moreover, the realistic scenario assumes that the lost inventory would reduce by 70%. However, in reality, reduction in lost inventory could also vary from 60% to 80%. These assumptions have also been outlined in the relevant "Proposed Future State" sections for all warehousing operations.

To account for this inherent uncertainty in quantifiable benefits, a sensitivity analysis for NPV is conducted. It is believed that such an analysis would aid the decision-makers at Waters while taking a decision about RFID implementation. It considered three distinct scenarios – conservative, realistic, and optimistic. Some of the parameters–time reduction in receiving, picking, and inventory cycle counts–have been assumed constant based on the above discussion. The variable parameters for the different scenarios have been listed below (Table 7-16).

Table 7-16. Parameters' Estimates for Sensitivity Analysis

	Conservative	Realistic	Optimistic
Additional Revenue due to reduction "picking" NILs	20%	30%	40%
Reduction in Total NILs	55%	65%	75%
Reduction in Incorrect Shipments	60%	70%	80%
Reduction in Lost Inventory	60%	70%	80%

Additionally, NPV for a specific scenario is dependent on the AAGR estimates as well. To account for the uncertainty in demand, a precedent of AAGR, the sensitivity analysis also considers three values for AAGR – 2.5%, 5%, and 7.5%.

Table 7-17. Sensitivity Analysis for NPV

Scenario / **AAGR**	**Conservative**	**Realistic**	**Optimistic**
2.50%	$444,417.66	$625,740.27	$807,062.88
5%	$490,769.76	$680,934.79	$871,099.83
7.50%	$539,382.41	$738,821.11	$938,259.81

The results shown in Table 7-17 indicate that the RFID implementation would yield a positive NPV in all of the scenarios considered above. As mentioned earlier, these NPV estimates don't include the cost of tagging or tags. The author recommends that a more detailed sensitivity analysis should be conducted by considering the costs and benefits over the entire value chain. This detailed analysis could employ sophisticated tools like the crystal ball add-in for MS Excel, which is a spreadsheet application for predictive modeling, simulation and forecasting. It has been used by researchers to estimate the NPV for RFID implementation by conducting a similar but more extensive scenario analysis [26].

CHAPTER 8

CONCLUSION & RECOMMENDATIONS

This chapter summarizes the results of the operational analysis for the inventory location optimization algorithm and RFID implementation. It also includes a set of recommendations for Waters to enhance the scope of the analysis and move forward with the projects.

8.1 Conclusion

8.1.1 Inventory Location Optimization Algorithm

The cost assignment procedure was successful in assigning discrete movement costs for storage locations for the high bay area in GDC. It should be noted that the procedure has been customized by observing the standard operating procedure and conducting time studies in the high bay area only. Due to this customization, the cost assignment tool in its present form is not scalable or applicable to other areas within the GDC. However, the basic methodology for the tool's development is in line with the needs of the inventory location optimization algorithm and could be referred to for future work.

Extensive development of the tool could yield better results, but even with the current cost assignments, simulations have indicated a promising reduction of 5% in walking time [1]. This could translate to savings of more than 600 hours in picking time annually. Moreover, if the inventory location optimization algorithm is updated with data for all storage locations and SKUs, it could inform the receivers of the optimal storage location during put-away. This improvement could potentially save 14% of the total time spent in receiving for incoming shipment assigned to "default" locations. In addition to this, it's worth mentioning that all these improvements come at a negligible cost to the company given that it doesn't require additional capital expenditure and the basic framework has already been developed as a part of this pilot.

8.1.2 RFID Implementation

The incorporation of RFID in the existing processes at GDC would result in significant time savings by automating their non-value adding components. In receiving, installation of dock-door portals for bulk scanning and handheld readers assisting during put-away could save more than 20% of the time spent while enhancing the accuracy. The time saved in packaging and shipping is less significant (3%) than the huge impact it can have on the accuracy of outgoing shipments. RFID would ease the inventory cycle counts by saving over 80% of the time spent currently which could translate to more frequent cycle counts and thus, better inventory accuracy. It is believed that altering these warehousing operations could result in indirect time savings in other activities such as handling NILs and incorrect shipments by the staff in GDC. However, significant investment in infrastructure upgrades would be required to reap these benefits.

One of these major investments would involve inclusion of tagging and EPC in Waters' supply chain. While tagging would only require Waters and subsidiaries to switch to RFID-encoded labels, EPC would overhaul the current identification systems to unique identification numbers and lead to setting up of multiple databases. These measures could, in turn, provide track & trace capability and the much-needed visibility in product inventory. From the NPV estimates and the associated sensitivity analysis, it can be concluded that RFID implementation would yield positive returns for GDC.

The quantifiable benefits outweigh the implementation costs of RFID, but the most important benefits for Waters are certainly strategic in nature. The market is evolving and so are the customer requirements, top-notch performance can no longer be the sole product differentiator in these times. It was found that the competitors have already embraced the technology and are passing on the benefits to the end customer. Additional value for the consumer ranges from asset management to tracking shelf-life of consumables. It's important that Waters started considering the impact of RFID on not just logistics but all other aspects of its business as well.

8.2 Recommendations & Future Work

The strategic roadmap outlined four key themes of relevance to initiate transformation at Waters. These ideas were handpicked from a list of potential ideas which was prepared during the visits to different departments. In addition to executing the ideas presented, the author recommends that internal process improvement teams revisit some of these business processes to understand the gaps between the present state and industry benchmarks. This should be followed by use of technology or systematic change to bridge them. For instance, most manufacturing facilities of Toyota have a *kaizen* cell which solely works on process improvement technologies.

8.2.1 Inventory Location Optimization Algorithm

As mentioned earlier, the major benefit from the algorithm can be achieved upon the inclusion of the shelving aisles within its scope. The cost-assignment tool should be updated by observing the nuances in picking operation for the SKUs placed in that area. In addition to the required updates to the tool, data for the volumetric capacity of various storage locations would be essential for the success of the algorithm. It's also recommended that the team at GDC consider investing in a cargo scanner to determine the dimensional weight of various SKUs. The placement algorithm would yield better results as the resolution of data increases. Moreover, the inclusion of receiving trips would require the relative frequency of picking and receiving which could also be calculated from the past order data available. Most importantly, the current solution doesn't include the effect of batch-picking, it is essential to extend these fundamental approaches and devise a methodology to include the effect of the same.

8.2.2 RFID Implementation

Assimilating RFID technology into the value chain at Waters would be a giant leap – both in terms of product architecture and logistics. It would result in the generation of large amounts of quality data that could potentially unearth existing inefficiencies within the system. Firstly, it is recommended that evaluating RFID be taken up as a company-wide initiative which involves resources from all departments to understand the pitfalls and benefits of the technology. Isolating GDC for its evaluation could lead to erroneous decisions given the intricacies involving tagging of all the products. The next step would be to quantify the additional value from its implementation and estimate the costs pertaining to systemic overhaul. The Net Present Value (NPV) estimates for the entire system would be extremely beneficial in taking a better decision pertaining to implementation. This would also require additional tests on technical feasibility since the scope of the current pilot involved a small set of business operations with a single SKU.

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