Visual Sort Marker Digitization in Sort Center Operations

by

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BS Industrial Engineering
Instituto Tecnológico de Veracruz, 2008

Submitted to the MIT Sloan School of Management and
the MIT Department of Civil and Environmental Engineering
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Abstract

Companies worldwide recognize the importance of sustainability and are looking for ways to incorporate sustainable practices into their operations. Companies are looking to become more sustainable by reducing their carbon footprint. It can be done through various means, such as investing in renewable energy sources, implementing energy efficiency measures, and reducing the use of non-renewable resources. Another way companies are looking to become more sustainable is by being more responsible in their supply chain, ensuring that their materials and products are ethically and sustainably sourced, for example.

With the growing awareness of the environmental impact of businesses, consumers are increasingly looking for companies that prioritize sustainability. Amazon, the world's largest online retailer, has announced its commitment to becoming more sustainable. This decision addresses the pressing issue of climate change and reduces the company's environmental footprint. By committing to sustainable practices, Amazon can attract and retain customers who value environmentally friendly products and services. In addition, Amazon's investment in sustainable practices can lead to cost savings in the long run.

One of the many sustainable strategies Amazon is working on is the Small Shipping Label (SSL). This initiative aims to reduce the shipping label size and has a potential entitlement of ~$1 billion per year. Smaller labels facilitate the use of smaller shipping boxes, which ultimately reduces the overall amount of packaging materials required. This reduction in packaging materials, in turn, contributes to a decrease in the carbon footprint associated with transportation. Smaller boxes translate as optimized truck space, since more packages can be shipped in a single trip. As a result, the number of trucks or planes required for delivery is reduced, reducing associated fuel consumption and emissions. SSL implementation requires the removal of a physical Visual Sort Marker (VSM) from the package label. One of the critical manual processes in Middle-Mile operations (Sort Slide) currently relies on physical VSMs to inform sortation decision-making at the package level. Amazon is working towards removing physical VSMs while mitigating any risks to Throughput Per Hour (TPH) and Delivery Estimate Accuracy (DEA). Manual dependencies limit inflight shipment replanning to handle events such as missorts, unpredictable weather conditions, truck breakdowns, etc. Elimination of reliance on physical VSMs will provide the ability to decrease packaging waste, allowing for shipping items in packages smaller than the current 4x6 shipping label, bringing savings on packaging and transportation costs, and aligning with The Climate Pledge.

This thesis looks into the operational challenges of implementing sustainable practices by assessing the trade-offs between sustainability vs. productivity. Its objective is to determine the effect of the short-term proposed solution for VSM removal in the Sort Center network. Specifically in the Sort Slide process capacity and utilization. The present analysis suggests that accepting a modestly degraded process rate may be a viable trade-off if it helps an organization achieve its sustainability goals and ensure the long-term viability of its financial growth.

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Finally, and most importantly, I would like to dedicate this work to my Aunt Luz. Thank you for pushing me forward to do more than I thought I could.

Note on Proprietary Information

In the interest of protecting Amazon's competitive and proprietary information, figures and processes presented throughout this thesis are used solely for the purpose of illustration. The data presented throughout this thesis has been modified and does not represent actual values. Data labels have been altered, converted or removed in order to protect competitive information, while still conveying the findings of this project.

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Introduction

The following thesis is based on a six-month internship conducted at different Amazon locations throughout the United States from February 2022 to August 2022. The internship and the following thesis are requirements for the Leaders of Global Operations program at the Massachusetts Institute of Technology.

This research aims to assess the feasibility of Amazon's proposed solutions for label dependency in manual sort centers and to facilitate the implementation of the Small Shipping Label program. This thesis studies explicitly how the addition of technology to the sorting process affects the network operations and evaluates the potential for process improvement through statistical process control and capability analysis. Feasibility is then determined by the effect of said solutions on the network's performance and its respective financial impact vs. the potential long-term benefits of the Small Shipping Label program.

This document is divided into five key sections. Chapter I offers an overview of the company and provides background for its decision to explore strategies to make its operations more sustainable and environmentally friendly. It introduces the specific sustainability program that started this research and its impact across organizations.

Chapter II focuses on the sorting process in non-automated sort centers. It highlights the macro level end-to-end shipping process map and offers more detail about the core part of this research, the Sort Slide Diverter Process, and its dependencies on the current process.

Chapter III introduces the baseline model, and the methodology followed for its construction, providing a starting point for the analysis. The company's proposed solutions for the sustainability strategy implementation in manual sort centers are discussed in this chapter. Their respective requirements, operational and financial impact, and test results. This section includes quantitative analysis and individual business models for each solution.

Chapter IV reports the key findings and recommendations for the company when designing and implementing new solutions in their non-automated sort centers.

Finally, Chapter V provides key information from research and publications in the form of a literature review, discussing subjects relevant to the future state of the supply chain industry as well as the methodology applied in this thesis.

Chapter I Background

1.1 Company Overview

Amazon is a multinational technology company based in Seattle, Washington. It was founded in 1994, and since then, it has expanded rapidly in its quest to be Earth's most customer-centric company. The company is best known for its online retail (e-commerce) platform, which offers various products, from books and electronics to clothing and household items.

Amazon has grown significantly since its inception and now operates in many different industries, including cloud computing, digital streaming, and artificial intelligence. By providing competitive prices, a vast selection of items, and convenient shopping options, the company continues to expand and improve as a leading e-commerce platform with over $386 billion in annual sales in 2020[1].

Fig 1. Amazon's Customer Centric "Virtuous Cycle"

One critical factor driving Amazon's growth is its focus on customer satisfaction [2]. Figure 1 illustrates how Amazon's business model is built on multiple reinforcing loops. The customer experience is at the heart of these loops, driving the company's growth. When customers have a positive experience, it leads to increased traffic on the website, attracting more vendors and sellers, and therefore expands the range of products available on the platform. The augmented assortment of products, in turn, leads to more sales, creating a better customer experience. The increased scale also allows the company to offer lower prices, further improving customer experience. This process creates a self-reinforcing cycle, which is the foundation of Amazon's business model.

Figure 1 does not show the negative feedback loops that could impede the company's growth, like the company's size and market dominance, for example, which can lead to reduced competition and less innovation. Another possible negative feedback loop could be its focus on price and convenience, potentially leading to a "race to the bottom" in terms of pricing, which can negatively impact seller profitability and lead to a reduction in the quality of products and services offered. However, Amazon has invested heavily in logistics and distribution infrastructure, allowing it to offer fast and reliable delivery to customers worldwide. With solid expertise in these areas, it would be easier for the company to sustain its rapid growth and maintain high-quality standards for fulfilling customer orders.

The company's emphasis on customer satisfaction, innovation, and expansion into new markets has helped to make it an influential player in the technology industry [3]. Though Amazon's growth in logistics may not be as widely acknowledged as its digital marketplace, the company has made significant investments to allow its logistics segment to compete with industry leaders such as FedEx and UPS, having already grown its fulfillment and logistics network by 50% in 2020 (compared to the prior year) [4]. In Georgia alone, for example, Amazon has a significant presence, with over 30 fulfillment and sortation centers, nine delivery stations, a tech hub, an air gateway, Amazon Hub lockers, and 12 Whole Foods Market locations [5]. Figure 2 illustrates the fivefold growth in the number of Amazon buildings (including fulfillment and delivery-focused facilities) between 2017 and 2022 in the United States alone [6].

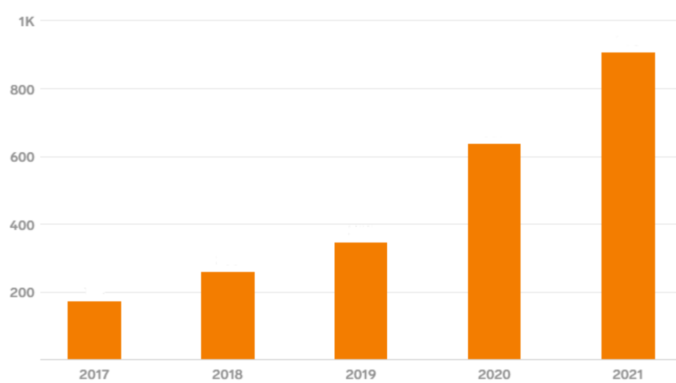

Fig 2. Number of Amazon buildings 2017-2021

Amazon's growth in the logistics field is not relegated to warehouses and floor spaces only. The company has also invested significantly in its transportation, electrifying its delivery vehicles with an order of 100,000 Rivian vans [7]. Furthermore, Amazon has rapidly expanded its air fleet, doubling its number of planes in the last couple of years, and now operates over 110 jets in its Global Amazon Air fleet [8].

1.2 Amazon's Supply Chain Networks

Amazon's logistics system utilizes a network of specialized facilities for processing and packaging orders, sorting large volumes of parcels by destination, and preparing shipments for final delivery routes. This fast expansion is a result of both horizontal[1] and vertical[2] integration, which demonstrates Amazon's extensive control over logistics and allows it to meet customer demand for faster deliveries while also offering a wide range of products [9]. Through horizontal integration, Amazon expands market coverage and reduces lead time. Through vertical integration, Amazon controls the distribution flows and channels, managing how the packages are routed across its facilities, including final delivery to the customer and offering third[3] and fourth-party[4] logistics services [11].

The company's supply chain logistics network is divided into three primary levels: Fulfillment (First Mile), Sortation (Middle Mile), and Delivery (Last Mile), as shown in Figure 3.

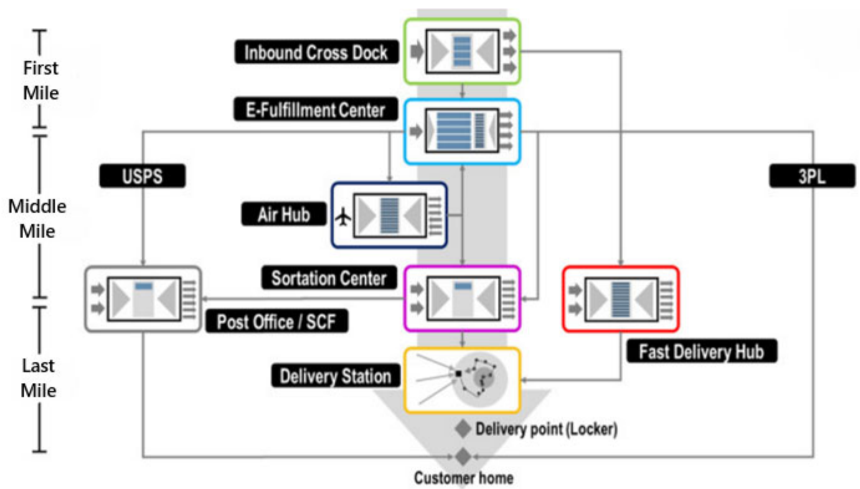

Fig 3. Amazon's First, Middle and Last Mile

[1] **Horizontal integration**. The expansion on the same level of the value chain. It's about increasing market share, possibly through mergers and acquisitions.

[2] **Vertical integration** is the combination of different links in the value chain, from raw materials to the consumer. Companies with a high degree of vertical integration control almost every part of their value chain.

[3] **Third-party logistics (3PL).** Refers to the use of third-party providers to handle the logistics of a manufacturer's goods, such as storage, delivery, distribution, and order returns.

[4] **Fourth-party logistics (4PL).** Operational model in which a business outsources its entire supply chain management and logistics to one external service provider [10].

First Mile involves procurement, primarily stocking fulfillment centers with inventory. The extensive range of goods sold by Amazon and products offered under its brand underlines multiple suppliers, origins, and transportation modes used for inbound deliveries to the fulfillment centers.

Fulfillment Centers (FC) are extensive facilities where customer orders are picked, packed, and shipped. Recently, many FCs have become partially or fully automated for more efficient retrieval and packaging of orders [12]. FCs are typically divided into handling sortable (items that fit in a box) and non-sortable goods (items too large for a box) because different item sizes require different warehouse handling equipment. Sortable warehouses can more easily be automated with conveyor belts, while non-sortable items require more complex handling [13].

Middle Mile involves the distribution of packaged orders from the FC to facilities near the final delivery point (delivery stations). Packages are transported from fulfillment centers to Amazon's sort centers (SC) via Amazon's freight and air networks. SCs sort packages by regional destination and arrange them in smaller batches, such as by postal code [14]. From the SC, items can be sent to parcel delivery stations for last-mile delivery, or given to third-party delivery companies (like UPS and the US Postal Service) who then use their networks to deliver the parcel to the customers.

The final step in the supply chain is the Last Mile, which involves delivering packages to their final destination, typically through delivery routes from specialized facilities. Within the Amazon supply chain network, packages move from fulfillment centers to sort centers, which aggregate shipments from multiple FCs, and then to delivery stations, where vans are loaded for "last mile" delivery to customers [15].

Unlike many retailers and shipping companies, Amazon has created its last-mile delivery services by building its own freight and parcel delivery network, expanding into ocean freight, leasing aircraft, and establishing an air cargo hub [16]. Additionally, Amazon has built a Delivery Station (DS) network, whose primary role is to sort packages for outbound routes to enable last-mile delivery to customers within a specific urban area [17]. Deliveries are often performed by Amazon Delivery Service Partners, independent Amazon Flex[5] drivers, or contracted local courier companies [18].

[5] **Amazon Flex**. Amazon delivery program where independent drivers or contractors deliver Amazon orders using their vehicles.

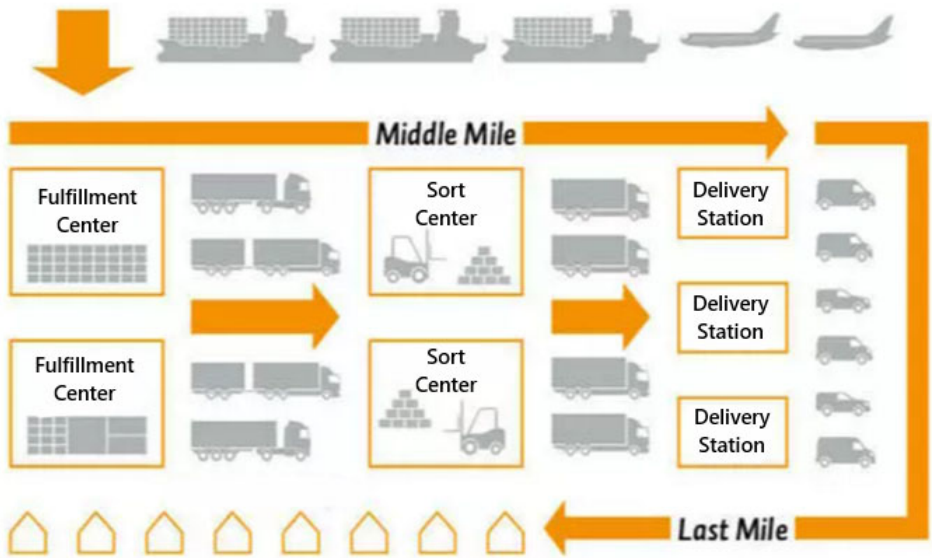

Fig 4. Amazon E2E Supply Chain Process

1.2.1 The Sort Center Network

Sort centers make Amazon's delivery system even more complex by utilizing algorithms to determine the most efficient way to get orders, often containing multiple items from different FCs, to customers [12]. This research takes place in the sort center (SC) network, a crucial part of Amazon's Middle Mile operations. Each sort center receives packages from nearby fulfillment centers, sorts these packages by destination, and then transports the sorted packages to Amazon's Last Mile delivery stations or to third party carriers for customer delivery.

The SC Network was introduced in the US in 2014 to establish a distribution structure that offered capacity, flexibility, and time performance by selecting the most appropriate distribution channels and focusing on where orders will be fulfilled and the routing of the delivery [19]. SCs rely on cross-docking operations, where inbound shipments arrive on one end and outbound shipments exit on the other. Furthermore, depending on the online retailer's strategy, they can act as FCs, particularly for goods in high and regular demand. SCs tend to be closer to cities than FC, maximizing accessibility to a metropolitan distribution system.

The primary role of the sort center is to aggregate shipments from multiple fulfillment centers where the shipments are destined to be delivered by a grouping of zip codes within a defined market region around the sort center [20]. As shipments arrive, packages are unloaded onto conveyor belts to be sorted into zip code ranges so they can be shipped to delivery stations or third parties. The process output is a set of sorted pallets holding packages destined to be delivered to specific zip codes. These pallets are then delivered to a third party or to an Amazon Logistics delivery station (AMZL, Amazon's own Last Mile delivery network).

Sort centers are essential in accessibility to regional distribution and represent the first layer of city logistics. From these centers, packages are either sent to delivery stations or to post offices for final delivery. When an area reaches a specific volume of parcel deliveries, Amazon is likely to utilize an SC, breaking loads bound to particular zip codes and transforming LTLs[6] into FTLs[7].

The primary benefits of the sort center network [21] are :

- Increases the speed to market for shipments and potentially reduces the order cycle time by a day or more.
- Reduces shipping costs relative to the traditional approach of relying on third-party couriers to deliver the package. For example, fulfillment centers can now deliver parcels to local customers without the involvement of UPS and FedEx, which eliminates their sortation and delivery cost.
- Is a key enabler for same-day or next-day delivery by providing a separate infrastructure dedicated to efficiently preparing outbound routes and logistical operations. It becomes the consolidation hub that offers the volume and synergy to construct efficient last-mile delivery operations.
- Transfers the control of the outbound transportation function away from third-party courier companies and back to Amazon, allowing for a substantial competitive advantage.

[6] **Less than truckload** (LTL). Refers to the transportation of products or goods that do not require a full truckload. These smaller freight loads typically result in many separate shipments being transported on one truck.

[7] **Full Truckload (FTL).** Refers to a shipping mode whereby a truck carries one dedicated shipment.

1.3 The Evolution of Supply Chain Technologies

The proliferation of digital technologies has significantly altered the consumer experience regarding product research, decision-making, buying, and delivery. As consumer preferences evolve, so do the demands of customers, leading to a dramatic shift in the expectations for order fulfillment [22]. To remain competitive, companies must now offer a broader range of products and ensure prompt, precise fulfillment of orders.

The supply network of the future is evolving from a linear flow of goods "from factories to distribution centers to stores" to a more complex network of interconnected facilities. Said network includes stores, distribution centers, and click-and-collect points. This increase in complexity presents opportunities for retailers that can integrate channels efficiently while penalizing those that cannot.

A popular method companies use to adapt to changing market conditions is the implementation of automated technology systems. Solutions can range from robotic stock picking to software that maximizes space utilization. For example, retrofitting an existing facility with robotic material handling hardware and software can optimize material flow, increase efficiency, and better utilize existing space without the need for relocation.

One aspect of the evolution of Supply Chains is the increasing use of "Big Data"[8] [23] and related technology to gain a more comprehensive understanding of the precise location of individual stock items [24]. By utilizing detailed data analysis to pinpoint supply chain inefficiencies, Big Data can generate efficiencies by accurately measuring costs at each stage of the supply chain. For example, using data to forecast inventory requirements and associated space needs throughout the network.

The e-commerce industry is moving towards a high-tech revolution as demands and delivery expectations continue to increase [25]. Using improved data and integrating E2E processes allows companies like Amazon to adapt to changes in demand fluctuations quickly. In recent years, the company has invested in automation and forward-thinking systems within its warehouses and throughout its network, creating the necessary conditions for Amazon to operate in a digital business ecosystem that enhances its ability to predict, withstand, and quickly respond to any supply chain disruptions.

[8] **Big Data**. Data that is so large, fast, or complex that it's difficult or impossible to process using traditional methods.

Amazon's Supply Chain is known for its innovation and continues advancing its technology and capabilities. The company's network has developed into an entirely Digital Supply Chain[9] [26], designed to be adaptable to future changes in technology and services, allowing for data mining from its processes and utilizing the equipment to generate the necessary data [27]. It improves efficiency in picking, packing, and shipping orders [28] and has a wide range of applications throughout its entire network. Its technology allows for operational support decisions and master plans for seasonal capacity preparations or transport scheduling that impact network flows. For instance, footprint assessments to determine the best locations for new production, storage, or cross-docking sites. Amazon also relies on its network data to perform stress testing to understand better the implications of accelerated growth in demand or supply disruptions; or to design and simulate continuous improvements and incremental network changes, such as assessing the impact of faster transit times for certain connections, later cut-offs for next-day delivery or different transport modes [29].

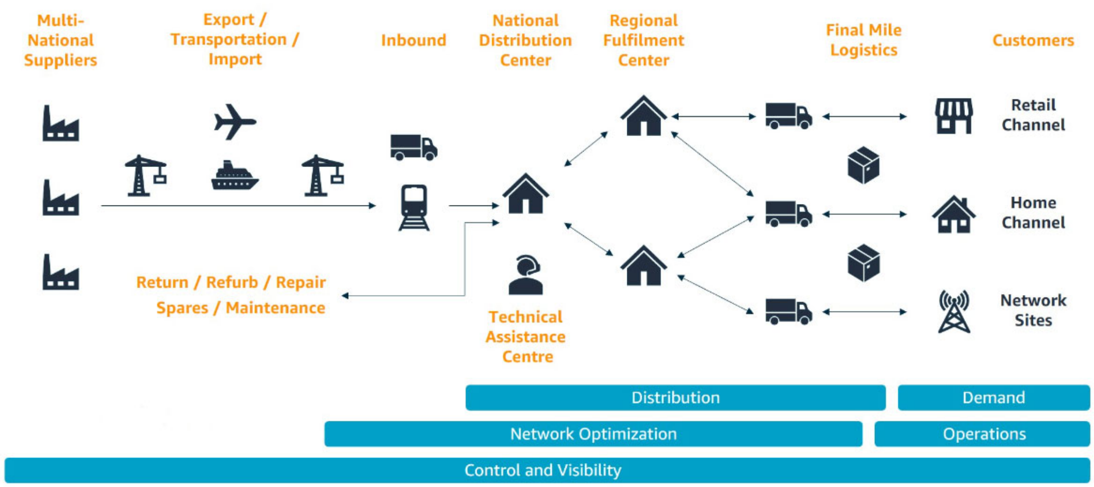

Fig 5. Supply Chain areas where data driven solutions apply, as published by AWS [27]

[9] **Digital Supply Chain**. A set of processes that use advanced technologies and better insights into the functions of each stakeholder along the chain to let each participant make better decisions about the sources of materials they need, the demand for their products and all of the relationship in between [26].

1.4 E-Commerce Sustainability & The Climate Pledge

A study of the US market by sustainable investment firm Generation found that e-commerce is 17% more carbon efficient than traditional retail. However, this conclusion is based on certain assumptions, such as the number of items purchased in a single visit, the amount of packaging, and the efficiency of last-mile delivery. These assumptions could change the results if altered, highlighting the need for continued analysis and monitoring of the carbon impact of e-commerce.

The United Nations reports that the entire supply chain of consumer goods, including extraction, production, and disposal, accounts for half of the global carbon emissions [30]. With worldwide materials use projected to double in the coming decades, businesses of all sizes may face financial losses if operating costs rise due to increased greenhouse gas emissions. This potential increase in operational expenses highlights the need for companies to actively work towards reducing their carbon footprint and finding sustainable alternatives. Brands and retailers are at the center of these supply chains, and only recently have significant companies started to map and understand their carbon footprint. According to the National Retail Federation, nearly 40 top companies have either set science-based targets to reduce their carbon footprint in alignment with the Paris Agreement or pledged to do so. One example is Amazon, which co-founded The Climate Pledge in 2019 [31]. The pledge is a commitment to reach net-zero carbon emissions by 2040, 10 years ahead of the Paris Agreement, in response to the pressing need for urgent climate change action across every business sector.

The Climate Pledge aims to make Amazon's operations more efficient to achieve further financial and carbon performance benefits. Amazon's 2020 sustainability report shows the beginning of progress in this area: "While Amazon's business grew significantly in 2020 and our absolute carbon emissions increased 19% during the same period, our overall carbon intensity[10] decreased 16%" [32]. This is illustrated in figure 6, where carbon emissions and carbon intensity are measured in million metric tonnes of carbon dioxide equivalents[11] (mmt CO_2e) and grams of carbon dioxide equivalent, per dollar of gross merchandise sales (CO_2e/$ GMS) respectively.

[10] **Carbon intensity.** Measure of carbon dioxide and other greenhouse gases (CO_2e) per unit of activity.

[11] **Carbon dioxide equivalent (CO_2e)**. Metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential, by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential.

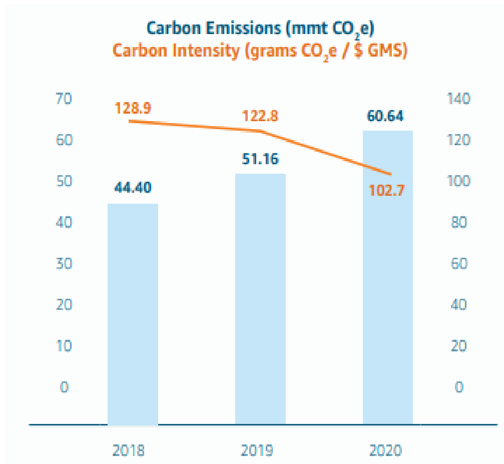

Fig 6. Amazon's Carbon Emissions Evolution as presented in the 2020 Sustainability Report

The Climate Pledge's large-scale decarbonization initiatives focus mostly in the following four areas [33]:

1. *Packaging:* Amazon is continuously working on developing innovative packaging solutions. Reducing the amount of packaging used and finding more sustainable materials are essential to achieving waste reduction targets. Strategies in this category are further explained in the next section due to their relevance in the program that started this research.

2. *Shipping:* With the increasing demand for customers' immediate satisfaction, it is crucial to find ways to reduce the impact of shipping. Strategies like Amazon Day Delivery, where multiple orders are combined in the same box whenever possible and then sent to be delivered to the customer on the selected day, allow for shipment consolidation for customers ordering multiple items. Consolidated shipments reduce the number of trips to the same delivery address and the number of boxes used to ship the items.

3. *Supply chain integration*. Through digital integration, Amazon has identified multiple opportunities to reduce waste and inefficiencies throughout its supply chain. Connecting all stakeholders, inputs, and information sources through a unified ERP system and powering savvier decision-making has been vital to decreasing its supply chain footprint. Initially used to improve customer experience, data management has also translated to more sustainable operations.

4. *Renewable energy*. Using renewable energy is central to Amazon's strategy to decarbonize its operations. The company is adopting alternative energy delivery solutions across its network. It has made significant investments in electrification, from the delivery vehicles to the charging infrastructure that powers them to the renewable energy projects that produce clean energy. Clean energy sources, such as wind and solar, reduce Amazon's reliance on fossil fuels to power its operations.

1.4.1 Packaging

The accelerated growth of Amazon's e-commerce operations has led to an increased usage of cardboard and other packaging materials, contributing to a significant environmental footprint. Ensuring that products are received in good condition can easily result in the use of excessive padding methods. Immediacy, where people buy many items one at a time instead of waiting for a larger order, also contributes to additional packaging waste. While packaging materials can be recycled, a 2018 study by the EPA[12] [34] found that about half of the almost 82,000 tons of containers and packaging generated in the US were recycled, with more than 30,000 tons ending up in landfills [33].

To further reduce its environmental impact and because packaging plays a crucial role in the customer delivery experience [35], committed to delivering products safely and sustainably, Amazon has been actively working towards making its operations more environmentally friendly. One of the ways it has made it possible is by reducing excess packaging. The company has made a 38% reduction in per-shipment packaging weight and eliminated more than 1.5 million tons of packaging through investments in materials, processes, and technologies since 2015.

By 2016, Amazon had eliminated 55,000 tons of produced waste by cutting down on the number of boxes used inside larger boxes. Additionally, the company is moving towards using 100% recycled packaging and has arranged for some suppliers to ship directly to consumers, bypassing the need for repackaging and transportation to and from Amazon distribution centers [36]. When additional packaging is necessary, Amazon strives to optimize it for increased recyclability, reduced waste, and lower carbon emissions. In the US, the company expanded the use of recyclable paper padded mailers, replacing nearly 70% of its mixed material bubble mailers in 2021.

[12] **EPA**. United States Environment Protection Agency. Its mission is to protect human health and the environment.

Figure 7 shows the entire range of fulfillment forms of packaging and its breakdown from 2021 shipments [35]. The company also changed its single-use plastic packaging, using less material and increasing recycled content. In 2021, the company increased the recycled content of its plastic film bags from 25% to 50% and that of its plastic padded bags from 15% to over 40% [37].

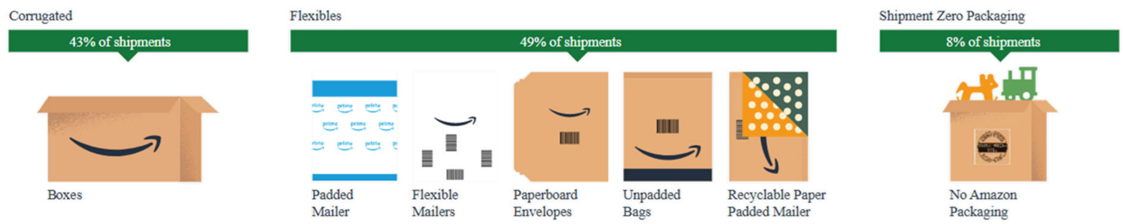

Fig 7 Amazon's Packaging Breakdown as reported in 2021

The Frustration-Free Packaging (FFP) program [35] is an example of the many packaging-related initiatives the company has invested in to reduce packaging waste. It is explicitly designed to serve customers, ease product liberation, and minimize waste by reinventing the packaging experience. It offers more sustainable packaging options that are easy to open, fully recyclable, and capable of shipping without additional packaging protection. In 2021, Amazon began working with its vendors, offering incentives encouraging them to adopt these best-in-class standards, converting their packaging to FFP. By the end of the year, more than 2 million products began operating under Amazon's FFP program.

1.5 Small Shipping Label Program

The current shipment labels used by Amazon and other carriers have two main drawbacks: a) The current shipping label requires every product to be shipped in a package larger than 4 "x6"; otherwise, the shipping label cannot be attached to the package, and b) The current shipping label contains static transportation plan information and any changes to the plan will require a re-label. The first inhibits Amazon's goal to be carbon neutral by 2040, as more than 30% of Amazon's shipping volume is comprised of products smaller than the 4 "x6" label. The second inhibits Amazon's Operational Performance goal of 100% on-time deliveries. Said obstruction happens because inflight shipments[13] might require a re-plan to handle multiple events, such as missorts or unpredictable weather conditions. Due to the presence of information printed on the physical label, a re-plan requires associates to sideline, re-plan, and re-label the packages, which results in additional operational and handling costs per package.

[13] **Inflight shipment.** An order that is in the process of being fulfilled.

The Small Shipping Label (SSL) program has the potential to solve both of these problems by introducing a standardized label format across all final delivery carriers (1P[14] or 3P[15]). This standard label consists of the customer name, customer address, and a universal barcode. Amazon and its 3P carrier partners will introduce process changes for their operations associates to receive processing information by scanning the barcode instead of reading the information on the labels. By eliminating most label fields, the label size can be reduced from 4"x6" to 2"x2" (shown in Figure 8 and Figure 9, respectively), resulting in a decreased need for packaging.

The current shipping label includes customers delivery data, as well as information related to the package's transportation plan like 3rd party delivery stations, AMZL nodes and sortation indicators. By printing this information on the shipping label, it remains static and would require a re-label process if re-routing was needed. Section 2.3 Visual Sort Marker Digitization elaborates on SSL's barcode allowing for up-to-date transportation plan information through the entire shipping process.

The Small Shipping Label (SSL) program presents an incredible effort to improve Amazon's carbon and material footprint (an estimated 500K MT of carbon footprint reduction annually). The utilization of smaller labels enables the utilization of correspondingly smaller shipping boxes, thereby leading to a reduction in the total amount of packaging materials required. This reduction, in turn, can contribute to a decrease in the carbon footprint attributed to transportation activities. The adoption of smaller boxes can allow for greater truck space utilization, facilitating the shipment of more packages within a single trip. Consequently, fewer trucks or planes are required, resulting in a reduction in the corresponding fuel consumption and associated emissions. Reducing shipment label size would also qualify a multitude of additional ASINs[16] as SIOC[17] (Ship In Own Container) eligible.

[14] **1P**. Orders delivered by Amazon.

[15] **3P**. Orders delivered by a third-party courier.

[16] **Amazon Standard Identification Number (ASIN).** Ten-digit alphanumeric code that identifies products on Amazon. !

[17] **Ships In Own Container (SIOC).** Form of product packaging in which a product ordered can be shipped to the customer in its original packaging, without any additional packaging required [38].

Fig 8. Proposed 2"x2" Small Shipping Label

Fig 9. Current 4"x 6"shipping label

Chapter II Problem Definition: Physical Label Dependencies

Implementing the Small Shipping Label program throughout all three levels of the Amazon Supply Chain Network requires changing processes to eliminate their dependence on the information contained in the printed label. This thesis focuses on the label dependencies in the Middle Mile, where the Sort Slide, a critical process in manual sort centers, prevents SSL implementation in the sort center network.

2.1 Sort Center E2E shipping process

Manual sort centers (locations without advanced/automatized conveyance where the sorting is done manually by associates) complete the sorting process using a Sort Slide Diverter. Figure 10 provides a simplified view of a manual sort center, highlighting the process path of a package free of defects.

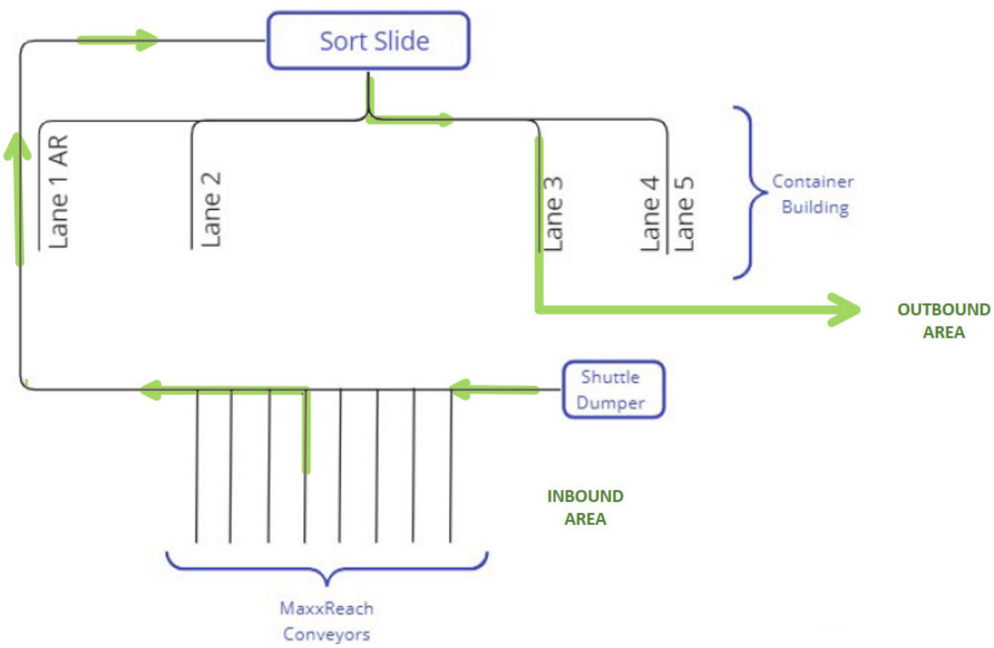

Fig 10. Manual Sort Center Example

The process path (highlighted in green in Figure 10) at manual Sort centers with physical label dependency is as follows: packages are inducted by fluid unload or Gaylord dump onto a conveyor belt that transports them to a Sort Slide Diverter, where packages are re-directed to different lanes depending on their next destination. Once at their respective lanes, packages are containerized or individually loaded on an outbound trailer.

2.2 Manual Sortation Process

During the sorting shift in a manual sort center, inbound packages are loaded onto a conveyor that then feeds the Sort Slide which then performs a sort. The sortation process starts when packages reach the associates, who sort packages by reading the four-character code located at the bottom left corner of the label; this code is referred to as Visual Sort Marker (VSM) for this thesis (highlighted with a red square in Figure 11), and the associates divert packages into one of four different chutes (which correspond to various downstream pallet build lanes) according to said code. Once the package has been diverted, the manual sortation process is completed.

2.3 Visual Sort Marker Digitization

The Small Shipping Label (SSL) does not contain the VSM in readable form, and hence cannot be sorted in the current process. Manual sort centers will require technological advancements to remove the existing physical label dependencies.

VSM Digitization can be defined as the need for a technology-supported solution to read information utilized for associate-level decision-making across several downstream process paths. Replacing the 4-digit VSM (highlighted with a red square in Figure 11) with a scanner-readable barcode eliminates current physical label dependency allowing SSL implementation and potentially reducing carbon footprint network-wide. Digitizing the transportation plan through a universal barcode also enables a package digital transportation plan to be altered dynamically without re-labeling. The transportation plan and processing instructions could then be updated automatically without requiring manual intervention from the operators to sideline, re-plan, or re-label the package.

Fig 11. Visual Sort Marker to be removed from the physical label

Manual sort centers do not currently have a Sortation Process that supports VSM Digitization. In 2021 several Amazon internal stakeholders from various teams participated in a VSM Dependency Solve and evaluated different methods to solve VSM Dependency. For the Sort Slide Diverter specifically, two solutions are being considered at this time: *Guide-By-Light,* the short-term proposed solution, where associates would scan packages and wait for one of four lights to illuminate to indicate which lane to send the package; and *Modsort,* the long-term solution, in which the package is scanned and then automatically sent down a belt, diverting it to one of the possible sorting locations.

This thesis aims to determine the effect of the proposed solutions for Visual Sort Marker removal in the Sortation Process and assess said solutions' feasibility in terms of installed capacity and operational costs. For example, the proposed short-term Guide-By-Light solution requires an extra scanning step that does not take place today, introducing the first hypothesis: the proposed short-term solution will increase the sorting time per processed packaged, degrading the Sort Slide Diverter throughout per hour (TPH). Sortation is the bottleneck of the Sort center E2E process, as it dictates the rate at which packages move to all container building positions. Increasing the sorting time per package at the Sort Slide Diverter would have a negative impact on outbound activities.

Chapter III Methods: Proposed Solutions Assessment

3.1 Current State Analysis: Sort Slide Diverter Baseline Calculation

A current state assessment documents the present set of circumstances of the Sort Slide Diverter process and its capabilities. Two main categories are analyzed during the baseline calculation: Capacity, to identify potential capacity constraints through the sort center network, and quality, to calculate the number of missorts that currently occur per shift and the associated re-sorting cost. In a manual sort center, packages are first scanned when they are inducted at inbound and once again when they are received at the container/pallet build area with no other scanning or time stamp in between these two operations. For this reason, Sort Slide specific data needed to be gathered throughout the network to build a baseline that would serve as a starting point for the feasibility assessment of the proposed options to solve Visual Sort Marker dependency.

3.1.1 Capacity: Throughput Per Hour

Once a package has arrived at the Sort Slide and is released by the divert arm at an available position, an associate reaches for the package, grabs it, and assesses it for damage and size. Then the package is either placed at the Problem Solve Area or sorted according to the Visual Sort Marker on its shipping label. The processing time considered for the capacity baseline includes only the manual actions performed by the associate working the Sort Slide Diverter. It starts when the associate reaches for a package at their respective position and finishes when said package is no longer being handled by the associate, as shown in Figure 12.

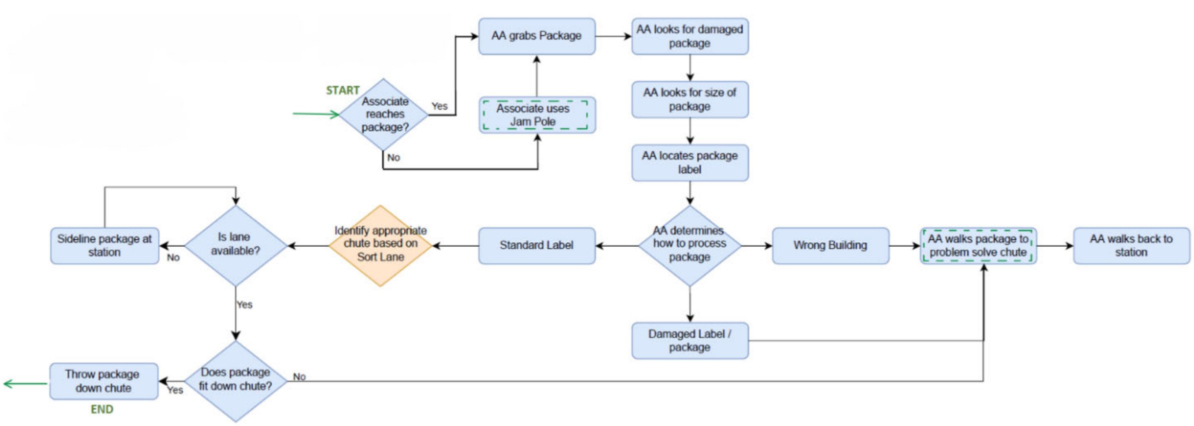

Fig 12. Manual Sortation tasks performed by the associate

A current state time study on the Sort Slide Diverter process took place to gather baseline cycle times, rates, and upstream/downstream flow limitations (i.e., MHE[18] jams and work availability). Almost 12,000 data points from Sort Slide Diverter positions were manually gathered from eight sites during different shifts throughout the US Sort center Network. With the support of a stop-watch app, the observer (either a VSM Digitization team member or a member of the site's operations team) recorded the processing times of different associates (with different expertise levels) per package at different Sort Slide stations. The statistical analysis of the current state supports a cycle time of ~5 seconds per package. This time accounts for delays from jams, defects, flow starvation, etc. This cycle time translates to an average network-wide baseline for the Sort Slide Diverter Throughput Per Hour[19] (TPH) of ~700 packages. Therefore, the average capacity for a standard Sort Slide Diverter with seven positions is ~5,000 packages per hour.

The dispersion diagram in Figure 13 shows most of the samples at a <5 seconds cycle time. There is a lot of variation in the cycle time, given that this is a manual task. The level of expertise of the associate directly impacts the time required to complete the sorting. External factors like shipping volumes also affect the cycle time, with sites with large volumes trending towards a lower Sort Slide cycle time than those with smaller volumes. The outlier data can also be explained by the tasks marked with a dotted line in Figure 12. The most common cases are associates having to stop sorting to grab a jam pole to reach packages stuck on the Slide and associates walking packages to the problem-solving area. These supporting tasks represent 5% of the sample and are considered in the baseline calculation because even though there is a relatively low occurrence, they are present on every shift.

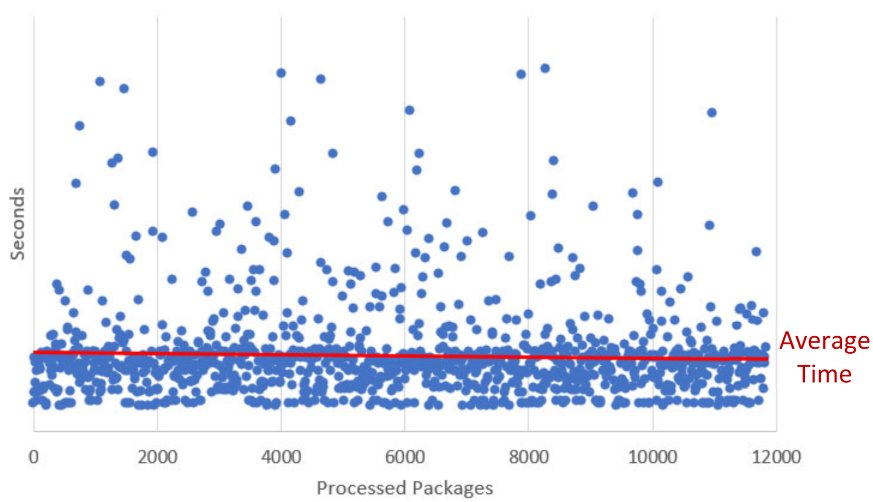

Fig 13. Network-Wide Sort Slide Processing Time Baseline

[18] **MHE.** Material Handling Equipment, ie. conveyor belts and systems, forklifts, etc.
[19] **Throughput Per Hour (TPH).** Number of units that can be processed within an hour.

For the statistical analysis, the first step was to identify the best distribution for the data. Using Q-Q Plots[20], data points were fit to different distributions. The curves obtained are included in Figure 14.

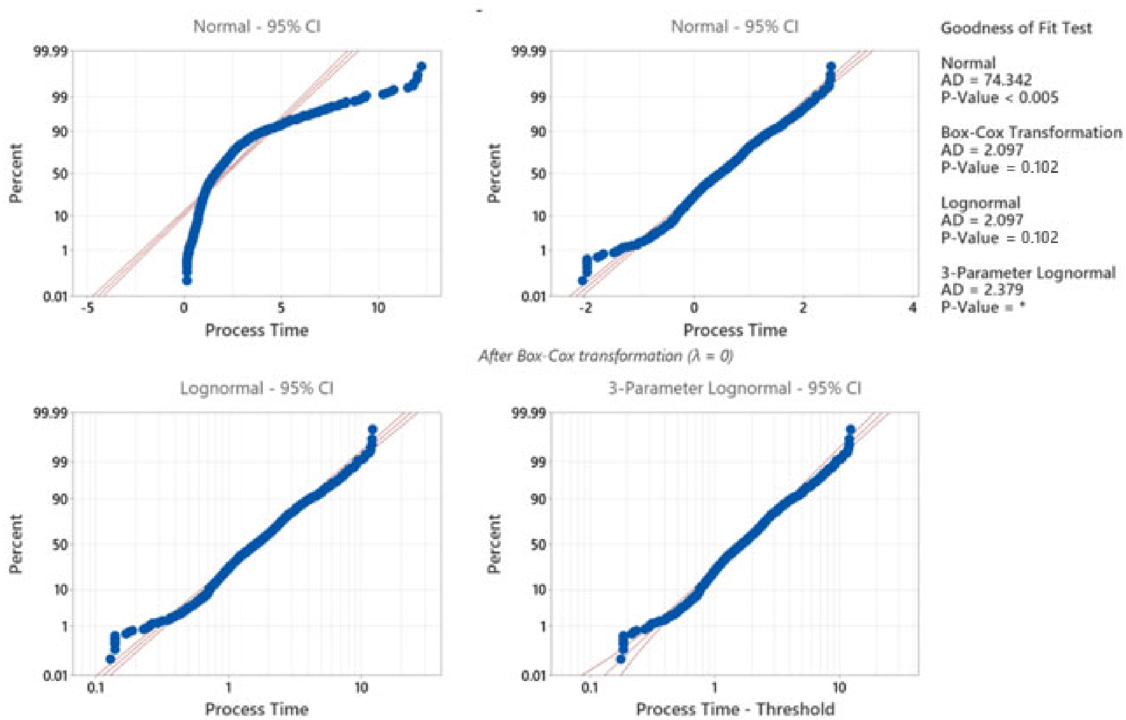

Fig 14. Distribution Identification for Baseline Process Time

For the fit test, a significance level of 0.05 was chosen. If the fit test has a p value that is less than 0.05, then this means the data does not follow the respective distribution (i.e., we reject the null hypothesis that the data comes from the assumed distribution). If the fit test has a P-value greater than 0.05, then we cannot reject the null hypothesis that the data follows the respective distribution. Fig 14 shows both Normal distribution after a Box-Cox transformation[21] and Lognormal distribution with a resulting P-Value>0.05, indicating the data fits the respective distribution. Since our data is a skewed distribution with low mean value, large variance, and all-positive values, the Lognormal distribution was chosen for the analysis. #

[20] **Q-Q plot.** Quantile-Quantile plot is a graphical tool designed to help assess if a set of data plausibly came from some theoretical distribution such as a Normal or exponential.

[21] **Box-Cox transformation**. Methodology to convert non-normal dependent variables into a normal shape, named after statisticians George Box and Sir David Roxbee Cox who collaborated on a 1964 paper and developed the technique. Given that Normality is an important assumption for many statistical techniques; if the data is not normal, applying a Box-Cox means that a broader number of tests are now applicable.

Once the network's average cycle time and the data distribution have been identified, the next step in this project was to assess the current performance of the manual sortation process. Current performance should be compared with performance standards. Nevertheless, in this case, there were minimal pre-existing performance standards. For the Sort Slide Diverter process, there was only an estimate of TPH across the network, which was dictated by the manufacturer's specifications. By design, the seven-station Sort Slide TPH is estimated to have a performance standard of 6,000 parcels per hour. This TPH translates into a cycle time of ~4 seconds per package. It is important to mention this cycle time does not account for the variance caused by associates' level of expertise, damaged packages, or jams.

Understanding the conditions mentioned above was a valuable input when establishing a manual sortation process performance index. For performance index calculations, the manufacturer's specifications of 6,000 parcels per hour were used as target vs the actual process samples, approximately 5,000 parcels per hour. The result is a Pp_k of 1.34. Pp_k is an acronym that stands for "Process Performance Index." Pp_k is a statistical measure used to assess the ability of a manufacturing process to produce products that meet specifications consistently [39].

The Pp_k value is calculated by comparing the process variability to the specifications and represents the capability of the process to produce products within the specified limits. A higher Pp_k value indicates a more capable process that produces products with greater consistency and quality, while a lower Pp_k value indicates a process that may be prone to producing defective products. In this case, the actual sortation process time is being compared with the manufacturer's standard specifications. A Pp_k value above 1.33 is considered acceptable, with at least 99% of the parcels processed within the manufacturer's specifications rates. Although this is below the 6σ methodology acceptable minimum score of 1.5, considering the data spread and lack of set performance requirements, it appears that the Sort Slide Diverter process performs at an acceptable level for its specific current conditions [40]. Fig 15 shows the data in a Lognormal distribution model. How most of the samples are centered within the specification limits can be appreciated.

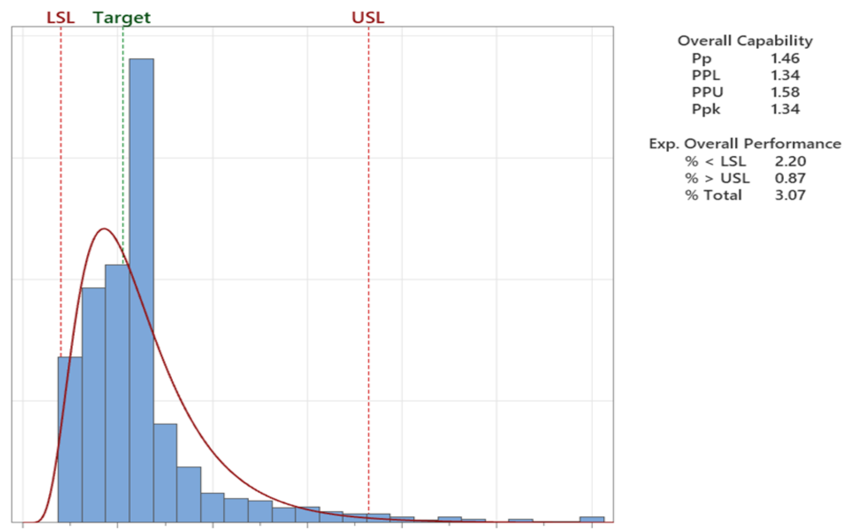

Fig 15. Sort Slide Diverter Performance Report based on a Lognormal Distribution Model

In addition to the Sort Slide Diverter Cycle Time samples, data was pulled from multiple databases to assess the volume distribution through the sort center network and the current Sort Slide labor cost and available capacity. Volume allocation is shown in Figure 16.

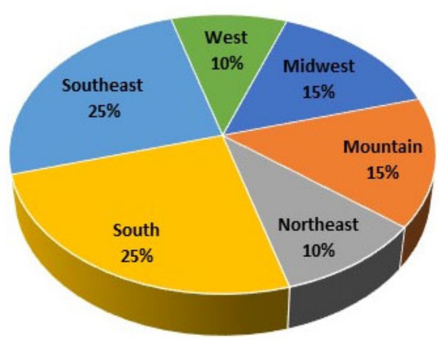

Fig 16. Volume Distribution - US Sort Center Network

Although specific sites are working at their maximum capacity through certain parts of the year, on average, the network is operating at under 60% of its current manual sortation capacity. This represents an annual labor cost of ~$154 M for the Jun' 21-May'22 baseline period. Sort Slide Diverter Baseline utilization and labor cost calculations are included in Appendix A. Figure 17 illustrates the US sort center Network utilization in a year, differentiating those sites working at their maximum capacity and the respective volumes processed during that period. Each bar represents a site in the sort center network, and the sort centers are grouped by region.

The bars marked as "available" processed their respective shipping volumes within regular working hours. The sites marked as "Max" required extra time to process their respective volumes.

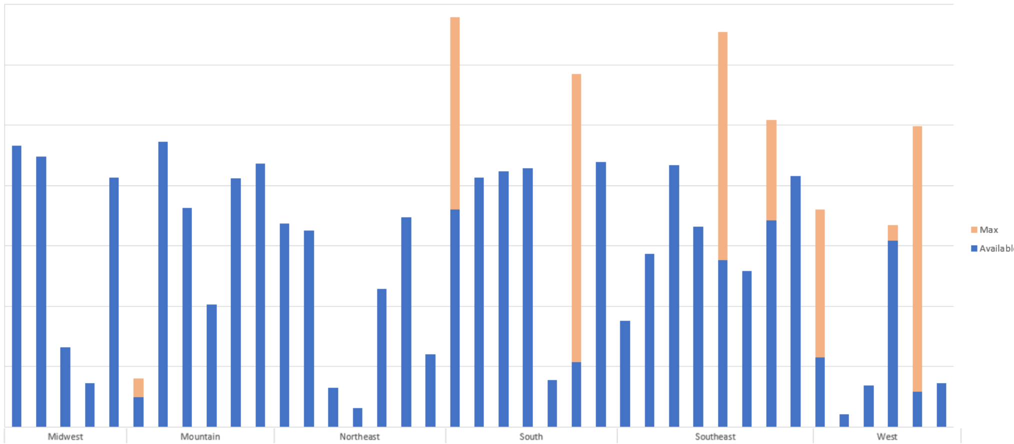

Fig 17. Sort Slide Throughput Jun’21 through May'22

2.1.2 Quality: Defect Rate

Root causes of sortation defects resulting in missorted[22] packages can be grouped in two general categories: External, when the package is delivered to the wrong building, and Internal, when the package is sent to the wrong container building lane during the sortation process. This thesis focuses on the second category, the missorts taking place at sortation.

As explained in Section 2.2, during Sortation at the Sort Slide Diverter, associates read the Visual Sort Marker located in the label and send the package down one of the four available chutes. Each chute connects to a conveyor belt that takes the package to its respective container-building lane, where it is placed in a pallet or gaylord[23], packaged and labeled, and finally moved to the outbound area to be handed over to a third-party delivery courier or Amazon's Last Mile network for final delivery.

Figure 18 shows the re-sortation path at a manual sort center with dotted arrows (straight line arrows indicate the standard process path): 1) When a package is sent down the wrong chute at the time of sortation, the associate at the respective container building lane scans the barcode located on the package's shipping label and receives an alert letting them know the package does not belong in that container. 2) The associate then places the missorted package in a gaylord, where wrong lane packages are collected until said gaylord is full. 3) Once the gaylord reaches its maximum capacity, it is sent back to the inbound area. 4) Packages are inducted to start the sortation process from the beginning one more time. The re-sortation process time per gaylord is calculated in Table 1.

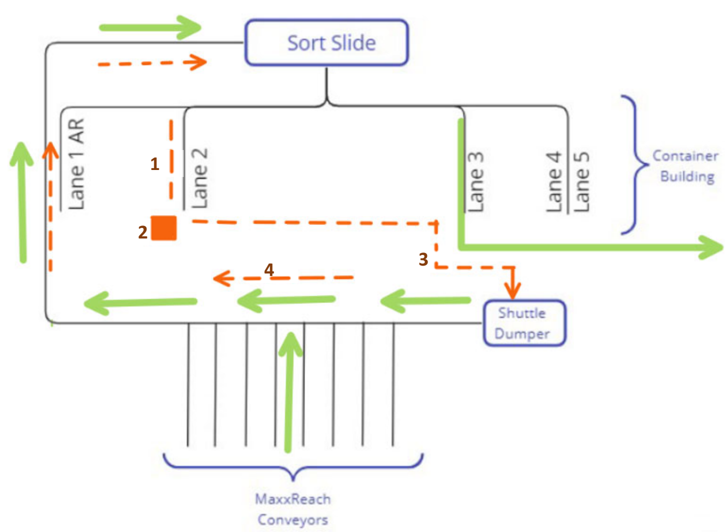

Fig 18. Re-sortation path of a missort package

[22] **Missort.** An item that has been incorrectly sorted.

[23] **Gaylord**. A large cardboard box, about five feet tall, into which sorted "flat" packages are diverted. The gaylord is then loaded onto a trailer for transport.

Similar to the process time baseline calculation, there is no available record of missorts at manual sort centers; therefore, the defect rate and the cost of these defects need to be calculated, starting by quantifying the number of missorts per shift. After gathering sample data for various sites at different peak[24] and off-peak periods, an average re-sortation time per gaylord was calculated following the process path from Figure 18 and assuming 200 packages per gaylord: 1) Each package takes 5 seconds to be sorted, 2) Once in the container building area, it takes 20 seconds for each package to be scanned, identified as missort and placed in the gaylord, 3) Once the gaylord is full, it takes 120 seconds to be transported from the container building area to the gaylord dumper, 4) Once at the gaylord dumper, it takes 33 seconds for the gaylord to be dumped on the inbound conveyor.

A single associate performs each of these steps; hence, we see from Table 1 that 200 missort packages results in 86 minutes (or ~25 seconds of incremental labor per missorted package).

Table 1:

Table 1. Gaylord re-sortation time calculation

Process	Seconds per Package	Seconds Per Gaylord	
Sort Slide	5	1000	
Container Building	20	4,000	
Transportation to Gaylord Dump		120	
Gaylord Dump		33	
Total Process Time		5,153	Seconds Per Gaylord
		86	**Minutes Per Gaylord**

Once re-sortation time was known, the following assumptions were considered (Table 2):

Table 2. Assumptions for defect calculation

Description	Value	Unit
Re-sortation Time	86	Minutes Per Gaylord
	1.44	Hours Per Gaylord
Packages per Gaylord	200	Packages
Volume per missorted gaylord	50,000	Packages sorted per Wrong Lane Gaylord
Aprox volume High Demand	250,000	Packages per Day
Aprox volume off-Demand	150,000	Packages per Day
Number of Peak Days in a year	20	Days
Number of Off-Peak Days in a year	345	Days

[24] **Peak.** It is the sales window when high volumes are expected. The exact duration varies depending on the site and the region. In the U.S. it generally starts in mid-November before thanksgiving and ends in early January, after the holidays. For defect calculation, 21 days of Peak per year were considered based on Operations Leadership advise.

The calculated missorts defect rate is 1.6%. Re-sortation takes 1.44 hours per gaylord (Detailed calculations included in Table 1). At a labor cost of $50 per hour, the cost to process a missorted gaylord is $72. Under the assumption that each gaylord contains 200 packages in average (Table 2), the cost to re-sort a missorted package is approximately $0.36.

As shown in Table 3, a total of 4,000 missorted packages are expected daily during peak season. At a labor cost of $0.36 per package, the daily re-sortation cost during peak season is $1,440.00 approximately. Peak season lasts 20 days in average (Table 2), resulting in $28,800.00 total labor cost for missorted packages. The same calculation is applied for off-peak season.

After adding peak and off-peak re-sortation costs, the total labor costs associated with re-sorting at this rate is approximately $327,000.00 per year. Calculations are included in Table 3.

Table 3. Defect rate & re-sortation costs calculation

	Aprox Inbound Volume Per Day	Total Missorts Gaylords Per Day	Total Missorts Packages Per Day	Defect Rate Per Day (Packages)	Re-sorting Cost Per Year
Peak Period	250,000	20	4000	1.60%	28,800.00
Off-Peak Period	150,000	12	2400	1.60%	298,080.00
					$ 326,880.00

Given the relatively low impact of these defects, this rate and associated costs are not alarming. However, given that these are costs with zero value added, considerable room for improvement is considered when assessing the proposed solutions for Visual Sort Marker dependency.

3.2 Short Term Solution: Guide-By-Light

Manual sort centers are fitted with a Sort Slide Diverter, where associates use the Visual Sort Marker (VSM) to determine where to divert a package. A Guide-By-Light system is Amazon's short-term solution to remove VSM dependency and unblock the Small Shipping Label (SSL) program.

Also known as Sort-To-Light in the order fulfillment industry, Guide-By-Light (GBL) is a visual technique that simplifies the sorting process by eliminating the decision-making aspect of the associate's tasks. This approach requires minimal modifications to the Associate workspace since it uses overhead scanners to read the labels and light indicators to signal to the associate what chute the package must go through. GBL is being pursued as a quick-deploy solution because the system requires a relatively low CapEx[25] investment, installation does not require significant operational downtime, and it can be easily reversed (equipment does not interfere with normal operations if a rollback is required).

3.2.1 Guide-By-Light Process

The only change in the Sort Slide Diverter process is the introduction of a scanner that replaces the associate physical VSM identification. The rest of the Sortation process remains unaffected.

In the GBL process, once the associate has reached the package and determines it is apt for sortation, instead of reading the VSM from the label, the associate orients the package with the shipping label facing up, and the label's barcode is scanned as the associate moves the package through the scanning zone. The code is then deciphered, and the package's next destination is communicated to local hardware, which illuminates a beacon indicating the destination chute for said package. The associate then pushes the package down the chute as indicated.

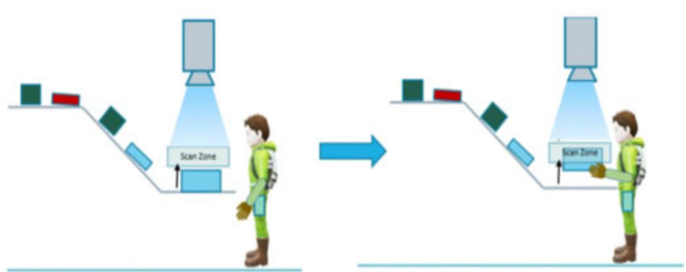

Fig 19. Guide-By-Light Overhead Scanner placement

[25] **CapEx**. Capital Expenditures are funds used by a company to acquire, upgrade, and maintain physical assets such as property, plants, buildings, technology, or equipment.

Fig 19 [41] shows the overhead scanner placement and the label's barcode scanning task. Figure 20 [41] illustrates the light beacon indicating the path the package must follow. In the left frame, the associate scans the package. The middle frame shows the indicator lighting up for Chute B once the system has identified it as the correct chute for that package. The right frame shows the associate moving said package to Chute B as indicated.

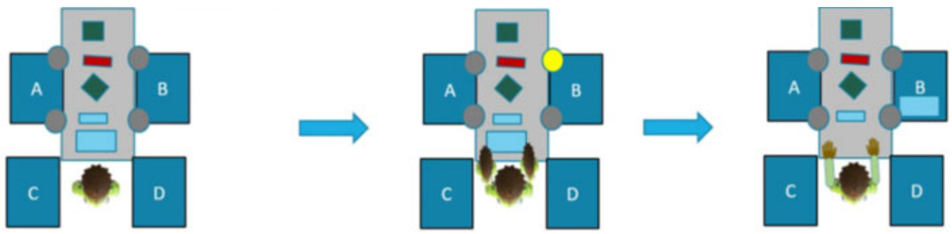

Fig 20. Guide-By-Light Beacon Indicators

3.2.2 Guide-By-Light Pilot Test

An initial test was performed to gather data and observe the proposed solution handling actual volumes. A removable, low-cost prototype of the Guide-by-light solution was installed at one low volume site to minimize the impact on the actual operation of said site. A barcode scanner and four LED lights mounted on a wooden frame were placed above a Sort Slide position.

The test was designed to assess the impact on the Sort Slide Diverter process performance from the physical change in the sorting process before investing resources in configuring the system to provide actual sortation instructions based on the VSM. Associates were asked to scan packages and wait for one of four lights to illuminate to indicate the divert instructions. The lights were set to illuminate randomly during the test to simulate the physical movement of the new process and to gather data on TPH impact without needing to configure the sort instructions to indicate the actual chute based on the package VSM. Lights were randomized to keep the associate from becoming accustomed to a pattern, simulating the real-world sorting process where associates do not know where the next package will be diverted to. Once lifted and scanned, associates placed the packages on the floor behind them so that packages were not sent down incorrect chutes (this movement was determined to be equivalent to setting the package down an actual chute based on cycle time observations of both processes).

Multiple scenarios were tested, including packages arriving with labels facing up to simulate fluid unload and packages arriving at the Slide with labels in any orientation to simulate a shuttle dump. Three individual associates on three different shifts with different levels of expertise in the Sort Slide Diverter process participated in the test to simulate actual conditions as closely as possible. While the associate performed the sorting process assisted by the scanning equipment, GBL sorting process cycle time was tracked to calculate the GBL solution TPH.

During the initial test, data regarding Voice of Associate was also collected, noting the process changes in workstation space/layout (caused by the overhead frame) and the associate's movements and standing position for future ergonomic assessments. The researcher personally interviewed the associates performing the tasks and asked them about their reactions towards the prototype and the new process. Overall, they had positive reactions, noting they believe the solution could help them improve their performance, and providing feedback about the light indicators.

3.2.3 Guide-By-Light Test Results

Given the addition of a scan-then-divert action in the GBL proposed solution vs. the look-then-divert action in the current state, a decline in the Sort Slide Diverter rate was expected. Rate degradation could be a challenge to the overall TPH and capacity of a Manual or Hybrid site since the Sort Slide Diverter is the primary bottleneck of the building, and it is currently not possible to add more positions to compensate for rate degradation.

When the associate was asked to use the Guide-By-Light system at the test site, placing each package to be read by the scanner and acknowledging the divert light signal, the average TPH resulted in ~692 per Sort Slide Diverter Station (~5.2 seconds per package)—representing a 3.8% TPH degradation when compared to the network's baseline.

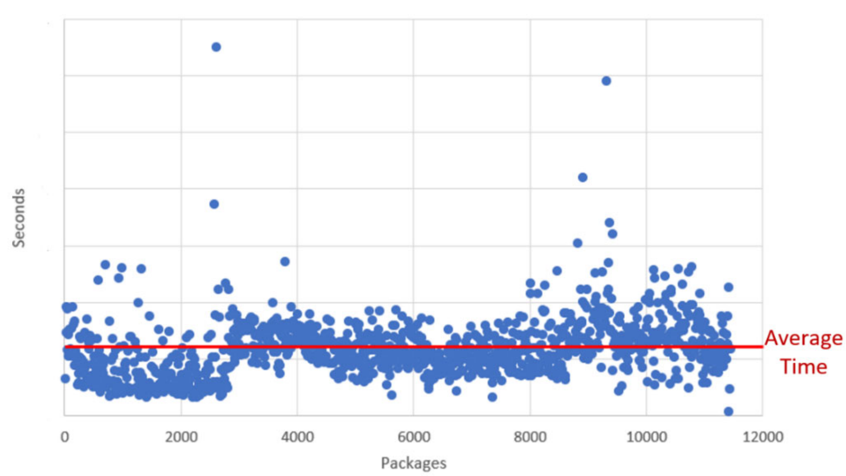

Fig 21. Guide-By-Light Processing Time

While some outlier datapoints can be observed in the Guide-By-Light test sample (Plotted in Figure 21), there is considerably less variance in these samples when compared with the network's baseline sample data illustrated in Figure 13. The GBL test was performed at only one site in the span of two days because of operational constraints.

Although samples were gathered from different shifts during this timeframe and the test was performed with the support of different associates, the volumes and process time were consistent.

We followed the same process as for the baseline to analyze the GBL data and fit a cycle time distribution. First, the best distribution for the data is identified using Q-Q Plots. Figure 22 shows the curves obtained:

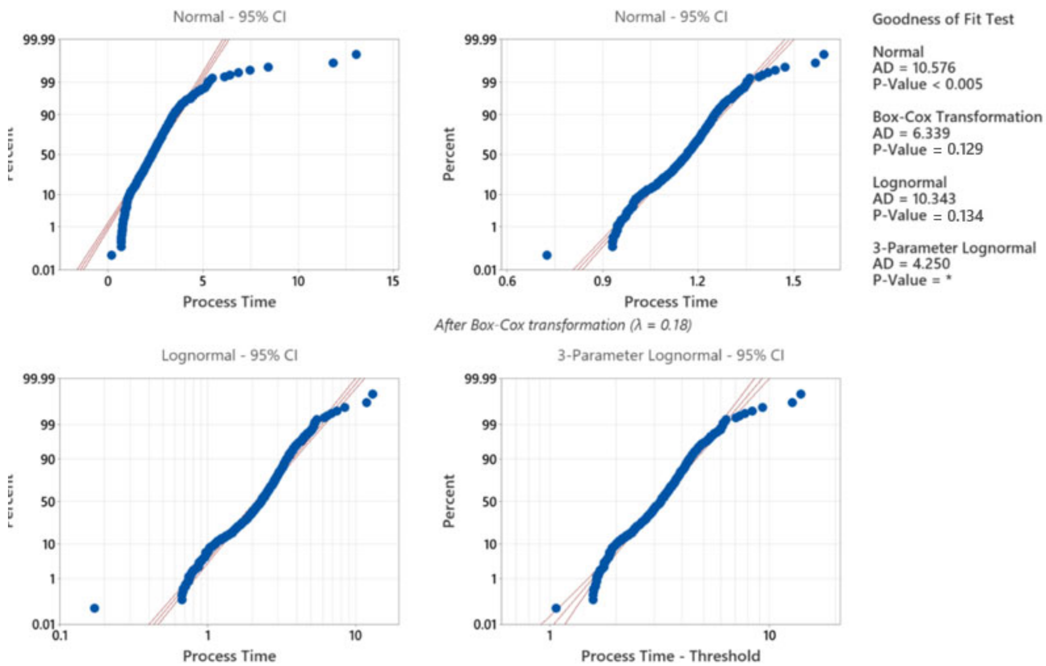

Fig 22. Distribution Identification for GBL Process Time

With a P-value >0.05, the GBL test data fits the Lognormal distribution best. For Performance Index calculations, the Sort Slide manufacturer's specifications (6,000 parcels processed per hour) are considered. The result is a Ppk of 1.41. As with the baseline, this value is above 1.33, meaning it can be considered acceptable. At 1.41, this Pp_k value means 99.94% of the parcels are processed within the specifications rates.##

# #

Figure 23 shows the data in a Lognormal distribution model. The GBL test sample has a higher Pp_k, corresponding to the lower variance and shorter spread present in this sample.

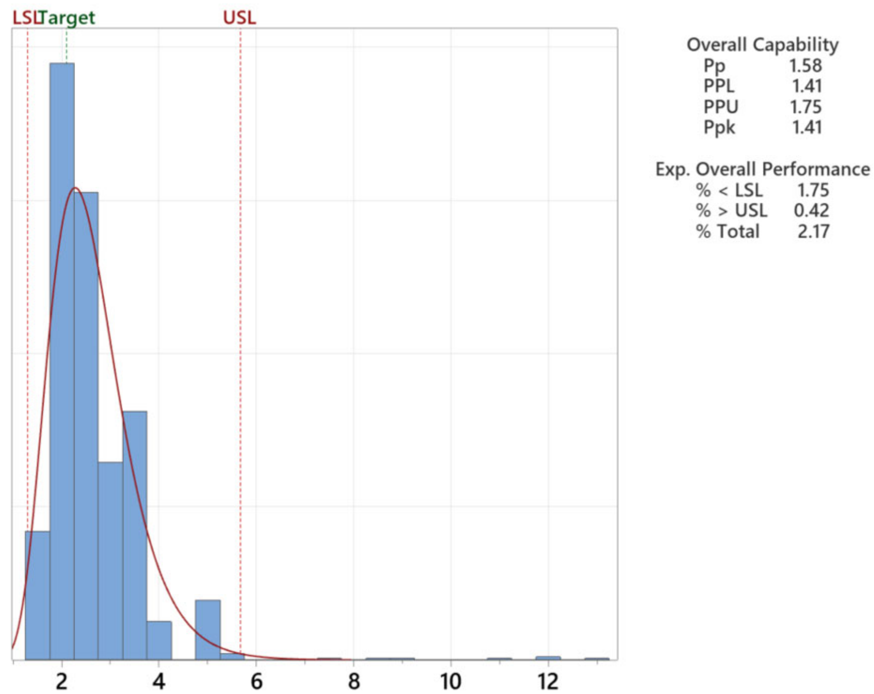

Fig 23. Guide-By-Light Performance Report based on a Lognormal Distribution Model

3.3 Long Term Solution: Modsort Technology

An automated Modsort is being evaluated as the Long-Term solution to replace Sort Slides and eliminate VSM dependency. A Modsort system is an automated linear sortation solution where the package is scanned and then sent down a belt where it is diverted to one of 5 possible sorting locations.

The Modsort solution includes higher CapEx investments, its installation requires significant operational downtime (1-3 days) and cannot be easily reversed. This solution also requires two associates performing manual singulation[26] before the packages reach the Modsort, adding an incremental three associates if fully staffed compared to a Sort Slide operating with all seven stations (ten associates on a fully staffed five module Modsort versus seven associates on a Sort Slide under the same conditions). Automated singulation may be possible depending on the site layout, but it would increase the MHE[27] footprint and CapEx.

A Modsort system has the potential to facilitate a steady flow of packages by creating minimum gaps between the loads of packages coming from inbound. By scanning the barcode on the shipping label, it can identify and determine the package destination, diverting items to the corresponding container-building lane on its roller-top conveyor belt.

Modsort systems are scalable and flexible warehouse applications, given their high degree of customization. Because of its modularity, it is also possible to retrofit[28] a sorting station into existing conveyor systems. Figure 24 shows a Modsort Three-way Divert Module, with its roller top conveyor belt connected to Mechlite fingers. Two associates manually singulate packages before packages reach the scanning zone. A conveyor belt transports and places the packages under the scanner, where the shipping label barcode is read, and the package's next destination is identified. The package is then diverted downstream on the Mechlite fingers to continue the shipping process.

Fig 24. Modsort Three Way Divert Module

[26] **Singulation**. Process where each parcel is uniformly separated, spaced, aligned, and oriented to assure bar code facing upwards.
[27] **MHE**. Material Handling Equipment
[28] #**Retrofit**. To install new or modified parts or equipment in something previously manufactured or constructed.#

3.3.1 Modsort Process

Since a Modsort System replaces the Sort Slide Diverter in this proposed Long-Term solution, the sorting process in this scenario is now automated. The only manual labor required is the singulation of the packages before scanning the shipping label. Upstream and downstream processes remain unaffected.

3.3.2 Modsort Performance

Because the Modsort System is not easily reversible since it involves MHE installation, a live test was not possible. All performance calculations are done using the manufacturer's specifications.

Each Modsort Scanning Module is expected to sustain a TPH rate of ~1500. The proposed Long-Term solution for VSM dependency is to replace Sort Slide Diverters with five Modsort modules (each module consisting of two scanners in series), providing a TPH of ~7,500. Compared with the US Sort center Network Baseline of ~5,000 packages per hour, there is a ~50% increase in throughput.

In terms of performance index, since this is an automated solution where package inflow is controlled by the Modsort system and, therefore, the number of outlier processing times is minimum, it is expected that the Pp_k for this solution is a higher value than GBL. Without sample data, the statement mentioned above is only an assumption.

Although the TPH increases significantly with the installation of a Modsort system, factors like CapEx, reversibility, and labor cost must be considered when assessing the proposed solutions for VSM dependency.

Chapter IV Results: VSM Digitization Impact in the U.S. Sort Center Network

4.1. Summary of Results

Forecasts for the expected 2023 shipping volumes (included in Appendix B) were calculated to determine the impact on Sort Slide capacity after Guide-By-Light implementation in the US sort center network.

At sites operating at maximum capacity during the high-volume period in current state, the seven positions Sort Slide Diverter with GBL solution overhead scanner installment will not have enough capacity to process all the forecasted volume given the degraded TPH, under the assumption that the site stays in operation 7 days a week, 24 hours per day. However, other sites are predicted to operate under their maximum capacity. This calculation combines the application of Flex time[29] during Sorting shifts through the network as needed, resulting in a ~4% labor cost increase (~$160M) network wide. Figure 25 illustrates the projected US sort center network throughput after GBL implementation. Each bar represents a site in the Sort center Network. The bars marked as "available" can process their respective shipping volumes within regular working hours. The sites marked as "Max" will require extra time to process their respective volumes. The sites marked as "Not enough" will not have enough capacity to process the expected volumes. In this scenario, ~20% of the shipping volumes need to be balanced and re-distributed across the network to direct the exceeding volumes to less utilized (and possibly less optimal) sort centers for processing, potentially increasing transportation costs. Calculations for the projected network capacity and labor costs are included in Appendix C.

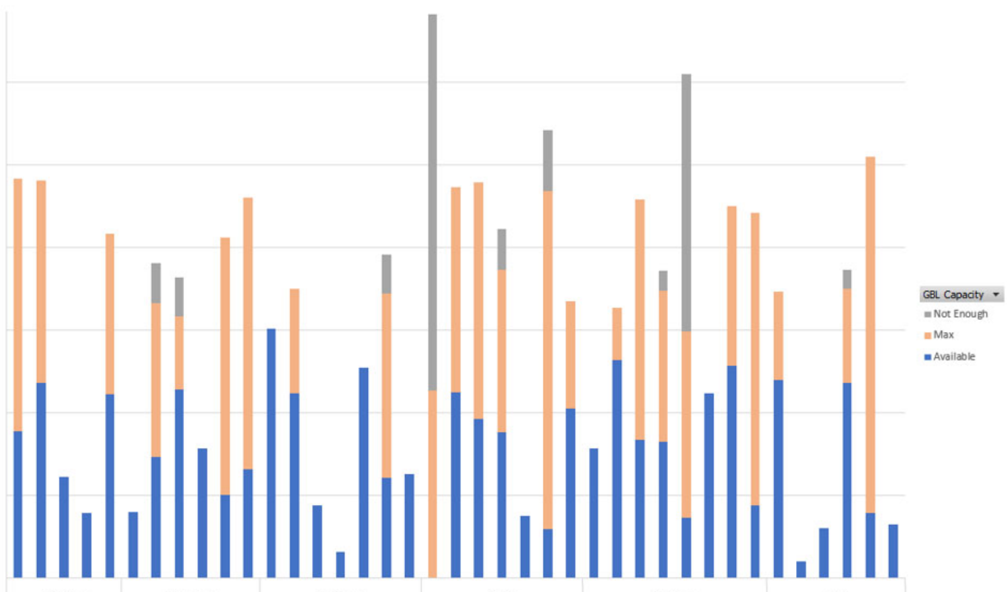

Fig 25. Guide-By-Light Projected Sort Slide Diverter Sort Center Network Throughput

[29] **Amazon Flex shifts.** Usually around 4-5 hours, but can be as short as 2 hours or as long as 8 hours.

The Modsort Long-Term proposed solution does not have a negative effect on the Network capacity since TPH, compared to the GBL solution, improves in this scenario. Therefore, the proposed five modules at each sort center can handle the forecasted volumes.

Figure 26 illustrates the projected US sort center network throughput after implementing Modsort sortation. Each bar represents a site in the Sort center Network. The bars marked as "available" process their respective shipping volumes within regular working hours. The sites marked as "Max" require extra time to process their respective volumes. Although the Modsort system requires double the number of associates per module compared to the current state Sort Slide (Modsort requires two associates at each of its five modules, while the Sort Slide requires one associate at each one of its seven stations), labor costs decrease by ~20% compared to current state; that is, the increased TPH in the Modsort scenario requires fewer hours per shift to process the forecasted volume (by applying flex time, shifts can vary from the standard 4 hours duration, to a maximum of 6 hours depending on volume) . Calculations for the projected network capacity and labor costs are included in Appendix D.

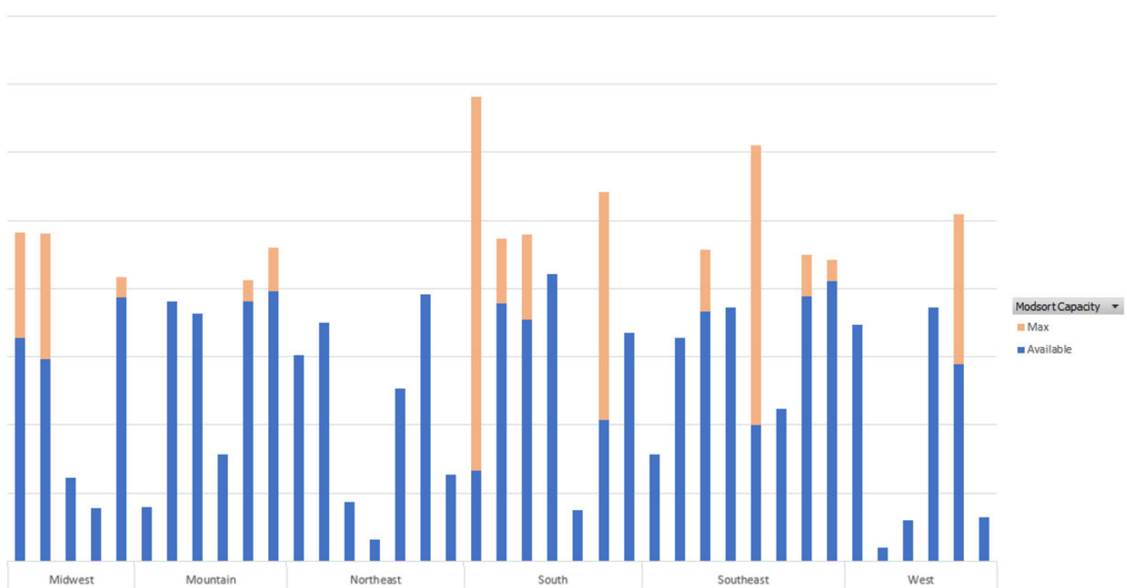

Fig 26. Projected Modsort Sort Center Network Throughput

Regarding missorts, both solutions eliminate the human decision-making factor from the sorting process. Because the GBL initial test did not involve actual sorting due to operational constraints at the site, the defects impact was calculated using error reduction factors assigned according to the level of human interaction in the respective solution.

As a semi-automated solution, GBL still relies on the associate placing the package down the correct chute. A missort reduction factor of 60% is applied to defect calculation. Modsort, however, has no manual intervention in the sorting process except for package singulation. As an automated solution, a 99% missort reduction factor applies when calculating defects and their respective missort costs.

Under the same assumptions described in Table 1 and Table 2, the resulting defect rates are 0.42% and ~0.01% for Guide-By-Light and Modsort, respectively. Approximately ~$100 K and ~$2.2 K in re-sortation labor costs, respectively. Figure 27 shows the projected defects and associated re-sortation labor costs in relation to the Baseline. Calculations for the projected defects and associated costs are included in Appendix E.

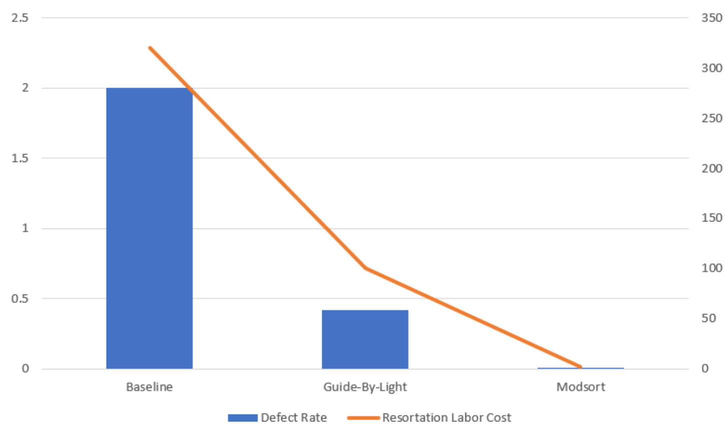

Fig 27. Projected defect rate & Re-sortation labor costs

Results and key support data are summarized in Table 4.

Table 4. Analysis Key Results

	Baseline Sort Slide 7 positions	**Guide-By-Light Sort Slide 7 positions**	**Modsort 5 Modules**
Performance (TPH) per site	5 K	4.8 K	7.5 K
Quality (Defect Rate) per site	2%	0.42%	0.01%
Installed Capacity	Enough to process Peak demand periods	23% of the Network will not have enough capacity to process Peak demand volumes with the current *Network volume distribution. Volumes need to be re-distributed across the network.	Enough to process Peak demand periods
CapEx**	-	$5.8 M	$600 M
Total Operating Cost (Year) :	$161.5 M	$163.6 M	$120 M
Ongoing Support Costs	$5 K	$13 K	$13 K
Average Re-Sortation Costs	$11.5 M	$3.6 M	$79.2 K
Labor Cost	$150 M	$160 M	$120 M
Installation Operational Downtime	-	1-2 hours per position	1-3 Days
Average cost of sortation per package (according to the forecasted volumes for 2023)	$ 0.093	$ 0.094	$ 0.07

*Re-routing transportation costs must be estimated and added to the GBL solution.

**CapEx is excluded from per package average sortation cost to allow for different payback periods to be included in the model as needed.

4.2 Recommendations & Future Work

The calculations included in this thesis were made under assumptions driven by historical data, samples provided by Operations and gathered on-site, process observations, and the results of one initial on-site test. It is important to mention that the Go/No-Go recommendation can only be given after an official Guide-By-Light Pilot takes place and its respective results are appropriately assessed.

Given the substantial costs of Network-wide Modsort system installation, if the GBL solution is determined to be successful with minimal TPH impact, then the Modsort solution would not be required to remove the physical VSM dependency. Nevertheless, the following observations (out of this thesis scope) aim to better understand the Guide-By-Light proposed solution's effects on the sort center Network in terms of capacity utilization, labor cost, and other potential benefits:

- *Network routing/Load balancing analysis.* At a network-wide level, the data shows sufficient capacity at the Sort Slide to process forecasted volumes using the Guide-By-Light proposed solution. A more granular analysis of the routing/load balancing adjustments required to fully realize this capacity is needed to properly assess GBL implementation feasibility with the existing number of Sort Slide stations.

- *Quantification of Sustainability gains*. VSM Digitization would unlock the projected savings of the Small Shipping Label program. SSL sustainability entitlement for the entire Supply Chain Network (First, Middle, and Last Mile) was calculated at a general level in early 2021 and has yet to be re-visited. A detailed summary of SSL savings applicable only to non-automated sort center would allow for a more effective GBL cost-benefit assessment.

- *Missorts records.* Standardization of wrong lane defects treatment and records of findings. It is almost impossible to quantify missorts accurately since there are no records of the packages diverted to the Wrong Lane, aside from the fact that the re-sorting process varies from site to site.

Having acknowledged the missing pieces of information, the currently available data indicates potential success for VSM Digitization by implementing the Guide-By-Light solution at Sort Slide stations. By the time the internship on which this thesis is based was completed, a proper Guide-By-Light Pilot had just been approved. Assuming said Pilot was conducted by the end of 2022, the data included in this document provides a solid baseline to input the Pilot results and assess Network Wide implementation feasibility with a higher degree of confidence.

Chapter V Literature Review

4.1 Statistical Process Control & Process Capability Assessment

In today's world, where resources are strained, and manufacturing costs are rising, business decisions must be made based on data. It is necessary to gather and analyze data [42], and this is where Statistical Process Control (SPC) comes in [43]. SPC is the use of statistical methods to monitor and control processes to ensure they perform optimally and produce a consistent product [44]. Optimal performance is accomplished by monitoring the process and detecting any variations that could impact the product quality. Key tools used in SPC include control charts, continuous improvement, and design experiments [45].

When a process is deemed "out of control," an alarm is triggered, and the assignable causes of variation can be identified and eliminated. It is, however, more effective to take a proactive approach to prevent out-of-control situations and make adjustments before non-conforming occurrences occur [46].

SPC can also be used to explore the natural variability of processes. Cause and Effect, Pareto analysis, and Capability analysis are examples of SPC tools that fulfill said purpose [43]. This thesis uses Capability Analysis to evaluate the performance of the Sortation process.

Once the data was collected, the current performance was compared to performance standards [47], but there were limited performance criteria for the Sort Slide Diverter. The only pre-existing standard was the Throughput Per Hour Rate estimated by the equipment manufacturer. Following the SPC methodology, the sortation performance was determined through capability analysis. The literature lists relevant tools to understand process performance, including histograms, dispersion diagrams, and capability analysis to determine the relationship between process variables and process performance [48].

5.2 The Retrofitting Approach

The manufacturing industry is undergoing a significant transformation as a result of automation, also known as the Fourth Industrial Revolution [49]. This transformation is characterized by a push towards greater transparency, where uncertainties can be discovered, and the actual process capability can be measured [50]. To take advantage of the benefits of transparency, new technologies must be integrated into current equipment, including those considered legacy devices, which may need to be replaced or upgraded through a process known as retrofitting [51].

One of the challenges companies face is an installed base of legacy machines and equipment that still need to be equipped for the current industry needs. As companies work to build up their digital connectivity through their end-to-end process, they must decide whether to replace these machines with new ones or retrofit their existing assets [52]. Although replacing machinery can positively impact the plant's digitization level, it also requires significant investments and goes against the idea of sustainable production. On the other hand, retrofitting minimizes financial efforts, risks, and time expenditure, presenting a more sustainable option for transforming the current state of legacy equipment [53].

Retrofitting offers several benefits for companies, including enhancing their competitiveness, boosting equipment efficiency, and promoting sustainability [54]:

- *Competitiveness.* Lowering production costs is critical in creating value in a globalized market. Retrofitting helps meet the growing demand for higher quality, lower costs, and increased productivity.
- *Equipment Efficiency*. To remain competitive, retrofitting aims to improve overall equipment efficiency, encompassing quality, availability, and performance.
- *Sustainability*. Retrofitting supports companies' efforts to comply with the constantly evolving regulations and guidelines set by political or societal entities, such as environmental standards, which have become increasingly stringent.

Although retrofitting has advantages, companies can face challenges while migrating to modern technology. The biggest challenge is often the limited resources available, including economic limitations [55]. Investing in new solutions and updating machinery can be costly, and replacing all machinery at once may not be economically feasible.

Another challenge is the high complexity of existing assets, which includes a variety of machines and systems that need standardized communication protocols. This can make it difficult for companies to digitize their equipment and achieve intercommunication between devices [56].

Despite these challenges, retrofitting can positively impact companies by extending the lifecycle of machines and reducing their CO_2 emissions footprint. It allows companies to utilize their existing assets and maintain their equipment in operation for longer without causing a negative impact on the system or the environment [55].

5.3 High Performance versus Sustainability Trade Offs in the Supply Chain Industry

Combining sustainability principles and optimal performance in the context of supply chain can be challenging [57]. This is because many factors that contribute to sustainability and performance often have conflicting goals. As a result, companies often have to find a balance between these goals to achieve their desired outcomes based on their business capabilities [58].

Common trade-offs between sustainability and high performance in the supply chain industry are [59]:

- *Efficiency versus Flexibility*. Sustainability aims to minimize waste and improve efficiency throughout the production and distribution processes. However, high-performance supply chains prioritize flexibility, allowing for quick adjustments in response to changes in the market or unexpected demands. This flexibility is achieved through buffer capacity, inventory, or time, which can be reduced by the efficiency gains from sustainability practices, potentially reducing the system's overall flexibility [60].

- *Complexity reduction versus Reverse logistics*. Reducing complexities in the supply network can improve the resilience of a high-performing supply chain [61]. However, reverse logistics practices can add more complexity to the network, reducing its resilience [62].

- *Redundancy versus Resource conservation*. High-performing supply chains balance flexibility and redundancy to manage demand variations, whereas sustainability emphasizes resource conservation. This focus on conservation can detract from the importance of redundancy in managing bullwhips in the supply chain [63].

- *Competency versus Adaptability*. A sustainable supply chain must be adaptable to future market demands, whereas a high-performing supply chain focuses on maintaining its competency through innovation [64]. Balancing adaptability and competency can be challenging as internal and external pressures influence innovation and competency in the supply chain.

- *Vulnerability reduction versus Social and environmental risk reduction.* Sustainable supply chains place high importance on addressing social and environmental risks in the supply chain, with risk assessments being a critical aspect. Meanwhile, high-performing supply chains aim to reduce vulnerabilities by reducing uncertainties [65]. This often conflicts with the focus on reducing social and environmental risks when taking the sustainability approach.

Companies and their supply chains continuously seek technological advancements to achieve sustainability and resilience in their supply chains. Decision-makers must be aware of the objective contradictions between sustainability and performance before implementing any strategies. The trade-offs can be intangible and often rely on qualitative data for measurement [66].

Conclusion

The Sortation Process dependency in the shipping label's Visual Sort Marker (VSM) in non-automated sort center is a stopper for implementing the Small Shipping Label (SSL) program. SSL enables dynamic transportation, network savings, and carbon footprint reduction. If VSMs were to be removed from the label, technology enhancements would be necessary to accommodate the change in the sorting process.

In 2021 Amazon narrowed the potential solutions down to Guide-By-Light (GBL) and Modsort. This thesis's primary focus was analyzing the proposed solutions to solve VSM dependency in non-automated sort centers and quantifying their impact on the network.

The analysis was performed in three stages:

I. Baseline calculation: Process Mapping and data collection

II. Proposed solutions performance calculation: GBL testing and Modsort research

III. GBL & Modsort performance versus Baseline assessment

The recommendation to move forward with the GBL proposed solution is based on the quantitative analysis results and the qualitative benefits of Retrofitting. Pursuing a solution that modestly degrades the Sortation process rate is supported by research on the trade-offs between sustainability and performance.

With new technology being developed at an unprecedented rate, in addition to the Climate Pledge and its commitment to zero emissions, it can be challenging to predict what sustainability requirements or technological advancements may arise in the near future. Choosing between retrofitting the existing Sort Slide Diverters at a low cost and having to re-balance the shipping volumes load through the network or installing new Modsort systems with considerably high CapEx and potentially unutilized capacity becomes a critical decision.

Appendices

Appendix A. Current State Network Utilization & Labor Costs

Current State
Network Utilization &

Appendix B. Forecasted 2022 & 2023 Volumes

Forecasted Volumes
2023.pdf

Appendix C. Guide-By-Light Network Utilization & Labor Costs

GBL Utilization &
Labor Costs.pdf

Appendix D. Modsort System Network Utilization & Labor Costs

Modsort Network
Utilization & Labor Cc

Appendix E. Defect Rate And Associated Costs Calculation

Defect Rate
Calculation.pdf

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