Analysis of Sorting Techniques in Customer Fulfillment Centers
by

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Submitted to the Department of Mechanical Engineering
and the Sloan School of Management in Partial Fulfillment of the Requirements
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Abstract

Fulfillment center management is growing in its importance as companies begin to focus in more detail on the complete operations and performance of their supply chains. This thesis focuses on the fulfillment center node in the supply chain network and investigates the optimization of fulfillment center operations.

The fulfillment center environment involves a significant amount of direct labor and most decisions in the facility operating structure are a series of trade-offs in labor and equipment costs. The primary flow of the fulfillment center is pick, sort and pack. In order to increase the pick density of the orders, sometimes orders are combined and picked together. The decision made in optimizing the picking process drives the need for additional downstream sorting processing.

Depending on the type of fulfillment center and its customer order patterns, some sorting operations are better suited than others. The key fulfillment center environmental characteristics that determine the fit of a sorting process will be analyzed. The parameters of process selection and the sorting solution options will be discussed. The general sorting analysis and framework described will be applied to the details of the internet retail environment.

As an example, in the Amazon.com network, there are three different sorting processes in place: manual, automatic and semi-automatic. It is important to fully understand how the current methods of sorting can be implemented in order to improve the overall cost picture of the customer fulfillment centers. The thesis develops a sorting phase diagram that can be used to determine the overall least operating cost sorting method for a given set of volumes and product cube features.

Thesis Supervisor: Stephen Graves
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Chapter 1: Introduction

Supply chain design and analysis have become an important area of focus for scholars and corporate executives. Managing supply chain interactions and dynamics has been a key source of advantage for some companies who have been able to use innovative and efficient techniques to manage the supply chain dynamics in their industry. Companies have begun to closely manage their inventory as well as the entire supply chain inventory in an attempt to reduce costs and increase responsiveness.

The warehouse or fulfillment center is key to carrying, managing and transferring inventory. Fulfillment centers and consolidation centers can be found throughout the supply chain network. Depending on the supply chain design, there can often be multiple types of fulfillment centers in the network. Understanding and managing fulfillment center operations is a key aspect of supply chain management and optimization.

This thesis focuses on the direct to consumer fulfillment center and investigates the optimization of fulfillment center operations. In particular, this document focuses on evaluating the techniques and operations used to accumulate and sort items for individual customer orders. An understanding about both upstream and downstream processes from the sorting process step is included because it is critical to a discerning analysis.

Depending on the type of warehouse or fulfillment center and its customer order patterns, some sorting operations are better suited than others. The key fulfillment center environmental characteristics that determine the fit of a sorting process will be analyzed. The parameters of process selection and various sorting solution options will be discussed. The general sorting analysis and framework described will be applied to the details of the internet retail environment.

The final result introduced for the internet retail environment is a sorting process phase diagram showing the optimal sorting process depending on the facility operating volume as well as the physical product characteristics. The diagram indicates the sorting process choice with the least cost operating structure for a given set of volumes and physical characteristics. The development of a sorting process phase diagram for the internet retail example can be generalized for other types of fulfillment centers.

1.1 General Supply Chain Structure

The general supply chain structure is depicted in Figure 1.1. Of course, there are many different permutations actually implemented in business today, but the graphic helps to depict the general position of fulfillment centers in a common supply chain.

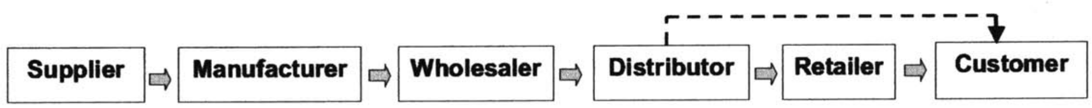

Figure 1.1 General Supply Chain Structure[1].
Depending on the particular supply chain, some of the supply chain nodes may be bypassed. For example, some recent supply chain structures bypass the retailer and sell instead direct to consumers. Fulfillment centers are implemented at various places along the supply chain nodes.

The figure above shows the supply chain structure as having a linear relationship when in fact the supply structure in practice is a network with multiple suppliers providing raw materials and parts to the manufacturer and numerous downstream nodes as part of the distribution channel. Fulfillment center operations and logistics appear multiple places along the supply chain. Incoming supplies to a manufacturing factory floor may often come directly from a wholesaler or from internal fulfillment centers for manufacturing

[1] Modification of the Figure 1.1 The Logistics network from (Simchi-Levi 1).

raw material. The manufacturer may have additional warehouses for spare parts and completed finished goods. In order to distribute manufactured products, the supply chain operations downstream from the manufacturer are fulfillment centers: some wholesalers, and others, retail distributors. Managing inventory is a key activity at many points along the supply chain network. It is for this reason that fulfillment centers are found in many different places along the supply chain.

As a result of internet technology, one key development is the growing bypass of retail outlets and the increased use of direct to consumer sales from distribution or fulfillment centers (depicted by the dotted line on the graph). The thesis will include discussion and analysis of the fulfillment center operations in the direct to consumer environment.

1.2 Role of Fulfillment Center in the Supply Chain

The fulfillment center can play different roles in the supply chain. Some of the typical roles include:

- Inventory Buffer
- Consolidation Center
- Value-Added Processor

The traditional role of the warehouse is often to act as an inventory buffer for the network in order to absorb the variation in the demand. The warehouse is able to combine demand variation over numerous customers and as a result place orders upstream with less demand variability. The warehouse can also consolidate products for downstream purchasing. Instead of going to several manufacturers, customers can get all or some of the products that they require from a single warehouse or distribution center. Likewise, for the upstream manufacturers, it eliminates the need for the manufacturer to service each individual customer separately. Instead, the manufacturer can send its product to a select number of wholesalers or distributors. Some warehouses have started to assume the role of differentiating or assembling products at the point of order of shipment. This facilitates delayed configuration or specification of modularized generic products. This type of work at the warehouse is usually termed value-added processing as the warehouse is actually increasing the value of the final product in addition to managing the inventory of finished goods (Bartholdi 3).

There are some essential economics that drive the existence of warehouses in the supply chain network. Economies of scale may be achieved by consolidating customer purchases through distribution centers. In addition, transportation costs can be reduced with a warehouse network. If manufacturers sell directly to consumers, they will most often have partially utilized delivery systems to reach those customers. Manufacturers can reduce the overall transportation cost burden by delivering to a few well-located distribution centers that in turn manage downstream delivery direct to final customers (Reveliotis 2).

1.3 Types of Fulfillment Centers

Fulfillment centers or warehouses can have very different business environment depending on their position in the supply chain and the downstream customers that they are working to satisfy. Here are some of the typical types of warehouses:

- Direct to Consumer Centers – This type of warehouse system is primarily used for catalog sales or internet retail. The customer base for this warehouse is direct individual consumers. When the customers are individual households, there will be a distinctive ordering pattern and expectation set. Most individual consumers do not place bulk orders, but instead buy individual items.
- Retail Distribution Centers – This type of warehouse replenishes the needs of a particular retail store network. The retail customers can often be restricted in the fact that they may be required to receive product from a particular distributor in their area which is part of their retail business structure.
- Manufacturing Support Centers – As discussed above, manufacturing facilities need warehouses in order to manage incoming material, finished goods and spare parts. Depending on the manufacturer, these warehouse functions used to support manufacturing can be combined in one facility or have separated operations. Depending on the type of inventory managed and the throughput or response expected, the warehouse operations within one manufacturing facility can be quite varied.

Understanding the type and position of the warehouse is key to evaluating and selecting the processes to implement in the warehouse operations. If the position of the warehouse is known, the warehouse customers' needs and requirements can be met with better proficiency. The customers' needs and requirements and their particular order patterns often correlate with the type of warehouse and the position in the supply chain (Reveliotis 2).

1.4 Thesis Outline

Chapter 2 describes the general operations in a typical warehouse or fulfillment center. This chapter also discusses the potential different alternatives in warehouse operation configurations depending on the unit load and volumes experienced at the given fulfillment center. Chapter 2 discusses the sorting process step and its potential necessity in the flow of outbound warehouse operations. Chapter 2 delves into the warehouse optimization studies and the research literature in this area. Chapter 3 discusses the different sorting process alternatives and potential sorting equipment and their applications.

Chapter 4 delves into the standard and generalized methodology for evaluating operations or systems within a warehouse or fulfillment center. Chapter 5 develops a detailed analysis of the labor component for sorting operations. Management and understanding of the labor component are a key aspect of reducing the warehouse operating costs.

Chapter 6 discusses the general business environment and shifting business conditions for the internet retailer, Amazon.com. Chapter 7 discusses the business operating challenges and current trends in the internet retailer environment. Chapter 8 addresses the specifics of the current flow of operations and operating costs of the sorting processes in place in the Amazon.com fulfillment center network.

Chapter 9 proposes the relationship between the physical cube of the products and the total production volume. This relationship can indicate the optimal sorting process choice. The result is a phase diagram showing the conditions for which each sorting process has the least operating cost, and the optimal sorting solution for that order profile segment. Chapter 10 includes general conclusions and recommendations for Amazon.com and other companies that are in the business of direct consumer sales from fulfillment or distribution centers.

Chapter 2: Fulfillment Center Operational Overview

Even though there are many types of warehouses and each warehouse plays a different role, there are typically generic warehouse operations. Depending on the type of warehouse some of the general operating activities may not be put into practice. It is also possible that the general category of processes may be in place at each warehouse, but that the details of the implementation may be modified to suit the particular type of business.

2.1 General Fulfillment Center Operations

The warehouse operations are often separated into inbound and outbound activities. The first step within most warehouse inbound operations involves the receiving of products or material and the storing of those products. After the products are stored in inventory, they must be eventually retrieved from their storage location in order to fulfill orders. The process of storing inventory is the final inbound operation. Once the inventory is adequately stored, the process flow transitions to outbound operations. The main processes performed in the outbound operations are picking, order sorting/accumulation, and packaging them for shipment or transfer to customer locations. The generic warehouse flow is shown in Figure 2.1. Depending on the particular warehouse operations, some of the warehouse processes may be bypassed. For example, cross-docking facilities do not actually store inventory, but directly transfers the incoming inventory to outgoing lanes or vehicles.

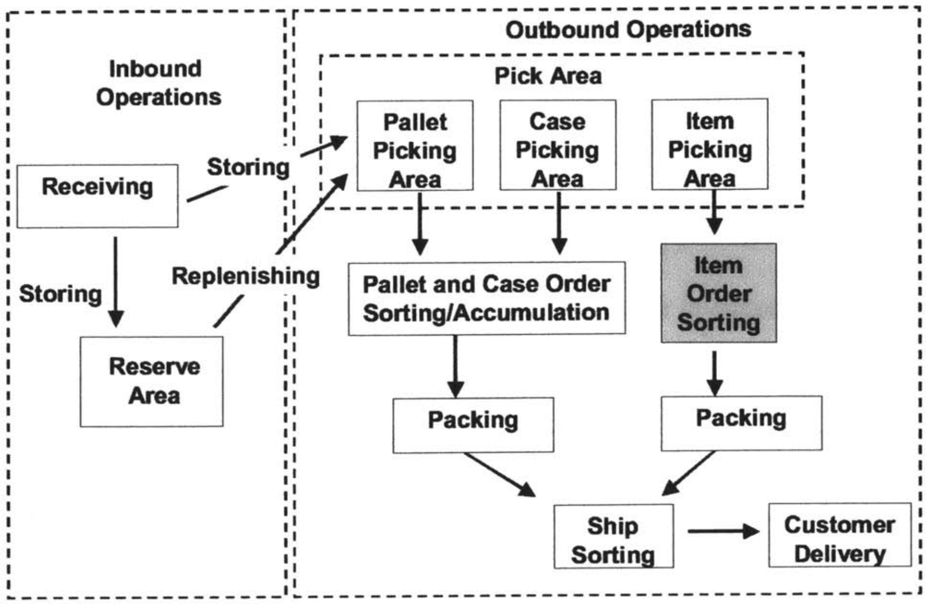

Figure 2.1 General Fulfillment Center Process Flow[2].
Depending on the particular warehouse, some of the depicted processes may be bypassed. The order sorting processes (highlighted in the figure) is the main focus of this thesis.

Inbound Operations

Receiving: The receiving process involves the inspection and scanning of incoming products. The products are checked for quality and compared to purchase orders to confirm that the product received is the product expected. The products are then staged for the storing process.

Storing: Once the items have been received, the products are stored in inventory, so that they are available for order fulfillment. The storage location and the product are often scanned and associated in the computer system with the storage location, so that the products can be found when needed for downstream processing. The storage process can be labor intensive as there is often significant travel time associated with storing

[2] Modification of Fig. 1. Example containing both OA/S-1 and OA/S-2. (Bozer 4).

products. Depending on the incoming products, some might be stored in pallets, cases or as individual items.

Replenishing: The replenishment activity involves moving product from reserve storage location to accessible and active pick locations in the inventory area. Some facilities do not use replenishment, but instead store all products in active picking areas.

Outbound Operations

Picking: The picking process involves selecting the desired customer items from the shelving area or storage locations (library shelving, flow rack, pallet rack). The type of storage depends highly on the form factors of the items being stored. The item form factors include the general shape and size of the products. Some of the fulfillment centers use a full-path picking system and others implement a zone picking system. In addition, some centers pick to totes that are placed directly on conveyors, and others, use carts to accumulate picked items.

Item Order Sorting: If a customer order contains multiple items and the customer orders combined for picking efficiency, then the picked items need to be sorted into individual customer orders. The current picking process design drives the need for downstream sorting. If an order consists of only a single item, then sorting process step is bypassed.

Pallet and Case Order Sorting/Accumulation: Pallets and cases that are picked from separate pick areas are accumulated in this step. The type of equipment for this order sorting may differ from the item sorting equipment due to the product form factors and volume of orders. This thesis focuses on item order sorting and not the process of accumulating and sorting pallets.

Packing and Label Attach: The customer orders are packed into a box and conveyed to a station that applies the shipping label and seals the box.

Ship Sorting: The customer shipment with the correct shipping label is sorted by different geographic injection points and different shipping method options.

Even though there are multiple sorting steps that are portrayed in the general warehouse operating flow, the primary focus of this document is the item order sorting. The order sorting and accumulation that occurs for pallets and cases is not investigated because this is not applicable to the direct to consumer sales environment. The equipment and the operating choices for the pallet sorting and order accumulation are quite different then the choices made when handling individual items. The form factors of individual items are often quite varied and that makes the interface with automated equipment complex. With pallets and cases the dimensions and form factors are quite uniform, so automated equipment can interface with the products.

2.2 Fulfillment Center Literature Review

The majority of the literature focuses on general warehouse operations and in particular in the picking and storing of products. There are multiple sources that provide a thorough primer for different types of warehouses, the general warehouse operating structure and key operating decisions. One good primer to warehouse management is the manuscript by Bartholdi and Hackman (Bartholdi 3). This manuscript is the primary text used in the Georgia Institute of Technology Warehouse Systems course (Reveliotis 2). The course lectures and the manuscript provided a background for a lot of the basic and introductory warehouse management knowledge captured in this thesis document.

The majority of the developed work and literature focuses on picking algorithms and storage optimization techniques. This is not surprising because, in general, the picking process involves the largest percentage of labor costs . In addition, the space costs of inventory management are also a large portion of the fulfillment center total cost. Managing these labor and space costs is important in gaining a cost advantage and maintaining competitiveness in the warehouse or distribution industry. Additional documentation has been developed that focuses on the warehouse management software systems, and efficient batching techniques.

Overall, there is not significant development of methods to evaluate sorting processes and techniques. However, some useful sources have been found that describe the different sorting equipment including description of various types of implementation (Maloney 4). Most of the other articles focus on detailed sorting process evaluation or algorithms in particular environmental conditions (Bozer 9, Choe 10). One article provides the analysis details of automated sorting control and design example based on simulation results. The work focuses on lane assignment based on incoming customer orders (Bozer 5). Due to the major focus on picking labor and the picking process, the sorting labor and equipment has not been thoroughly investigated and limited literature exists.

2.3 Picking and Sorting Trade-off

The decision to introduce the sorting process within a fulfillment center's operations is based on the desire to optimize or reduce the picking labor costs. Basically, the picking process involves a significant amount of travel time to each of the required pick locations. Due to the extensive travel time required, it is sometimes preferred to combine multiple orders together, so that a picker can pick many items on a single trip through the inventory storage area. The benefit of the batching technique is greatest when the picking area is large and the number of items in an individual order is small. The small order environment is typical in the direct to consumer business because the unit size handled is individual items instead of pallets or cases containing many items.

Even though the batching technique helps to improve picking labor costs, it requires the introduction of additional labor and potentially new equipment downstream from the picking process. The orders that are combined together for picking will need to be separated again and that is the reason that a downstream sorting process will need to be incorporated. The coupling and decoupling of orders into batch is depicted in Figure 2.2 and the effect of combining and sorting items is shown.

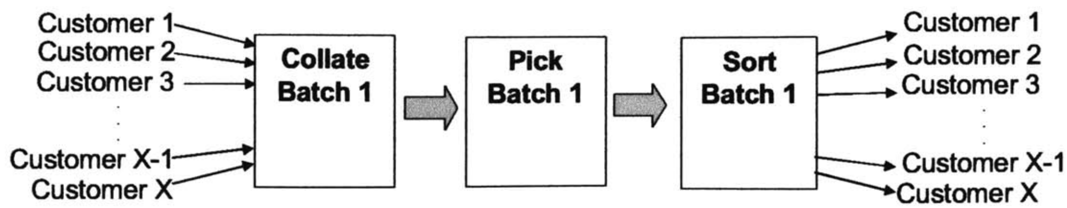

Figure 2.2 The Coupling and Decoupling of Customer Orders in Batches.
This figure shows how orders are combined together to support the picking process and then sorted again into individual orders.

If the warehouse layout and order distribution are as in Figure 2.3, the travel time to pick the two orders separately will be greater than the travel time to pick the items for both items together on one pick trip. In the representation below, the aisle width is assumed to be 5 ft. and the bin size 5 ft. by 5 ft. and the picker follows a pick path that was determined using an S-shaped heuristic. The S-shape curve is a standard pick path heuristic used to determine efficient picking routes. Basically, the general rule of the S-shape heuristic is that the picker will travel to the aisle furthest to the left with an active pick. The picker will continue to proceed up and down consecutive aisles to all active pick locations using the shortest route possible.

The potential to reduce travel time per item makes the batching system appealing in warehouses and for the internet or catalog retailer business environment. If it is beneficial to operate with a pick batch system, then it should be determined how many customer orders and which customer orders should constitute a batch. The batched items should be co-located, otherwise the batching process may not achieve the benefits expected. Currently, the number of customer orders to include in a batch is limited by the design of the downstream manual and semi-automated sorting stations. As a result, batching benefits can be limited by downstream workstation design. However, even though batching helps costs and labor productivity results, it can work against having a high-throughput and responsive operation.

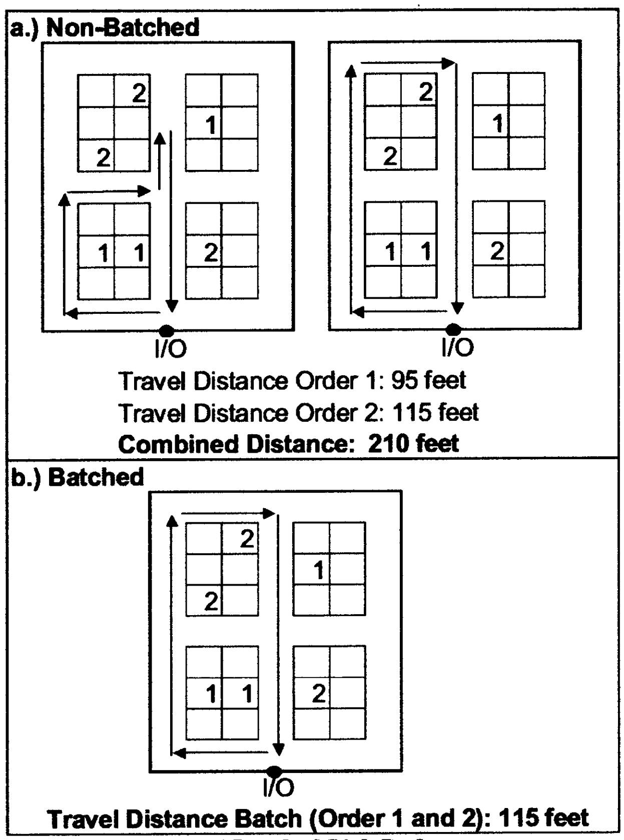

Figure 2.3 Graphic of Non-Batched and Batched Pick Paths.
Part (a) shows a non-batched travel distance and part (b) depicts a batched travel distance for comparison. The locations with a 1 are active pick locations for Order 1 and the locations with a 2 are for Order 2. The I/O point is the input and output point for picker path origination and return.

2.4 Batch Effect and Customer Responsiveness

Using a batching system to gain labor productivity efficiencies works against the ability to be truly responsive to customers. By batching orders, there is a waiting phenomenon that occurs. Even if all the items for a single order are picked early in the pick path, the completed order must wait for all of the other items associated with the additional customer orders to be completely picked. Likewise, the batch effect can work against order throughput at the sorting step with some sorting system designs. Often a completed and sorted order will have to wait for all the other orders in the batch to be fully sorted and completed before the sorted batch is passed to the downstream stacking or packing labor. Basically, the cost advantages to increased labor productivity with large batch size must be weighed against the impact on waiting time and customer responsiveness.

Chapter 3: Picking and Sorting Alternatives

The various different types of picking and order sorting alternatives that can be implemented in a customer fulfillment centers will be reviewed in this chapter. The preferred choice for actual implementation will depend on the business environment of the fulfillment center. The positive and negative features for the application of the picking and sorting alternatives will be discussed briefly in this chapter. The full development of a systematic approach to analyze the various picking and sorting options will be discussed in the following chapter.

3.1 Sorting Alternatives with Full-Path Picking

Full-path picking is a picking technique in which the picker must walk the full-path of the pick area. The pickers must travel to all storage locations that contain products. If the items required for a customer order are located at the far opposite corners of the picking area, then the picker must visit both locations and hence travel the full-length of the pick area. Given that the number of labor hours can be directly related to the picker walking distance, the labor hours for picking a full-path environment can be significant. The number of picks per trip is critical in this environment as the picking productivity is a simple ratio of the number of items picked to the number of labor hours. The following are the possible ways of implementing picking and sorting in a full-path pick environment (Reveliotis 2, Sharp 7):

- Single Order Picking – With a single order pick, sorting will not be required at all. Each incoming order will be assigned to a single picker. The picker will pick each item completing the order and then forward all the items to the packing and shipping process steps.

- Combined Picking and Sorting – In this alternative, the pickers sort the various picked products into separate customer orders while in the process of picking.
- Downstream Sorting – The key to this technique is full pick batch implementation. The pickers pick the items for several customer orders, but they do not tag or separate the products in any way. Downstream labor and equipment partition the products into their respective customer orders.

The key considerations for implementing a single order pick system is the size of customer orders. If the customer orders are large, then the picking productivity can be high and any additional batching would have a minimal effect on improving the pick labor productivity. The size of the customer order may be large enough to justify not implementing a batch system in the warehouse. If the unit of product that flows through the warehouse is pallets, which require special forklift equipment, there may be little advantage to batching pallet picking for the given operator because only one or two pallets can be transferred at a time. In addition to the order size, the size of the pick area that pickers will cover is another key factor in the consideration of the single order pick alternative. If the pick area is very large, then batching may be required to maintain the ratio between the number of items picked and the picker walking distance.

The key considerations for implementing a combined picking and sorting system is the impact on picking productivity. There are potential gains from batched picking work, but additional sorting work added to the picking job will need to be weighed against the gains. In addition, an important consideration is the size of the container that the picker will need, in order to be able to pick and sort items effectively while in the active pick area. The picker will be required to do additional activities out in the pick area. The picker will need to be provided information about each product picked, so that they are able to match the picked product with the respective customer order. The aisle spacing and the ability of the picker to maneuver with a sorting cart or equivalent piece of equipment will be required. Aisle congestion will be a concern , as will be the size and number of order partitions required in the sorting container. The container or sorting equipment will need to be sized to fit all items, otherwise the picker will encounter problems while in the process of traversing the picking environment.

For the downstream sorting implementation, the key considerations is the trade-off between improved picking labor productivity and additional downstream labor costs. In addition to the labor required to run the downstream sorting process, there is additional computing and equipment capital that may be required. In addition, the batching technique reduces responsiveness as multiple customer orders may potentially wait prior to downstream processing. The balance in picking labor cost reduction and the additional sorting costs must be evaluated and determined prior to implementation.

3.2 Sorting Alternatives with Zone Picking

In contrast to the full-path picking process, the picking area can be separated or partitioned into zones. With zone picking, each picker is assigned to pick the items for a customer order that fall in that region of the picking area. Full-path picking is still implemented, but the pick area is decreased. The reason for implementing pick zones is to improve picker productivity by decreasing the labor hours and potentially increasing the batch size over the zones and complete pick area. The sorting alternatives with zone picking are as follows:

- Single Order Zone Pick – With this type of implementation, pickers pick the items for a single order. Each picker picks the items in their respective zones and then the items are accumulated together across zones. Sorting is not required because the items for various customer orders are not mixed together.
- Combined Zone Picking and Sorting – In this set-up, the order container or cart is passedd from one zone to another and the items from each zone are placed into the segmented part of the container corresponding to each customer order. No downstream sorting is required.
- Downstream Sorting – Implementing downstream sorting with zoned picking is also possible. Orders are combined into a batch to improve pick density. A single batch is separated over the number of zones where active picks are located. The picks from each zone then need to be accumulated at the sorting step.

It is also possible to take multiple batches and combine them in a wave. Usually, the batch size is limited by the downstream sorting equipment design and hence it may be desirable for picking productivity to merge batches together. With this type of implementation an additional presort step may be required. Figure 3.1 shows how batches can be combined and picked over waves and then sorted. The reason for using the zone type of picking is for parallel processing. When multiple batches are combined in a wave, then the number of picks can be quite large for the full-path picking described in section 3.1, so in order to improve throughput time the parallel processing of zone picking is introduced (Reveliotis 2, Sharp 7).

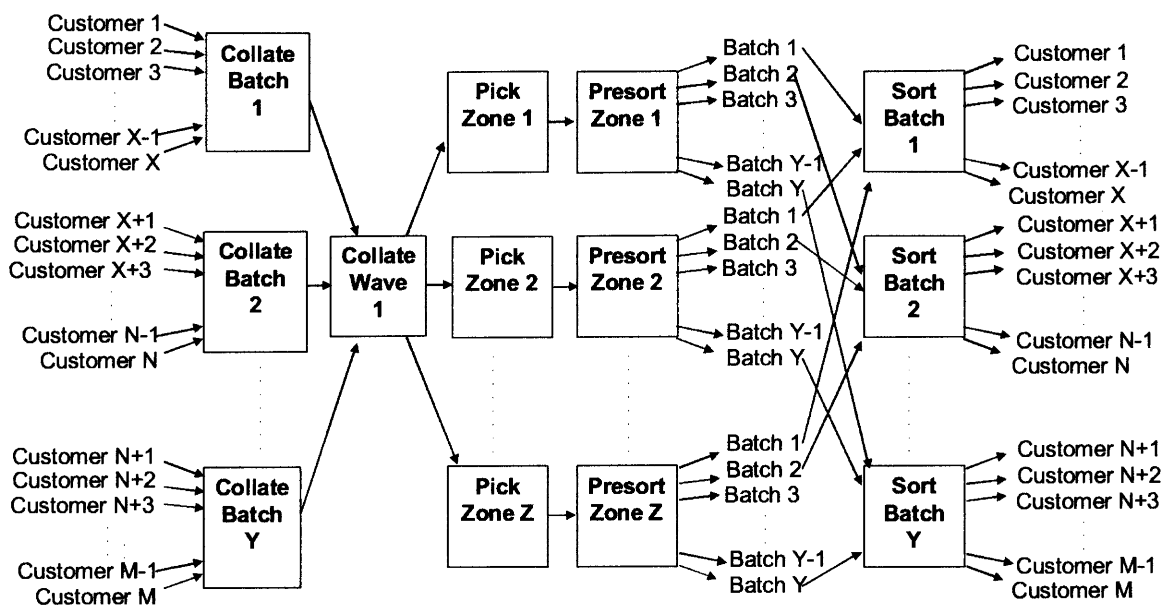

Figure 3.1 The Coupling and Decoupling of Orders in Waves and Batches.
In the figure, multiple batches are created and then the batches are partitioned and assigned to the pick zones. The picked items are presorted into the separate batches and then finally sorted again to individual customer orders.

Just as in the full-path picking, one key consideration in implementing a single order pick over multiple zones is the size of the customer order. If the order is large, then it might be reasonable to dispatch a picker per zone assigned to retrieve the items for this one order. For the combined zone picking and sorting, the logistics and transition between the multiple zones will need to be determined. The information about the association of products with customer orders will need to be provided to the picking personnel. The impact on picking labor productivity for the additional sorting task will need to be weighed against the benefits of batching. Lastly, the downstream sorting with zone picking requires considerations similar to the full-path picking scenario. However, if the batches are combined in waves, then the impact and costs of the additional presort will also need be considered and weighed against any additional picking benefits.

3.3 Downstream Sorting Equipment Alternatives

There are many different types of equipment that can be used to sort products and customer packages. Equipment can be as simple as carts and totes or as complicated as full-automated conveyors with routers and automatic delivery systems. Depending on the operating process choices made and the fulfillment center business environment, some equipment choices are a better fit than others. Some of the equipment listed below combine the activity of sorting and picking in one process step. The list below includes some of the different types of sorting equipment that can be implemented in warehouse setting (Maloney 4). The key features of each alternative are summarized in Table 3.1.

- Manual Sorting Stations
- Tilt Tray Sorting System
- Automatic Dispensing Equipment
- Shoe Sorting System
- Carousel System

Sorting stations are the simplest of the sorting equipment choices listed above. The sorting stations involve a significant amount more labor as they are often implemented with highly manual processes. There is little capital cost involved with this type of equipment and the products that can be accommodated in the carts are often limited based on the size of the partitions in the stations for sorting the various customer orders. This type of equipment is usually a good fit for customer orders that have a small number of items and the characteristics of the products are uniform and relatively small in size. The sorting rate will be highly dependent on the individual processing rate. The incoming material to the sorting stations can be delivered manually in pick carts or a conveyor system. A semi-automated system is a combination of conveyor material handling for incoming totes with the manual sorting stations.

	Application	Positive Characteristics	Negative Characteristics
Manual Sorting Stations (Rebin)	• Small customer order • Small size products	• Low investment costs	• Limited by individual rate
Tilt Tray Sorting System	• High volume • Varied product characteristics	• High throughput based on mechanical capability	• High investment costs • May require labor interface • Large footprint
Automatic Dispensing Equipment	• High velocity products • Uniform small size products	• Automatic picking and sorting combined	• Investment costs required
Shoe Sorting System	• Shipping containers and tote management	• High throughput based on mechanical capability	• Investment costs required • Potential quality impact to product
Carousel System	• High velocity products	• Picking and sorting combined	• Investment costs required • Waiting time associated with carousel rotation • Replenishment and picking use can conflict

Table 3.1 Summary Chart of Sorting Equipment Alternatives.
The chart highlights the key positive and negative features of the sorting equipment and operations.

The tilt tray sorters are fully-automated sorters that use a system of trays that deliver packages or products to individualized chutes. The tray system is used to deliver and sort the items. The items are scanned by automatic overhead scanners or manual scanners. The scanned items are associated with their customer order and the tray mechanics are controlled, in order to deliver the items to the chutes associated with each customer order. For some sorting applications, tilt tray sorters are used to separate packages into geographic locations instead of individual orders. Because of their complexity and size, these systems are typically quite capital intensive. The systems are capped by the mechanical performance, but are also limited by the speed of labor that loads or unloads the system. The tilt trays can be designed with two trays per location, one that tilts to the left and one that tilts to the right or with one tray that tilts bi-directionally. In addition the chute design can have single or multiple layers of dispensing chutes. The chutes can be designed to feed automatically to the final shipping container or the products packed manually. The tilt tray system is generally more versatile in the product shape and size that can be processed than the carts, but the system is limited by the tray size and chute size.

The automatic dispensing system can combine the picking and sorting processes in one piece of equipment. The automatic dispensing system is designed as a product dispenser using gravity feed. This type of equipment works best for smaller uniform product types. The dispenser releases products to containers or a conveyor system that passes underneath it. The dispenser can activate or not activate dispensing on the order assigned to each passing container. It usually works best for high velocity products or for a warehouse with a limited product size envelope. The automatic dispensing system involves investment and infrastructure because a dispenser will be required for each available product.

A shoe sorter is a conveyor system with a system of shoes that act as diverters for the passing items. The shoe sorter is often used for totes or passing closed packages. The shoe sorter also separates the passing containers onto a chute system for accumulation. For individual items, the sorter has spacing that can catch or damage products. Most companies handling individual items require a no damage quality requirement. As a result, a shoe sorter is not the best fit for this business environment. These systems can be loud and fast moving. There are investment costs, but these costs are often less than the tilt tray system costs.

The carousel system is an automatic picking system with shelving or containers that rotate. The personnel interact with system at the end of the aisle and have to wait for the carousel to rotate to where the desired product is located. Most often this type of equipment is implemented with a single person managing multiple carousels at the same time. In this set up, the person will most likely retrieve the desired product from the carousel and then sort the item upon picking it. There is a significant amount of capital required. One has to balance the picking waiting time for carousel rotation versus the cost of having a picker walk to the active pick locations.

Chapter 4: Sorting Process Suitability Evaluation

The suitability of the sorting process to a particular fulfillment center business environment is highly dependent on the customer order structure and customer order trends. The key metrics of a well-run fulfillment center will depend on the customer requirements and expectations for performance. For the direct to consumer fulfillment, the cost effectiveness of the picking and sorting trade-off is the key metric for sorting process evaluation. Sorting quality and responsiveness are also important process characteristics, but this study does not address them in depth.

4.1 Key Parameters for Evaluation

One of the first key decisions of sorting suitability is the benefit of introducing a batch system within the operating environment. The improvement in efficiency with a pick batch system will depend on the size of customer orders, the pick area, and pick order set-up time. In general, batching improves picking labor productivity, but the increase of the batch size demonstrates diminishing returns. The greatest benefit of introducing a batch system is experienced when the customer order size is small, the pick area is large and the order pick set-up time is significant. The relationship between increased batch size and pick labor productivity is shown in Figure 4.1. The curve generated in the Figure 4.1 is based on Equation A.1 in the appendix. The time per batch and the time per item were actually collected from observations made of the Amazon.com manual sorting process. The time study numbers were collected for a controlled batch size and average number of items per order. This time study data was extrapolated to provide the curve in the figure. The extrapolation is generated from varying the number of orders per batch and the number of items per order using Equation A.1. The diminishing effect of increasing batch size can be seen in the figure and it is also clear that the effect of batching is greatest at the smaller number of items per customer order.

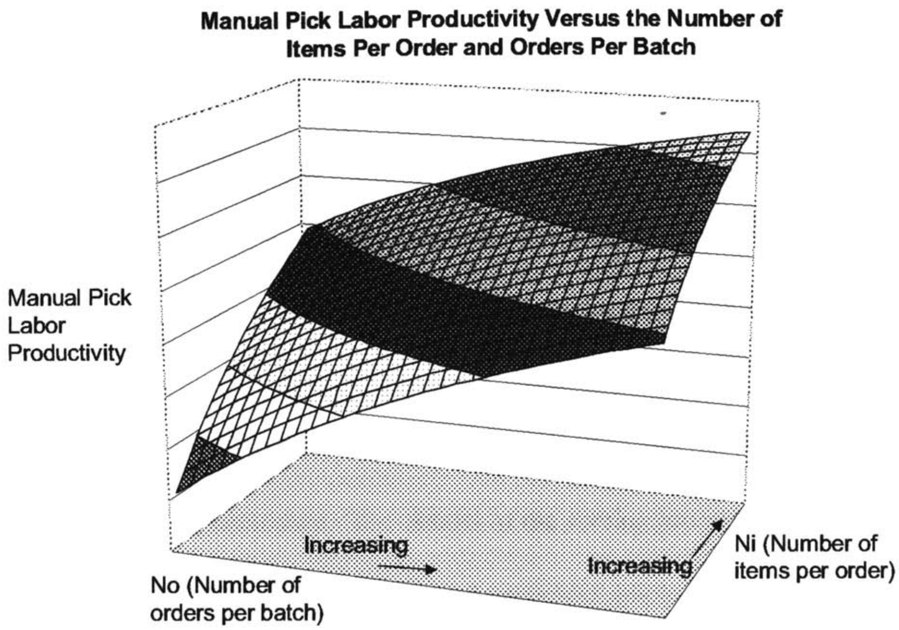

Figure 4.1 Pick Productivity as a Function of Batch And Order Size.
This figure shows an extrapolated curve based on varying order and batch sizes. The figure extrapolation is based on empirical data collected from the manual picking processing time at Amazon.com. The actual manual labor productivity numbers have been removed to protect information confidentiality.

Given that it is beneficial for the warehouse environment to introduce batches, then the choice of the sorting operation as well as the sorting equipment will be evaluated. It is critical that any new sorting costs fall under the threshold of the pick savings realized by introducing batches. The batch size will need to be determined and is often restricted by sorting process design. Because even though increased batch size improves labor productivity, there is an order throughput trade-off. As a result, it is best to find the batch size with the greatest slope or impact. If the slope decreases, then the increased batch size shows diminishing returns.

4.2 Sorting Evaluation

Once it is determined that batching and sorting will be introduced into the facility, the details of various sorting alternatives need to be evaluated and investigated. Some of the sorting alternatives can be eliminated based on the qualitative analysis about the application and fit to the particular business environment of the fulfillment center. The key factors to evaluate are the order volume received at the facility and the product characteristics. If the order volume is high, then the fixed costs of some of the highly automated systems can be better absorbed. If the product characteristics are variable, then the orders can be segmented for processing or a versatile type of sorting solution will need to be implemented. The details of the sorting process costs and the sorting process fit is described in Chapter 9 for a particular internet retail business environment.

Chapter 5: Fulfillment Center Process Labor Productivity

Fulfillment center management is a study in the effective use of direct manual labor. For many of the outbound fulfillment center processes, the effectiveness and productivity of the labor directly affects the capability of the outbound process steps and likewise directly relates to the overall fulfillment center capability and cost structure. In general, it is important to look for the best way to distribute labor throughout the fulfillment center facility and then attempt to make the required labor at each process step more productive through process or equipment improvements.

5.1 Picking Labor Important Factors

The implementation of a downstream sorting step is based on the attempt to increase picking productivity by combining orders for the picking labor. The major factors for picking labor productivity are:

- Items Per Processing Unit (Pallet, Case or Items)
- Number of Items Per Order (Manual and Semi-Automated Centers)/Number of Items Per Tote (Automated Centers)
- Combination of Orders For Picking (Batch System)
- Number of Customer Orders Per Batch or Per Wave (Manual and Semi-Automated Centers)
- Pick Density of Forward Pick Area
- Size of Pick Area
- Individual Pace

Some of the above factors can be controlled in the operations environment and some of them are directly related to the positioning of the fulfillment center in the supply chain. The processing unit size and the number of units per order are not directly controllable in the operating environment and are more a function of the business environment. Basically, the small number of units per order is typical of direct consumer sales and is part of the general retail business. The order size can most likely only be changed through marketing incentives that encourage consumers to purchase more items per order. However, such marketing incentives may work to have consumers postpone purchases until they have accumulated enough items to order so that they would be able to take advantage of an incentive structure that rewarded larger orders. This behavior change could in turn postpone the ability to recognize revenue and to turn inventory having a potential negative business impact. The unit size to be handled throughout the fulfillment center processing is also a function of the fulfillment center business model. If the fulfillment center function is a wholesale or a retail store distribution, the ordering quantities would either be sized in pallets or cases. When fulfilling direct to consumers as in Amazon business, the item quantities ordered are usually individual items. Lastly, operations only has indirect control over the number of items per tote. Operating policies can encourage pickers to fill totes completely before placing the totes on conveyor, but if the size of the picked items is generally large compared to the tote size, the number of items that can physically fit in a tote will be low despite operating policies.

The items per processing unit of the picking process has a significant impact on realized labor productivity. If the processing unit to be picked is a pallet, then the travel time of a single picker to that storage location can be averaged over the entire number of units on that pallet. If the processing unit to be picked is smaller such as a case or an individual item, then the travel distance to the storage location cannot be averaged over a large quantity of items. The negative productivity impact is greatest when pickers are handling individual items at each location. From the equations below, the labor productivity is simply the ratio of the units picked over the labor hours required to pick those units[3]:

$$\text{Pick Labor Productivity} = \frac{\text{Units Picked}}{\text{Labor Hours}}$$

$$\text{Units Picked}_{\text{pallet}} > \text{Units Picked}_{\text{items}}$$

$$\text{Labor Hours}_{\text{pallet}} = \text{Labor Hours}_{\text{items}}$$

$$\text{Pick Productivity}_{\text{pallet}} > \text{Pick Productivity}_{\text{items}}$$

If the number of items per order is large, then the picker can travel to multiple storage locations for one customer order on the same pick trip. The picker may be able to pick the entire order efficiently and not need to have a downstream sorting step because the order integrity is maintained. However, if the order size is small, then the pick list may need to incorporate additional orders in order to increase the pick labor productivity.

For the automated facilities, the average number of items per pick tote is an important factor in labor productivity. If the number of units per tote is small, then more pick labor hours is spent managing totes instead of picking items.

The pick density of the pick path is another important factor in the labor productivity. High pick density (number of picks per distance traveled) can translate to high picker productivity. There are two ways that pick density can be achieved: storing items in a close and compact manner and increasing the number of items picked on a

[3] Equation A.11 in the appendix is used to develop this pick productivity relationship.

single pick trip. A batching system is introduced if the fulfillment center plans to increase pick density by increasing the number of picks per single pick trip. Any storage locations that become available should be reallocated as soon as possible to ensure that all locations a picker passes are filled with product.

The overall size of the pick area to be traversed can negatively impact the picker labor productivity. If the pick area has a large square footage, then the amount of time required to follow a pick path in that area will be increased. If the pick area size is reduced to smaller zones by operations policies, then the overall travel distance per picker can be reduced, but additional sorting may be required as seen in the current processing at the semi-automated facilities. Likewise, products with a high turn rate should be located in a way that they are close and easily accessible to the operating point of the pickers.

Lastly, the individual pace of workers can impact the realized productivity. This can be indirectly controlled by operations by influencing behavior through incentive-based systems that encourage employees to work productively.

	Factor Trend	Labor Productivity Impact	Operations Control
Items Per Processing Unit	↓	↓	No
Number of Items Per Order/ Number of Items Per Tote	↓	↓	No
Number of Customer Orders Per Batch	↑	↑	Yes
Pick Density	↑	↑	Yes
Size of Pick Area	↑	↓	Yes
Individual Pace	↑	↑	Yes

Table 5.1 Operating Environment Factors Impact On Pick Labor Productivity.
The highlighted section of the table indicated the factors that the operation management cannot control. The arrows indicated the general correlation of the factor trend and labor productivity.

The summary of the impact of the various operating environment factors and their impact on labor productivity can be seen in Table 5.1. The first two factors listed can not be controlled by operations policies and are highlighted.

5.2 Sorting Labor Important Factors

The introduction of sorting labor is needed in order to separate the items from a pick batch or pick tote into each individual customer order. Understanding the key factors for sorting labor productivity is essential to make sure that the gains achieved in picker productivity through batching are not reversed with the introduction of additional sorting labor and equipment downstream. The major factors for sorting labor productivity are:

- Number of Items Per Order (Manual and Semi-Automated Centers)
- Number of Items Per Tote (Semi-Automated and Automated Centers)
- Number of Customer Orders Per Batch or Wave (Manual and Semi-Automated Centers)
- Workstation Set-up
- Individual Pace

The number of items per order and the number of customer orders in a batch or wave are the key metrics for determining the overall size of a batch or wave to be processed at the manual and semi-automated sorting process steps. If the batch size is large then the workstation set-up time will be spread over more units in the batch. In general, a large batch size has a positive effect on the sorting labor productivity. Likewise, the number of items per tote affects the amount of items over which the tote handling time can be averaged.

The individual pace of the sorting labor to remove and scan items has a direct impact on the labor productivity realized. The familiarity of the sorting personnel with the slot locations and numbering scheme has an impact on the searching time required to match a unit with its slot. The sorting station set-up can impact the individual pace of workers. The set-up may require that sorting personnel lift or move totes. In addition, the set-up will determine how far a person may have to reach, turn or walk to place an item in its assigned location. Operations can influence the individual pace by designing an effective workspace and providing incentives for employees to meet or exceed targeted rates.

	Factor Trend	Labor Productivity Impact	Operations Control
Number of Items Per Order/ Number of Items Per Tote	↓	↓	No
Number of Customer Orders Per Batch	↑	↑	Yes
Workstation Set-up	↑	↓	Yes
Individual Pace	↑	↑	Yes

Table 5.2 Operating Environment Factors Impact On Sort Labor Productivity.
The highlighted section of the table indicated the factors that the operation management cannot control. The arrows indicated the general correlation of the factor trend and labor productivity.

5.3 Packing Labor Important Factors

After the sorting process is complete and the items have been separated into the individual customer orders, the items must be packed into boxes so that they can be processed through the shipping department and delivered to the customers. The major factors for packing labor productivity are:

- Processing Unit Physical Size
- Number of Items Per Order
- Box Preparation and Set-up
- Size of Pack Area
- Individual Pace

If the physical size of the unit to be processed by the packing step is increasing, then the handling of the items by the packer may be slowed. In addition, if the items are bulky, then the packer is required to arrange them in the box in addition to placing each of the items in the box.

The number of items in an order will increase the packing time, but then the packing labor activity will be averaged over the greater number of items per order. The incremental time for an extra item will most likely be less than the overall set-up time. However, if the order gets particularly large there probably is a point where the impact of additional items tends to have a negative effect on labor productivity.

The box preparation and set-up time will have a negative impact on labor productivity especially if there is any walking or search time associated with finding and constructing a box. As the physical size characteristics of items change, packers may have to use larger boxes or multiple boxes to accommodate all of the items.

If the size of the packing area that the packer must cover is large in size, then any walking between orders to be processed will have a negative impact on labor productivity. The size or footprint of the packing area is often much greater with automated equipment systems which often have large spacing between consecutively completed chutes.

Finally, the individual pace of the packers can have an impact on the labor productivity achieved. With increased experience, packers can look at the items that required packing and immediately determine the required box size dimensions.

The impact of the operating environment on packing productivity is summed up in Table 5.3.

	Factor Trend	Labor Productivity Impact	Operations Control
Processing Unit Physical Size	↑	↓	No
Number of Items Per Order	↓	↑	No
Box Preparation and Set-up	↑	↓	Yes
Size of Pack Area	↑	↓	Yes
Individual Pace	↑	↑	Yes

Table 5.3 Operating Environment Factors Impact On Pack Labor Productivity.
The highlighted section of the table indicated the factors that the operation management cannot control. The arrows indicated the general correlation of the factor trend and labor productivity.

5.4 Labor Productivity and Product Size

Feasibility experiments were conducted to determine the relationship between the product size and the manual sorting labor productivity to see if expanding the product size capability can be accomplished in a cost effective manner. The experiments were done with a prototype work station that was sized to be able to accommodate larger sized items.

The methodology of the experiment involved the following factors. Three operators were used to repeat each trial run. The experiments were run with three different product cubes and with two sorting workstation configurations. One workstation configuration involved 28 sorting slots and the slot size was 14.9 inches wide by 10.5 inches high by 48 inches deep. In the first configuration, the slots were arranged with 4 rows by 7 columns. The second workstation configuration had the same slot size, but the slots were arranged with 3 rows by 9 columns with 27 slots. In the first configuration, the operator had to do less walking, but more bending and in the second configuration, walking was augmented and bending reduced. The sample size was determined by having the operator place 3 items per sorting slot which was the maximum number that could be accommodated in the prototype at the maximum product cube size tested. Each operator was timed on their ability to process 84 items in the first configuration and 81 items in the second configuration. The slots were numbered with their row and column position.

The procedure for each trial was that incoming material was delivered to the operator in totes on conveyor. The item was removed from the tote and the operator scanned the barcode. The barcode reader beeped when the barcode was read and a computer screen indicated to the operator the location to place the given item. The same sequence of sorting slots was used for each operator for identical trial set-ups. The slot sequence was randomly generated prior to the trial run beginning.

For the different product cubes, actual product books and compact discs were used as a representative case for small cube products. For the larger cubes, cardboard boxes weighed down with a 5 lb. ream of paper were used. Boxes with standard dimensions were used to reproduce large cube items. Barcodes were added to the cardboard boxes in random locations to replicate the barcode searching process that occurs in practice.

The increased material handling impact was captured in these experiments as the number of items per tote was decreased as the product cube was increased. About 25-30 items per tote could be accommodated with the small sized items. The largest cube size was representative of the point where only two of these sized items could be put in a tote container. For the same sample size, the tote handling was significantly increased for the maximum size sorted, as a result of the fewer items per tote. Approximately, forty totes were handled in the large cube trials.

The larger items are bulkier and more difficult to maneuver. It can be more difficult to lift the items and find the barcode for scanning. The bulkiness of the items contributed to the decrease in the labor productivity with increasing cube. From the log regression performed on the data collected from the experiments, the relationship between sorting productivity and product cube can be determined. The results of the regression are depicted in Figure 5.1. The fit to the data shows an asymptotic behavior. The reduction in the labor productivity approaches a labor productivity asymptote for large product handling. The experimental tests were done where every item in the sample for a given test run was either the same product size or a very tight product size distribution. The actual product distribution experienced at the sort process step has a varying combination of small and large cube items depending on the customer orders. The developed relationship depicts the worse case scenario of labor productivity for a particular cube size. The different workstation set-ups investigated were not found to be statistically different. The relationship determined by the log regression is used to extrapolate the sorting process cost data in relation to product cube in Chapter 9. Labor costs are increased according to the relationship determined by this log regression.

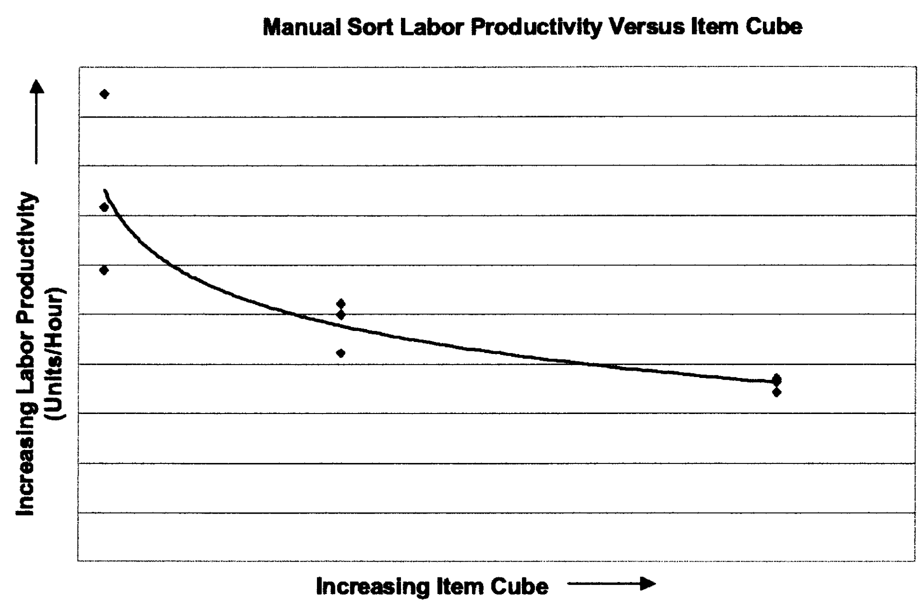

Figure 5.1 Plot of Manual Sort Productivity Versus Item Cube.
The figure shows the log regression fit to the empirical data set. The labor productivity values have been scaled to show the relative magnitude. The actual labor productivity numbers have been masked for information confidentiality. The three points at each cube signify the results for each of the operators.

In addition to the larger item effect, there is also probably a learning effect impacting the experimental results as some of the operators were not familiar with the standard manual sorting. The variation among operators decreased as the operators became more familiar with the cart layout and could locate the order slot easier. The operators became more familiar with visually searching the cart layout for the numbered location to place the scanned item.

Chapter 6: Amazon.com and Internet Retail

Unlike many other internet companies, Amazon.com has survived the internet rise and fall. The company's initial successes were built on the speed, reliability and ease of surfing the company website. And the continued improvement of the website features and services sustains Amazon's top rank in the internet retail domain. Maintaining an edge in internet retail requires, in addition to superior website services, that Amazon.com be a company that excels at both the operations and logistics activities that accompany being a large distributor. Having competency in low-cost high-throughput order fulfillment is an essential directive for the company in order to capture margins and additional sales volume growth.

When Amazon.com started in 1995, the goal was to provide an alternative book buying method for customers. Amazon.com began its journey into on-line retail with a selection of product offerings that was limited to books, music and video. The company followed a strategy that was focused on fast growth. The initial company growth was made possible by large capital inflows that were quite the norm for financing the internet boom. The fast penetration strategy was vital because the barriers to entry on serving the internet community were generally lower than was required in traditional retail store establishment. Because an internet company serves customers via home delivery, the internet company needs only to establish a network of fulfillment centers that are in reasonable proximity to customers' geographic region versus a traditional retailer who must establish itself locally in close driving distance to the potential customer base in order to win sales. By being one of the first to the internet market, Amazon.com gained a first mover advantage that helped in establishing the Amazon.com brand as well-recognized both domestically and internationally. The brand recognition continues to grow as the company provides quality service to its customer base.

Starting with the books and media-only business was an important first step for the company as consumers gradually adapted to the on-line buying experience. Buying books was not something that generally required physical contact or touch prior to making a buying decision. The descriptions and ratings provided on the internet site often supplied even more information than one would generally receive from visiting a local book store.

Since its beginning, internet retail provided customers with a convenience that was not available elsewhere. The convenience of having a desired item readily delivered to your door was a service for which the early adopters were willing to pay a premium. The internet retail businesses allowed a person to shop in the comfort of their own home instead of having to travel to multiple store locations to find a desired item.

In addition to the early adopter market that might be willing to pay a premium for convenience, there is also a large market segment of price comparison shoppers. Basically, the internet is rich with information and consumers are able to get competitive price information from other sites with little effort. The internet provides its users with information that previously was not readily available to the traditional retail consumer. In order to maintain competitive prices to capture the price sensitive shopper segment, it is critical to have a low cost fulfillment structure. The accessibility of information on the internet was both an asset and liability to the retailers - it allowed internet sites to convey information about their available products, but also allowed consumers to easily check competitors' offerings. The internet has provided the forum to make available information that revolutionizes the way that people shop for, buy and compare goods.

6.1 Changing Business Environment

In an effort to enhance the customer experience, Amazon.com has focused on increasing and diversifying the selection of products that it is making available to their customers on the website. Amazon.com currently handles the fulfillment for two strategic partners: Toys 'R Us and Target. Amazon.com now offers toys, kitchenware, electronics, baby items, clothes and a lot of additional items that their strategic partners have added to the established Amazon.com inventory. The introduction of the new strategic partners has significantly changed the product offerings. By increasing product selection, Amazon.com appeals to customers by offering a one-stop shopping website. In general, this strategy is positive because the new products are, for the most part, higher revenue per item offerings and the increased selection tends to augment the volume of items ordered off the website. The change in the product profile has translated to an increase in the average product size dimensions as well as the variance of those product dimensions. This shift in product size poses challenges to the operating environment at the customer fulfillment centers. If the costs of fulfilling these items can be well-managed or reduced, Amazon.com has the opportunity to increase the margins that it captures in fulfilling these products. The Amazon.com Fulfillment Center's goal is to minimize operating costs while maximizing the overall customer experience. As Amazon.com considers adding additional strategic partners, the product mix will probably only continue to grow in its variety and this will add complexity to order fulfillment in an operationally cost-effective manner.

Amazon.com has positioned itself in the supply chain as a consolidation center. The company adds value by being able to combine all of the different items that a customer orders into a single shipment to your front door. Consolidating items for a single order is in general a good fulfillment strategy as the transportation costs for sending ordered items individually can be exorbitant compared to the costs of consolidating all items into a single shipment. Generally, consumers find it convenient to receive all the items that they ordered in a single shipment to their front door.

6.2 Business Challenges

As consumers continue to grow more comfortable with the prospect of on-line shopping and ordering, their expectations for retailer performance also increase. Customer responsiveness and cost competitiveness have become critical objectives to continued business success. If a customer orders an item by next day freight, their general expectation is not for a week of fulfillment time and next day shipping. The customer is expecting a significantly reduced fulfillment time, so that the item ordered is actually received the following day. The internet business environment is far from the traditional catalog retail market that operated with a much longer turn-around time expectation. In the traditional catalog retail market, many order forms were received through the mail. Internet orders are received immediately and processed real-time. Traditional catalog customers usually only ordered via catalog as long as they were not on a tight time schedule to receive the given item. Internet shoppers expect fast turnaround and delivery as well as competitive prices; otherwise, they might find it as convenient to shop through traditional retail stores where the item might be readily available on the shelf.

Serving the retail market segment comes with a predictable seasonal fourth-quarter holiday spike. The fourth-quarter volume spike at Amazon.com has continually grown as the product offerings started to include toys, baby, home, and apparel items. With the addition of Toys 'R Us and Target, the seasonal spike has become more severe relative to the off-peak quarters of the year. One impact of the fourth quarter season is that any equipment that is sized to be fully-utilized during the holiday season will go under-utilized during the other three quarters of the year.

The fulfillment center environment involves a significant amount of direct labor and most decisions in the facility operating structure are a series of trade-offs in labor and equipment costs. Currently, in the manual facilities, Amazon.com combines incoming customer orders in batches so that the picking labor productivity is increased. The nature of direct consumer sales is a large amount of small item orders. Even as customers become more comfortable with on-line retail, the average order size has not shifted significantly. In order to increase the pick density of the orders, the orders are combined and picked together. The choice to combine customer orders results in the need to have a downstream sorting process step. The decisions made to optimize the picking process drive the need for additional downstream processing.

6.3 Fulfillment Center Landscape

After approximately 7 years in existence, Amazon.com has built fulfillment centers throughout the world. The landscape of those fulfillment centers is almost as varied as is the product mix that Amazon.com delivers to its customers. The Amazon.com fulfillment centers incorporate varying levels of automated processes. In the Amazon.com network, there are three different sorting processes in place: manual, semi-automatic and automatic. Currently, there are two domestic fulfillment centers with manual processes located in Kentucky and Delaware and three manual international facilities in Japan, Canada, and France. There are two fulfillment centers with semi-automated processes located in the United Kingdom and Germany. Finally, there are three domestic fulfillment centers with automated processes in Nevada, Kansas and Kentucky. There are no fully-automated sorting systems in place at international fulfillment centers. Determining the operational and cost effectiveness of these different fulfillment centers and the fit to Amazon.com current business environment is an important strategic objective. The goal is to develop a strategic plan that can be implemented for future fulfillment center design as well as improving the landscape of the current set of fulfillment centers to better fit the product mix and seasonal volume challenges. In the end, the goal is to reduce the overall cost picture of the customer fulfillment center operation and the cost of fulfillment center expansion.

Like many manufacturing facilities, the right level of automation for facilities is an important question. Understanding how manual and semi-automated processes fit together is an important objective for an internet retailer to serve its customers and to manage its costs. The automobile industry faced this situation in the early 1980s when there was a trend to introduce automation in as many manufacturing processes as possible. Now, the automobile industry has found that automation is a good fit for the majority of the spot welding and painting process steps, but the majority of other assembly and inspection jobs are still better served as fully manual or manually assisted processes (Milkman 14). How much automation is needed and what is the efficient level of automation for each process step in the assembly line? The fit of automated and manual sorting processes is the question that subsequent chapters will attempt to answer for the specifics of the fulfillment center processes in the direct to consumer fulfillment business.

Chapter 7: Amazon.com Operating Environment Challenges

7.1 Product Size Dimensions

The product size dimensions when Amazon.com first began its on-line retail activities had a very limited envelope. Most compact discs and videos come in standardized packaging dimensions. The only differences usually seen in the music and video packaging are greatest hit or collector editions that come in multi-CD or multi-video arrangements. Likewise, the variation in book size is not that large, but the distribution of book sizes does show more variation than the music or videos. The book sizes range from small paperback books to large coffee table books.

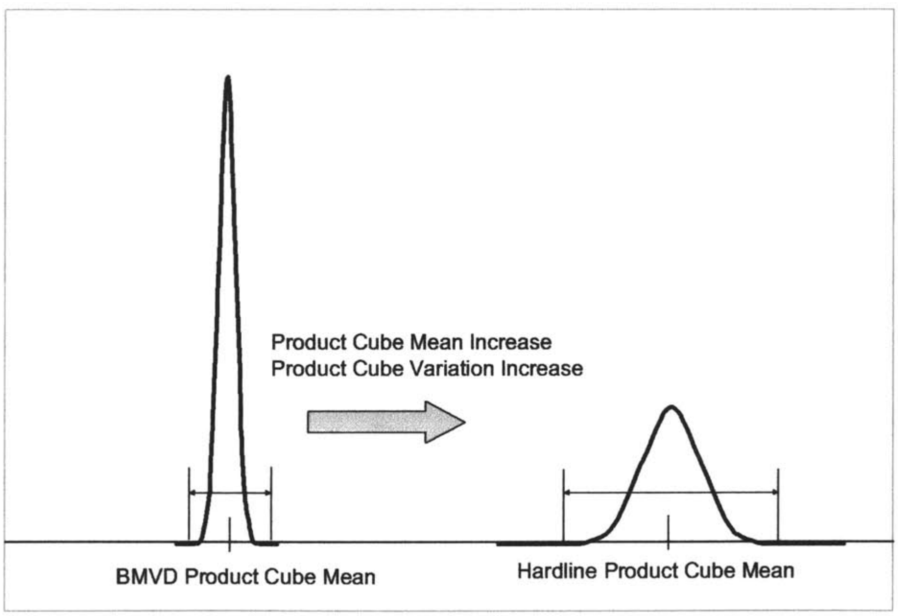

Figure 7.1 BMVD and Hardline Product Cube Distribution Comparison.
The normal distributions generated here are from representative product characteristic data from the product offering in the two different categories. The actual mean product form factors has been removed to protect confidential information. The normal curves scale has been modified slightly to protect the data confidentiality. The BMVD product group includes Books, Music, Video and DVD and the hardline products encompass all other product offerings

The introduction of toys and other product categories increased the average product cube and the range of product sizes as there is very little standardization in the packaging. In fact, packaging is used by manufacturers of hardline products as a differentiator to make particular products more appealing to consumers. The difference in the books, music, video and DVD (BMVD) and hardline products distribution for the item cube can be seen in Figure 7.1. The BMVD distribution is highly concentrated around a lower mean and the hardline distribution shows greater spread around a higher mean.

The operating impacts of the larger size items and the greater product variation are as follows:

- Fewer items per pick tote
- Bulkier items for handling by personnel
- Item variability for mechanized processing

By having fewer items in a pick tote, there will be in general more handling involved for both picking and sorting labor. The picker will have to use more totes to physically accommodate the picked products and each tote will need to be opened and closed virtually in the warehouse management system. Likewise, the picker will spend more time delivering completed pick totes to the conveyor system. At the sorting process, the inducting labor will also need to spend more of their labor hours handling totes. Each tote needs to be released to the active unloading area, the items removed and scanned and then the empty tote must be placed on take-away conveyor. If there are only a few items per tote, the inductor will spend more time releasing and placing totes on the take-away conveyor. The reduced number of items per tote has a negative impact on labor productivity.

In general, bulkier items will slow the pace that both picker and inductors can handle the items. The larger items might require a person to use two hands to pick up and handle the items. Likewise, the larger size items often also correlate with greater weight. The combination of the weight and bulkiness will slow the pace at which laborers handle the hardline items. The larger items also have the barcodes located in varied places and the picker or inductor will have to use some time to search for and locate the barcode on these items. For books and music, the barcode is most often located on the back of the item and generally easier to find. The bulkier and heavier items in general have a negative impact on labor productivity.

If the item product variability is increased, the use of automated equipment will need to be very flexible in its design. Most automated equipment and end effectors are designed for a particular product with specified dimensions. More flexible automation is often more expensive and it is often difficult to make the equipment work for every product configuration that may be presented. Automated storage and retrieval system are used in some segments of the warehousing industry, but they are often interfacing with a known product configuration such as a pallet or a case of items. To handle individual items without pallet or case packaging using an automated system is significantly more difficult.

In general, the larger items impose a negative effect on labor productivity, due to the fewer items that can be carried per tote and the bulkiness and weight of the items to be lifted or handled. In addition, the variability in the product envelope makes it more difficult to implement automated solutions to eliminate the need for labor to handle these individual items.

7.2 Product Order Distribution

Although many consumers still consider Amazon.com a place to primarily make book, music and video purchases, the ordering patterns of Amazon.com customers are changing with the increased selection of product offerings being made available at the Amazon.com website. Many consumers are still ordering books and other media, but there is a growing percentage of orders that are hardline products only, and also an increasing percentage of mixed orders. Mixed orders are orders that have at least one product from each category: one hardline and one BMVD.

The operating impacts of the growing percentage of hardline only and mixed product shipments are as follows:

- Growing capacity need for handling larger items
- Limited capability of current manual and semi-automated systems

The growing trend of mixed shipments indicates a need for additional capacity that can handle the larger variation and the higher mean cube product associated with hardline products. The sorting system will need to be designed to handle the largest item in the order. If books are mixed with hardline items, then the sorting system will need to be designed to handle the generally larger hardline items.

The limited size capability of the manual and semi-automated systems is a concern with a growing trend of consumers mixing book sales with hardline sales. For the customer, the ability to mix items in a single order is a desirable convenience, but for internal manual and semi-automated sorting operations, handling the size variation can be challenging.

7.3 Seasonal Volume Spike

Amazon.com experiences the seasonal upswing of product volume during the holiday season at the end of the calendar year that comes with being a part of the retail market. When Amazon.com first started in the book market the fourth quarter upswing was felt to some degree, but the impact has amplified since the introduction of retailers such as Toys 'R Us and Target. As the difference between the peak and off-peak volume grows, the ability to manage and utilize capacity more challenging. The trend for the fourth quarter spike is growing at a steeper slope than the volume growth during the first three quarters of the year.

The operating impacts of the seasonal variation in volume are as follows:

- Capacity utilization swings greatly
- Capacity sizing strategy is difficult to determine

The utilization of facilities and equipment capacity follows the trend of the seasonal volume spike. If equipment capacity is designed to be well-utilized during the fourth quarter of the year, the equipment will then be under-utilized during the first quarter of the following year. As a result, if fixed equipment capacity is implemented, the economics of the fixed system costs will be averaged over the high volumes run during the fourth quarter and over lower volume during the off-peak.

The strategy for capacity sizing is difficult to determine with such a large seasonal spike. Should the capacity be sized to meet the base load demand and additional swing capacity implemented to meet the additional capacity required beyond the base load during the fourth quarter? Or should the capacity be sized to meet the fourth quarter historical demand and be under utilized during the off-peak?

7.4 Order Size

The average order size for Amazon.com has shown a stable historical trend. The nature of direct consumer sales is a large quantity of small sized orders. Even during the fourth quarter, the average order size does not change. Likewise, it might be expected that as the general public becomes more comfortable with the on-line shopping that the number of items ordered per customer might increase in correlation with their growing comfort level. However, those trends are not demonstrated as the multi-item order size maintains a consistently stable average.

The operating impacts of smaller order size are as follows:

- Fewer items to average non-productive labor activities (pick travel time)
- More customer orders required to maintain a certain batch size

With only a few items per order, there are less items being processed per order over which the non-productive labor activities can be averaged. For the picking labor, the non-productive time is the travel time between picking locations, and for sorting labor, the non-productive time is the required workstation set-up time. The labor productivity of the sort and pick processes is negatively impacted by the small order size, but this can be counteracted with a batching strategy.

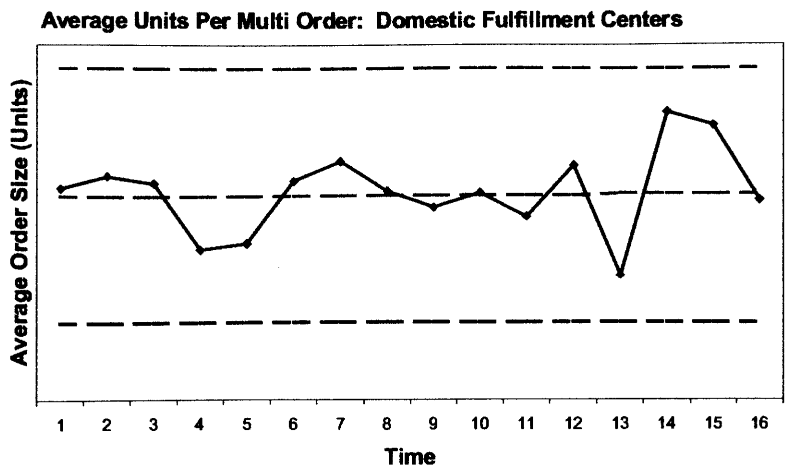

Figure 7.2 Control Chart of the Average Order Size.
This control chart shows that the average order size is in control over a historical time period. The chart is considered in control because there are no discernable trends. The data is randomly distributed above and below the center line. The control limits were calculated adding and subtracting 3 times the standard error from the mean value. The single item orders have been eliminated from this result. The figure is generated from actual historical shipment data. The actual shipment size numbers have been removed to protect confidential information.

In order to maintain a batch size with the required pick density for efficient picking labor productivity, the number of customer orders included in a given batch must increase because the average customer order size is so small. If the number of items per order is high, then fewer orders would need to be combined to maintain a given batch size. The need to maintain batching for pick density due to the small order size makes it difficult to look for ways to eliminate sorting as a required downstream process step. If items are combined upstream in batches, then there must be subsequent sorting to recover the individual customer orders.

The number of items per order displays an exponential underlying distribution with a single-sided peak and long trailing tail to higher items per order. Even though the underlying distribution is exponential, the averages calculated in the control chart have sufficiently high enough sample size to assume that the distribution is normal according to the Central Limit Theorem.

Chapter 8: Amazon.com Fulfillment Sorting Operations

8.1 Amazon.com General Outbound Process Flow

A customer's first interaction with Amazon.com is through the company's website engine. Once an order is received, the inventory levels are checked and if the order is chosen to be fulfilled through the internal network, it is assigned to one of the domestic fulfillment centers that has the least transportation costs associated with fulfilling the order. It is preferable to fulfill an order, if all items are available, at the fulfillment center located closest to the customer as this often translates directly to reduced shipping costs. Internationally, the decision on where to fulfill an order is greatly simplified as there is only a single fulfillment center associated with the orders received on each international website. Once the order is charged to the customer's credit card and assigned to be fulfilled from a given center, the operations within the Amazon.com outbound operations begin. The Amazon.com Outbound Process Flow is shown in the Figure 8.1. The general definitions and flow of the picking, order sorting, packing and ship sorting processes are provided in section 2.1.

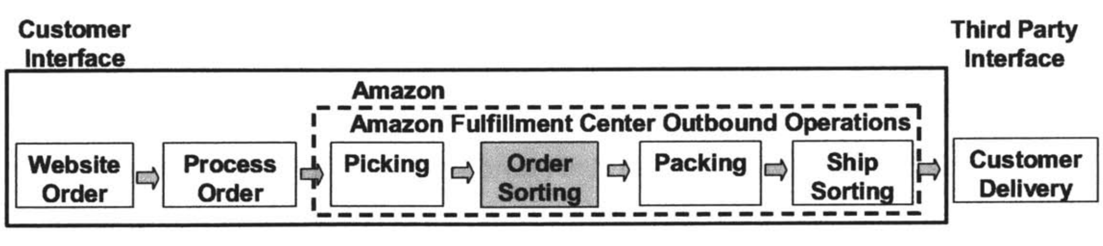

Figure 8.1 General Amazon.com Outbound Process Flow.
This figure gives a general overall view of the outbound warehouse operations at Amazon.com. The highlighted process (Order Sorting) is the primary subject of this thesis document.

8.2 Product Definition and Outbound Process Choice

Amazon.com ships many different products various product categories. Currently, the standard product categories are based on the size of the item. A sortable item is a product with package dimensions that allows the item to fit into the automated sorting system (tilt-tray sorter) and the associated tilt-tray packing chutes. The definition of a sortable item dimensions varies from facility to facility depending on the capabilities of the sorting process and equipment. If the item is too large to be put onto the automatic sorting system, then it is categorized as a full case item and processed through a separate full case process flow path. If the item is too large for the full case process line, then the item is classified as a non-conveyable item. In the manual fulfillment centers, the products that are too large for the sorting system are considered non-conveyable. Products that are considered full-case in automated facilities are lumped into the non-conveyable category in a manual center. Any item that is too large to be transported on the internal conveyor system or sorting system is run through separate process lines. The current product segmentation is depicted in Figure 8.2.

The full-case and non-conveyable sized items are processed as single items and sent out individually. Because these items are not combined with other items in the order, there is no need for downstream order sorting. Sortable-sized items can also be processed as single items if a customer orders only one item. Sortable-sized single item orders are picked together and moved directly to packing and shipping once the items have been picked, bypassing the sorting process step.

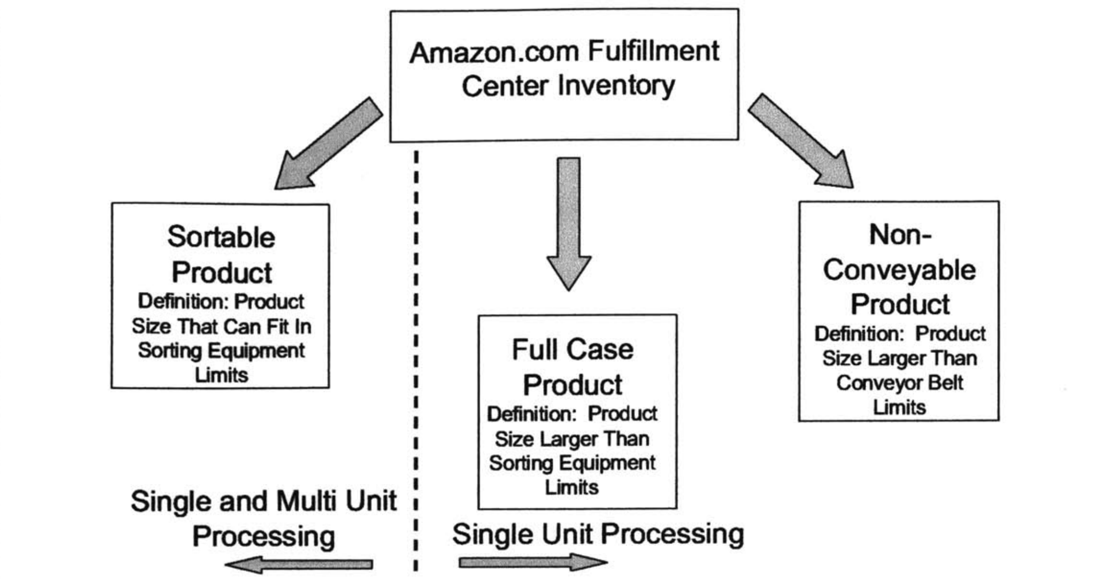

Figure 8.2 Product Segmentation Graphic.
This figure describes the current product segmentation at Amazon.com. The sortable items can be sent in single or multi-unit shipments. The full case and non-conveyable items are not combined together and are instead sent in single unit shipments.

Just as single line item orders have a separate process, if a large number of a single item is ordered, then that order is separated from the sortable process flow and these large orders are processed offline in a separate process known as Bigs (e.g. an order for 50 opies of Simchi-Levi et al textbook).

In addition to products being categorized by size for determining the appropriate outbound process flow, the products are also categorized by type. For example, Books, Music, Video and DVDs are one type of sortable product categories (BMVD). All other product types, including toys, kitchen items, baby items, electronics, are classified as hardline products. Hardline products can be sortable, full-case or non-conveyable, depending on their size. In general, the BMVD product dimension envelope is smaller and more consistent, so there is some correlation between the type of products and the size categorization.

8.3 Manual Sorting Center Process

8.3.1 Picking Process

The picking process in the current manual fulfillment center design isfull-path picking. With full-path picking, the picker follows the full path to the storage locations where all of the requested items are located. If a requested item is located in one far corner of the pick area and a second requested item for the same order is located in the opposite corner, the assigned picker has to traverse the entire distance between both storage locations; hence, the full path.

In general, the picking area for the manual centers is located on a single level and the picked items are placed in totes that are arranged on a pick cart. The pickers travel through a series of aisles with static library and bin shelving. There is a single input and output point at one end of the pick area. As a result, pickers must return with full pick carts to the area from which they started the pick path journey. The current storage policy is primarily randomized storage. Basically, an item can be stored in any available storage location. Some of the products that Amazon.com receives are in small quantities, so the randomized storage policy works well because as inventory is turned over, the released space can be reassigned to newly received product unlike dedicated storage space, where storage locations remained reserved for particular products even if the space is emptied. In general, the randomized storage policy reduces the amount of storage space required to hold the inventory. This is important because the smaller the picking area, the smaller the full-path trajectory for the picker.

The current manual process involves batch picking which means that each picker is assigned to pick a group of customer orders. The grouping of orders helps to increase the density of items to be picked by the pickers as they travel the full path of the pick area.

In order to know what items to pick and from where, the picker is provided with a pick list for multiple units orders or a group of packing slips for single unit orders prior to starting the picking process. The packing slips or pick lists are used as a picking reference. The picker loads his or her arms with picked items and returns to load the pick cart when his or her carrying capacity is reached. The number of return trips to the parked cart location varies from picker to picker. The picker serves as the first point for quality-control during the outbound process as the picker notes any damaged items that were found. The picker does not scan the barcode of the items picked, but does scan the batch number into the fulfillment center management system. Because of all the direct labor and travel time, the picking process step in most fulfillment centers is the greatest outbound cost in terms of direct labor.

8.3.2 Sorting Process

The manual sorting process is required to sort the picked items from a single batch into the individual customer orders. The picked items are returned to the single input/output point. The picked items are organized in a buffer until a sorting station (rebin station) is available for processing. The sorting personnel start the sorting process by setting up their workstation. They retrieve a full pick cart which contains a single batch of customer orders and an empty rebin cart. The empty rebin cart is a rolling cart with multiple shelves and moveable dividers. Each slot in the rebin cart is numbered. The rebin person removes an item from the pick cart and scans it. The rebin computer terminal responds with the location where that item should be placed in the rebin cart for that individual order.

The current rebin slot is designed to handle multiple books, music, videos or DVDs, but the dividers are adjustable to be able to modify the slot size for slightly larger orders. The manual process centers primarily focus their sortable order fulfillment activities around the segment of the business that is only books, music, video and DVD. The manual centers do not carry much inventory of the larger size toys, electronics, apparel or kitchenware as these items can not be accommodated in the currently designed rebin cart.

The number of slots in the rebin cart directly limits the number of customer orders that can be combined in a single pick batch. If a customer order is larger than the item limit per rebin slot, then that customer order spans multiple rebin slots which further limits the maximum number of customer orders that can be combined in a single pick batch.

Once all items have been scanned and placed into their corresponding slots, the rebin person isolates and labels any problem orders. For example, damaged items are removed with the other items for that same order and set aside for special personnel to resolve the problem. Likewise, orders that are missing items are removed and set aside until the missing item can be picked and replaced.

At this point, the rebin person adds the packing slips (P-slips) to each of the rebin cart slots. If any orders span multiple slots, the items in the order are combined in one slot and the corresponding packing slip is added with those items in the chosen slot. The packing slips have the rebin slot numbers that correspond to the cart printed on them. From this printed information, the rebin personnel makes the association between the packing slip and the customer orders located in the rebin slots.

The full rebin cart is then moved to a second buffer location where it waits to be processed by the stack labor. The stack labor places the items for an order and the corresponding packing slip on a cardboard footprint which mates to the size of the box required to ship all of the items in the customer order. The stacked items are carried via conveyor to the packing steps of the outbound process. The boxes are then closed, labeled and conveyed to the shipping area.

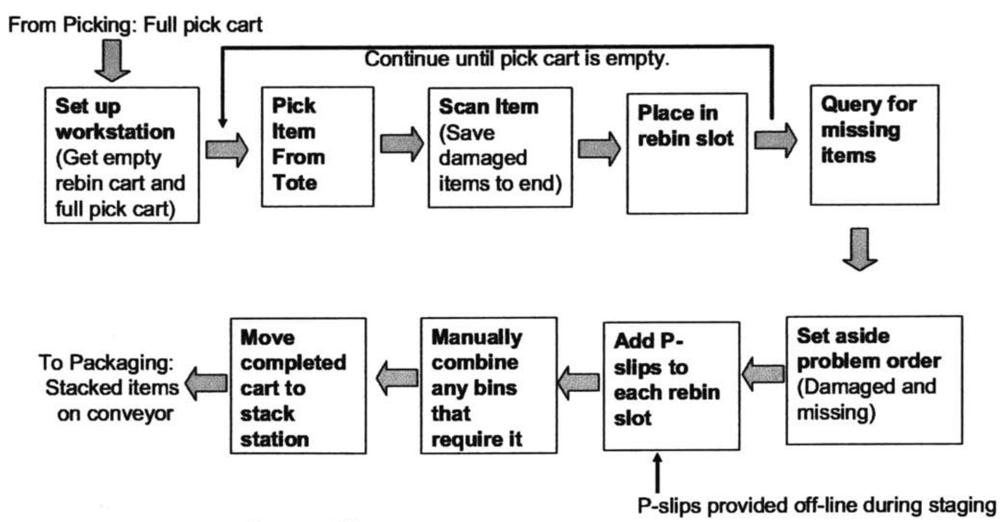

Figure 8.3 Manual Sorting Process Flow.
Flow diagram of manual sorting activities including the input and output conditions to the process as implemented.

8.3.3 General Observations of Manual Center

The general observations of the manual center are that the process rates are highly dependent on human factors, particularly the rates of individual employees. The process does not involve much capital investment as the process equipment is limited to scanners, computer terminals, and carts. Additional capacity can be easily added without significant additional equipment investment as long as the floor space and layout allow. The product size window that can be processed is limited in size to what can generally fit onto a bookshelf.

8.4 Semi-Automated Sorting Center Process

8.4.1 Picking Process

The picking process implemented at the semi-automated sorting centers uses a zone picking process. The picking area is separated into partitioned zones, and pickers pick items only in the zone that they are assigned. In each zone, only a portion of each batch is picked. This reduces the picking item density for each zone area. As a result, customer batches are combined together in what is known as waves in order to increase the density per zone area. The picker conducts full path picking within the zone area for the assigned wave. The introduction of waves in these facilities means that an additional sorting step is required to separate a wave into its batches. All items picked by a single picker for a wave are transported by cart to presort processing station. The semi-automated process still requires the final manual sorting step that further separates batches into individual customer orders.

8.4.2 Sorting Processes

The first sorting process in the semi-automated facility is called a presorting step. This is the process step where the picked items from a wave are separated into their assigned batches. Presorting is done at each zone output point where presort personnel receives a library cart with the picked items from that zone. The items are scanned and separated into totes that are associated with the original batch identification. The totes are then placed on a conveyor system that queues the totes for each batch for processing through the next sorting step into individual customer orders. The conveyor system assists in merging the picked items from the multiple zones of the pick area. The totes from each zone for a particular batch are queued together in a lane to wait for final downstream manual sorting.

The next sorting step is similar to the rebin process described in section 8.3.2 except that the items arrive to the sorting station via conveyor and the rebin slots are fixed in size. In order to maintain the flow of the conveyors into the sorting area, the system must be well-balanced. In general, the mating of the totes from the various zones must be well-synchronized. If the totes for a batch are received from some of the zones and not all of them, the batch is assigned a buffer lane to wait until the additional totes are received. When all totes for a batch have arrived from the pick zones, the totes are forwarded for processing to the manual rebin station when the station is ready.

At this point, the rebin personnel scans and places items into the rebin slots associated with each customer order. Each fixed-size rebin slot has a container that fits within it. The rebin slots have similar dimensions to those used in the manual process except that the rebin slots are deeper in this set-up, so that the slots can fit two interior containers. The rebin slots are open on both ends, so that the station can be accessed from one side by rebin personnel and accessed on the other side by packing personnel. When the entire batch is processed, the rebin personnel pushes the completed interior containers through to the opposite side of the rebin set-up where the items in the containers are processed by packing personnel. Completed rebin containers can be processed by packing personnel while the rebin station is refreshed with new containers and rebinning starts for the next batch. The completed customer orders are packed manually and conveyed to shipping.

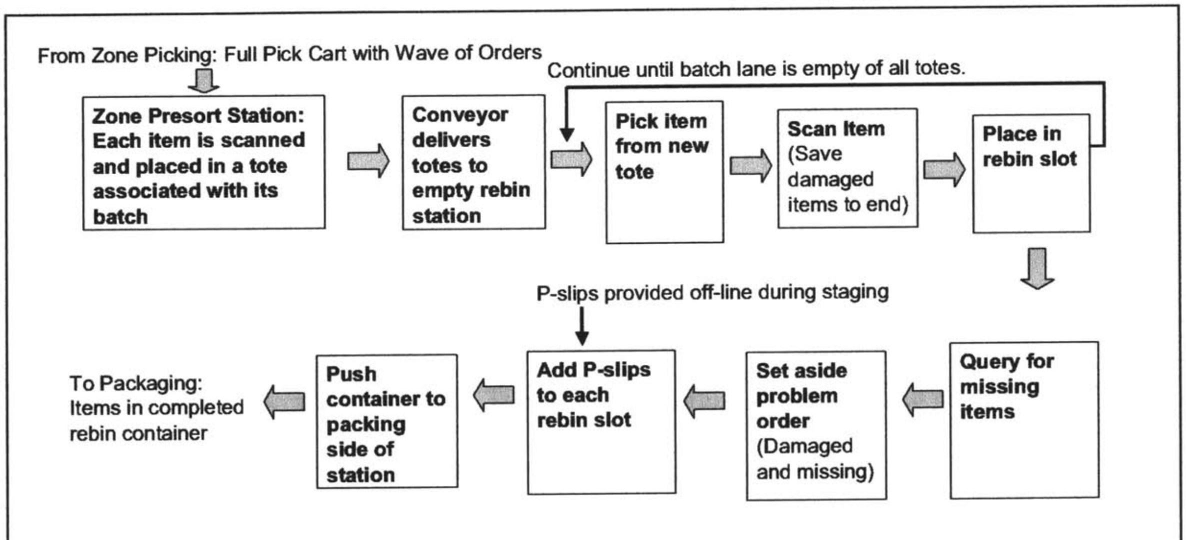

Figure 8.4 Semi-Automated Process Flow.
Flow diagram of semi-automated sorting activities including the input and output conditions to the process as implemented. The semi-automated process is similar to the manual process. The key differences are the presort stations and the conveyor material handling.

8.4.3 General Observations for Semi-Automated Center

The zone picking arrangement used at the semi-automated center drives the need for both a primary and secondary sorting step. There is a medium capital investment for the semi-automated center as the fixed rebin stations and full conveyor system must be implemented to support the transport of totes from the picking area to the sorting area.

The capacity of the system is slightly more limited as the conveyor and sorting stations are fixed in their design. The addition of capacity is not as flexible as the rolling cart system of the manual sorting center. There is a need to have synchronous flow, so as not to block the buffer lanes. The semi-automated facilities have some, but little batch effect as the work flow seems almost like continuous flow to the operator at the final manual sort station. Because this process uses a final manual sort with fixed slot sizes, the process is limited in the product size dimensions that can be run through it. This is a similar restriction as noted in section 8.3.2 with the manual rebin process.

8.5 Automated Sorting Center Process

8.5.1 Picking Process

The picking process used in the automated centers is a manual pick where, in the pick area, the picking instructions are provided to the pickers via a radio-frequency scanner. As a result, picking instructions can be given in real-time instead of being fully pre-determined on written pick lists. The pickers generally stay in a given picking module as the picking instructions are meant to be localized to the area where the picker is operating in order to reduce picker travel time. The definition of picking zones is not as restrictive as in the semi-automated center. Pickers can receive instructions that require them to travel between pick modules. Depending on the picking area, the pickers maneuver the aisles with totes that ride freely on conveyor or with totes on carts. The pick area is a system of modules with a combination of flow rack and library shelving. Each picked item is scanned into the pick tote. Once a pick tote is full, it is scanned full and the picker loads the pick tote onto a conveyor system that brings the picked items to the queue for the sorting system. All pick items are stored virtually in the tote location. The items for each picker are not necessarily from an individual customer order. The ordered items are grouped together based on prioritization, so that all picked items for an individual customer order arrive in close proximity to each other at the sorting machine. The required items to be picked for a customer order are not picked by a single picker in a single tote; hence, the individual order integrity is not maintained. The grouping that occurs requires the need for the downstream sorting step.

8.5.2 Sorting Process

The automated sorting equipment is a tilt tray system. This type of automated equipment is used widely throughout the warehousing/distribution industry. It involves a system of trays that travel along a linear rectilinear path. Items are inducted onto the trays and the tray system delivers the scanned items to a chute system. When the tray encounters the assigned chute for the given item being transported, the tray tilts allowing the item to slide into the desired chute. The system has many chutes around the linear track. When a chute is complete, the items are manually scanned into a box and sent off for final packing and shipping.

Picked items in totes are accumulated in lanes for processing at the tilt tray sorter. The buffer lanes are similar to the accumulation process of totes at the semi-automated facility except that there is no required wait for entire batch accumulation. The inductor activates a tote and it moves down the conveyor to the active unloading area. The tote barcode is automatically read by a scanner. The inductor scans each item and place it on the induction belt. The induction belt associates the scanned item with its chute and assign a tray for the item delivery. The item is delivered by system of belts to the tray system. The tray tilts at the desired chute and the item is delivered to the chute associated with the customer order.

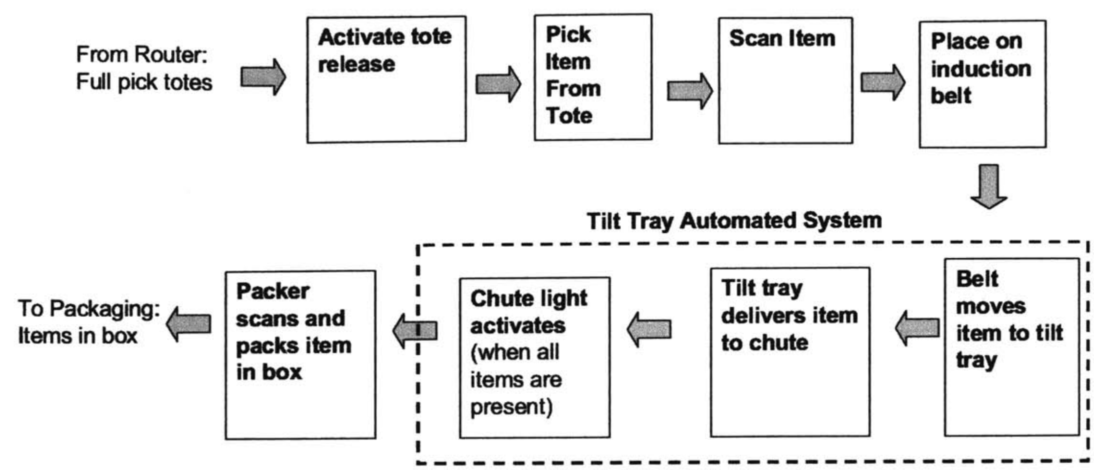

Figure 8.5 Automated Process Flow.
Flow diagram of automated sorting activities including the input and output conditions to the process as implemented. The activities that occur on the automated tilt tray system are highlighted and grouped together.

When all items for a given customer order have arrived at the chute, a light activates indicating that the chute is complete and the items are ready for packing. Once the packer obtains the appropriately sized box, each item is scanned as it is placed in the box. The packed items are now associated with the box barcode number. The boxed items are conveyed for final packing and label attachment and then sorting for shipping to the customer.

8.5.3 General Observations for Automated Center

Generally, the automated equipment has a higher capital investment requirement than the other alternatives discussed previously. The ability for additional capacity can be limited by the current performance of the equipment and the upgrade potential of the equipment. The automated equipment has the capability to handle larger size items than the previously discussed manual and semi-automated systems. The maximum throughput of the process is limited to the operating performance of the automated equipment and the labor interfacing with the equipment. The impact of order grouping in the automated centers does not have the same batching effect that is seen at the manual and semi-automated facilities. The picked product for any order or tote can be introduced at any of the automated induction stations. The totes do not have to be accumulated in buffer lanes to wait for batch completion prior to processing. When the totes arrive, the product can be introduced to the automated system and likewise as orders are completed in their assigned chutes, the packing process can begin immediately if packing labor is nearby to start processing the order. The automated system set-up and design reduce the time that items spend waiting for batch completion prior to processing at the next downstream step.

Chapter 9: Sorting Process Phase Diagram

In determining the optimal fit for the sorting processes with changing product profiles, the key parameter evaluated was cost. The quality and responsiveness of the fulfillment center operations are important characteristics, but this analysis focuses primarily on reducing and managing the costs of operating the sorting process in practice.

9.1 Overall Outbound Labor Cost Distribution

Understanding the labor productivity is key to comprehending the cost structure for the various sorting processes at the customer fulfillment centers. Given that the investments for equipment have already occurred, these costs are considered sunk. Any new capacity that is implemented requires the new investment costs to be factored into any net present value calculations. The costs currently being experienced at the fulfillment centers are the fixed and variable operating costs. These costs will continue to be experienced throughout the life of the process or equipment. In addition to the direct labor costs, there are maintenance labor, maintenance parts, supervisory labor, building rent and utilities costs required to support any installed equipment and the general process operation. These costs will be experienced throughout the life of any equipment installed.

When looking at the overall distribution of labor costs in the outbound area, the picking and shipping area have the largest direct labor costs. This is due to the travel time associated with picking and packing products. At some of the centers, the shipping costs are also augmented by the manual loading of trucks and sorting of packages into the shipping categories. The distribution of outbound labor costs is depicted in Figure 9.1.

Evaluation of the combined sorting and picking labor costs is important. If eliminating the sorting step results in only slightly higher picking costs than the cost combination of sorting and batch picking, then the implementation of sorting step should be reconsidered.

The direct and indirect labor involved in the sorting process step at the various fulfillment center types provides some interesting insights. The direct labor associated with the automatic sorting process is a higher percentage of the outbound cost than the sorting costs associated with the other processing centers. When automated equipment is implemented, it is often expected that the labor required to support that automated system will be reduced with the introduction of the additional equipment. From the data shown in Figure 9.1, it seems that the automated system requires the most labor. However. understanding the process boundary conditions and various site definitions for allocating labor costs is key for comparing process costs. In Figure 9.1, the cost distribution reflects the current site definitions for labor cost allocation. The manual sorting includes the manual rebin and stack labor. The automatic sorting includes induct, pack and support labor and, finally, the semi-automatic sorting labor costs include the manual rebin and support labor. The semi-automatic pack labor is part of the shipping percentage for this facility. For all centers, the picking and shipping labor costs include the full-case, non-conveyable and single item order processing. In general, the semi-automatic facility shows the least overall labor costs and the sorting labor is generally a smaller percentage.

However, looking at the sorting boundary definition will be critical and is discussed in section 9.2.

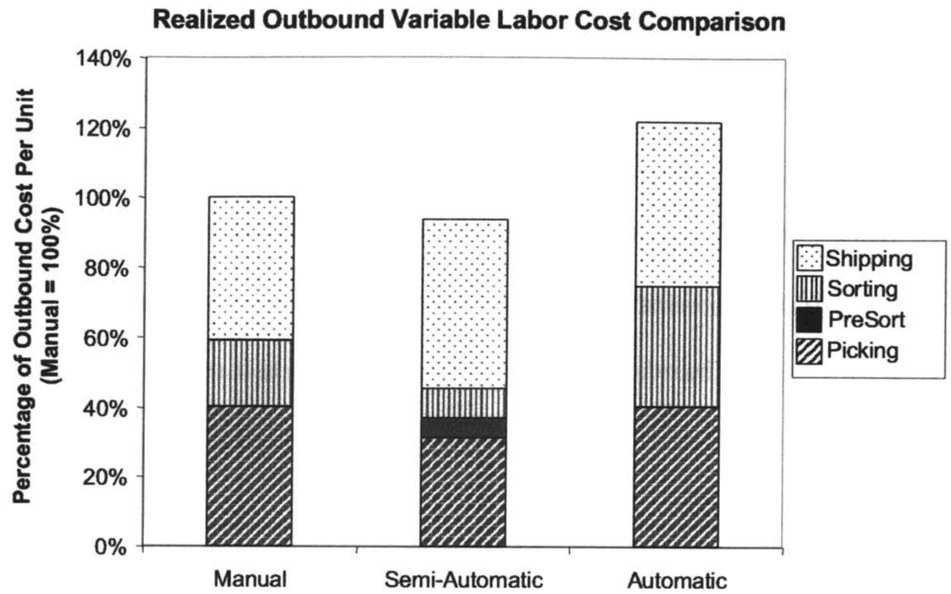

Figure 9.1 Distribution of Outbound Direct Labor Costs.
This figure shows the comparative distribution of outbound variable labor costs. The presort process costs are only shown for the semi-automatic sorting. The other processes do not have a comparable intermediary process.

The majority of the outbound processes at the manual and semi-automated facilities are manual, so most of the process costs are directly proportional to the labor required. The productivity of the manual labor directly translates to the process step productivity and potential throughput. For the automated process, there is also a significant amount of manual labor that must interface with the automated equipment. Even though the automated equipment has a throughput cap based on the system size and operating speed, the available capacity of the system may not be fully realized depending on the capability of the labor to feed the automated system and remove completed orders from the system.

Understanding the relationship between process labor productivity and labor costs is important for analyzing the cost structure of the processes evaluated. Figure 9.2 shows the relationship of labor productivity rates with a constant hourly wage rate. The direct labor costs are reduced with greater labor productivity rates, but as can be seen the impact to labor cost per unit diminishes as labor productivity increases. Labor productivity can be translated to direct labor costs. The automatic sorting (induct labor)has significantly increased productivity compared to manual processing . All sorting processes must be followed by a pack step. The combined sort/pack labor productivity is reduced by the lower packing productivity.

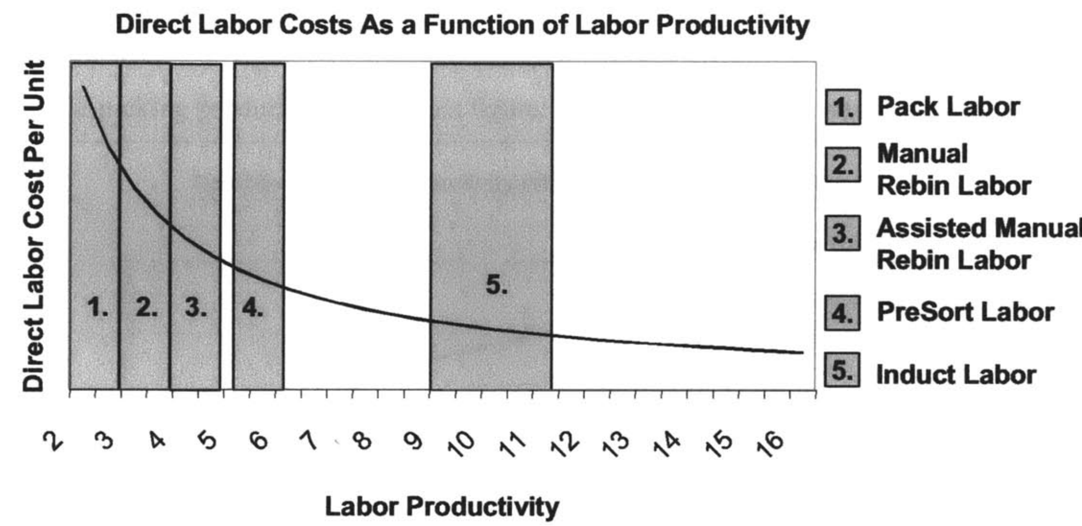

Figure 9.2 Direct Labor Costs as a function of Labor Productivity.
The figure shows the relationship between labor costs and labor productivity. The equation used to generate these results is Equation A.14 shown in the thesis appendix. The highlighted sections indicate the general range of labor productivity values for the listed processes. The labor productivity actual values have been scaled to show the relative magnitude of the values. The actual labor productivity numbers have been masked for information confidentiality.

The limiting effect of the lower packing productivity rates is depicted in Figure 9.3. The impact of higher sorting rates to the overall combined labor productivity shows a diminishing effect. A constant pack rate is assumed for this analysis. Even though the sorting rates are quite varied by process, each process is followed by a slower manual packing process. As a result, the overall labor productivity potentially achieved system-wide is limited. Despite this interaction, the sorting process was analyzed as a segmented unit looking for the local optimum in the sorting process. However, looking at the global processes may be beneficial given that the sorting labor productivity is usually always greater than the packing productivity. In this analysis, it was determined to isolate the sorting process from the upstream and downstream processes, but it is important to understand the impact and interactions for a thorough development. Equation A.13, the equation for combined labor productivity described in the appendix, was used as a basis for Figure 9.3. The combined labor productivity equation was modified in order to exclude picking productivity from this figure. A constant pack rate was assumed.

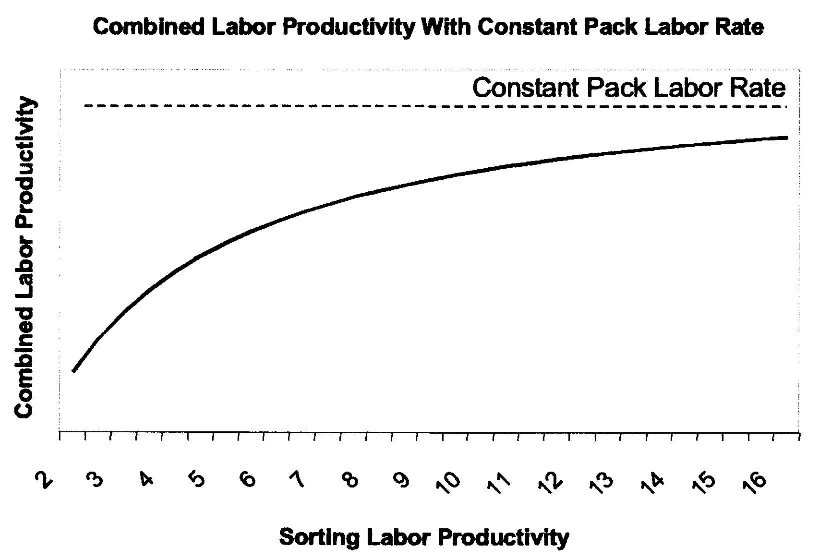

Figure 9.3 Graphic of Combined Labor Productivity.
This figure shows the relationship of combined labor productivity and varying sorting labor productivity values. The pack labor productivity is held constant The equation used to generate these results is a modified version of Equation A.13 shown in the thesis appendix. The modification is as follows:

$$\text{Combined Productivity} = \frac{1}{\frac{1}{\text{Sort Productivity}} + \frac{1}{\text{Pack Productivity}}}$$

9.2 Sorting Process Boundary Definition

In order to conduct a sound comparison between sorting processes, the following boundaries around the sorting process were determined. To make the boundary decision, it was important to look at the input and output conditions for each of the processes. The input/output conditions and the sorting boundary for each process are depicted in Figure 9.4. The manual and automatic sorting boundaries were determined to be between picking and packing. As a result, the packing labor that is included in the current sorting labor figures must be removed. The boundary for the semi-automated center was determined to be after the presort process step. The presort process step was removed because it is basically a different decision making point about combining batches in waves. The other processes could implement the combination of batches in waves to achieve potentially greater picking labor productivity. Because the other facilities maintain batch integrity and the pick labor was not going to be explicitly included in the sorting process cost comparison, it was a logical conclusion to separate the presort process step from the cross-site comparison. The presort processing and batch combination in waves could be implemented at the manual center. There was not a clear link between the presort and sort step at the semi-automated center. The presort step would most likely not be implemented at an automatic center because the process is more of a continuous flow. But, if multiple induction introduction points were implemented at the automatic sorter, then presort might be needed to make sure that product is directed to the correct bank of induction stations.

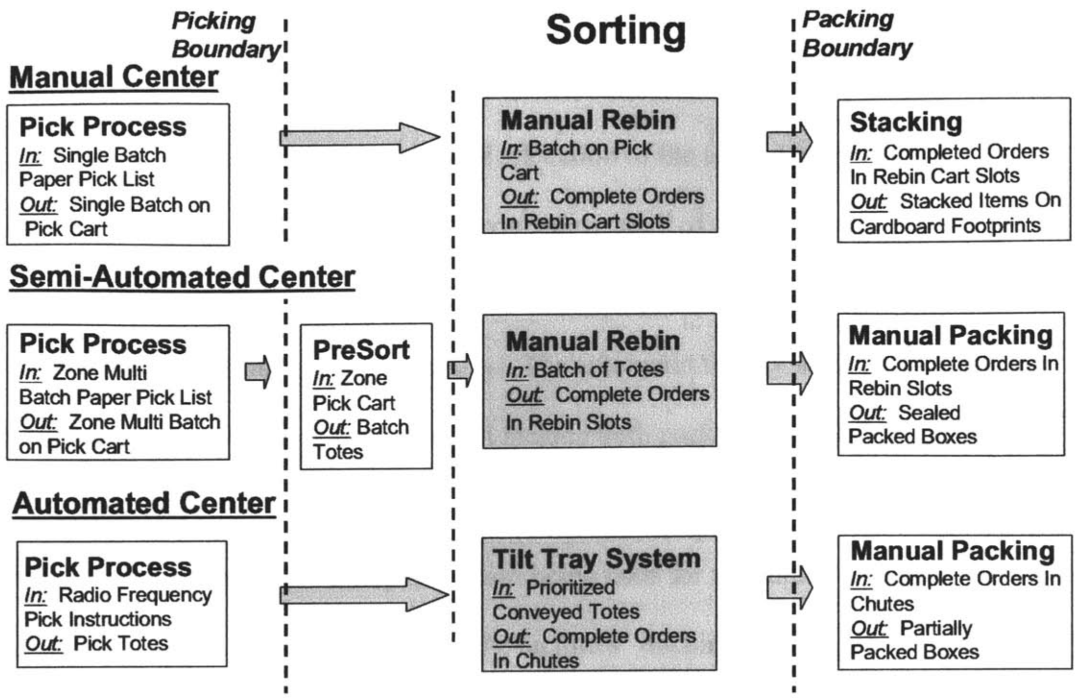

Figure 9.4 Sorting Boundary Graphic.
The figure shows the boundary conditions for the sorting analysis in this thesis document. The highlighted processes are the focus of the comparative analysis. The presort process of the semi-automated center is excluded because this is primarily a function of the zone picking processes used at this type of facility.

9.3 Sorting Centers Operating Cost Comparison

The operating costs numbers determined here are used to construct the sorting process phase diagram that will be described in section 9.4 of this chapter. The breakdown of the sorting operating cost per unit attributed to each process type are shown in Figure 9.5. The operating costs per unit developed in this section are reflective of the current product cube distribution and item volumes. The development of the sorting process operating costs per unit is bounded by the process boundary described in section 9.2. To determine the facility costs attributed to the sorting process, a cost allocation methodology was used.

The fixed labor costs are based on the outbound operating managers headcount required to operate the sorting process. The fixed headcount cost was a partial allocation of the senior operations manager and full allocation of the sorting area manager. The fixed labor costs were determined to be equivalent at all of the facilities.

The direct labor cost figures were acquired from actual labor hours tracked by the facilities for the various sorting processes. The automatic facility labor costs had to be modified because the labor hours tracked include both packing and sorting labor hours. The sorting labor cost numbers needed to be extracted from the combined figures because of the restricted sorting boundary definition being used for this analysis. For the semi-automatic system and manual systems, the facilities' tracking of hours could be translated directly into the operating cost per unit figure.

The other fixed costs were determined by allocating a percentage of the facility costs. The materials costs for each facility were determined by taking a percentage of the facility supplies costs. The maintenance labor costs were determined by a varying percentage of the maintenance department or service labor costs. A higher percentage was allocated to the system with the highest complexity because the system complexity translated to larger maintenance needs. The maintenance labor and part costs were consistent with the service contracts held at the facilities. And, generally, these costs were small compared to the order of magnitude of the other operating costs considered. The indirect labor costs were determined by taking a percentage of the direct labor costs and mirrored the level of indirect support required. The building and overhead costs for each facility were determined by taking a percentage of the building infrastructure costs that was based on the ratio of the sorting system footprint to the entire facility footprint.

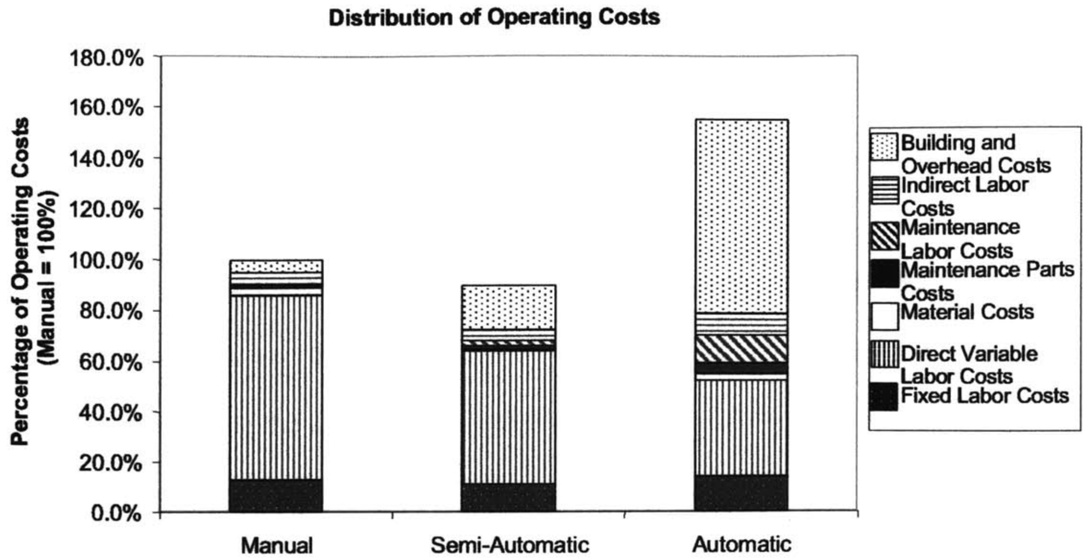

Figure 9.5 Sorting Operating Costs Comparison.
This figure provides the details of the percentages of the various operating costs breakdowns for each of the sorting center types. The cost breakdown is determined by allocating the operating costs to the various sorting processes. The details of the costs are excluded to preserve information confidentiality.

The semi-automatic system has the least overall operating costs. This is largely due to the high labor productivity rates achieved at the sorting stations compared to the manual facility. The semi-automated sorting achieves higher productivity rates because the sorting personnel have very little set-up required at their stations and the material handling is automated, so they rarely have to leave their workstation. In addition, the semi-automatic system has a much smaller footprint that the automated system.

The automated sorting system has the overall highest operating costs due to the high building and overhead costs. The automated equipment requires a large footprint and as a result, takes up a large percentage of the overall fulfillment center footprint. The direct labor costs make up the second largest percentage of the operating cost structure. However, in comparison to semi-automatic or manual systems, the direct labor costs for the automated facility are the least. The automated facility does not require as much labor to support it as the other manual processes, but it still needs a fair amount of manual intervention.

9.4 Sorting Phase Diagram Results

In order to determine where the sorting processes fit with a given product size and the facility volume, a sorting phase diagram was developed. The sorting phase diagram is based on selecting the least extrapolated cost plane for each point on the graph and determining the cost plane intersections. The intersections of the least cost planes are the boundaries shown on the phase diagram. The operating cost per unit that was determined for each sorting process in section 9.3 is extrapolated for increasing volume on one axis and increasing cube size on the other axis.

The extrapolation with relation to increased cube size was completed using the empirical relationship between productivity and cube determined in section 5.4. The manual and semi-automated sorting cost curves were extrapolated to the product cube break point. The automated and expanded semi-automated process cost curves span all cube sizes represented in the phase diagram. The direct labor costs for each sorting process are scaled according to the labor productivity impact of processing products with higher cube determined in section 5.4.

The extrapolation with respect to the facility volumes assumes that the direct labor scales linearly. The fixed operating costs are assumed to be invariant for the given system capacity. As the volumes increase, the burden of carrying the fixed operating costs diminishes because these costs are divided by higher volumes.

The plane with the least given operating cost for a given set of product characteristics and volumes was determined to be optimal for a given cube and volume pair. The results of the least optimal operating cost plane and the boundaries determined are depicted in the sorting phase diagram in Figure 9.6.

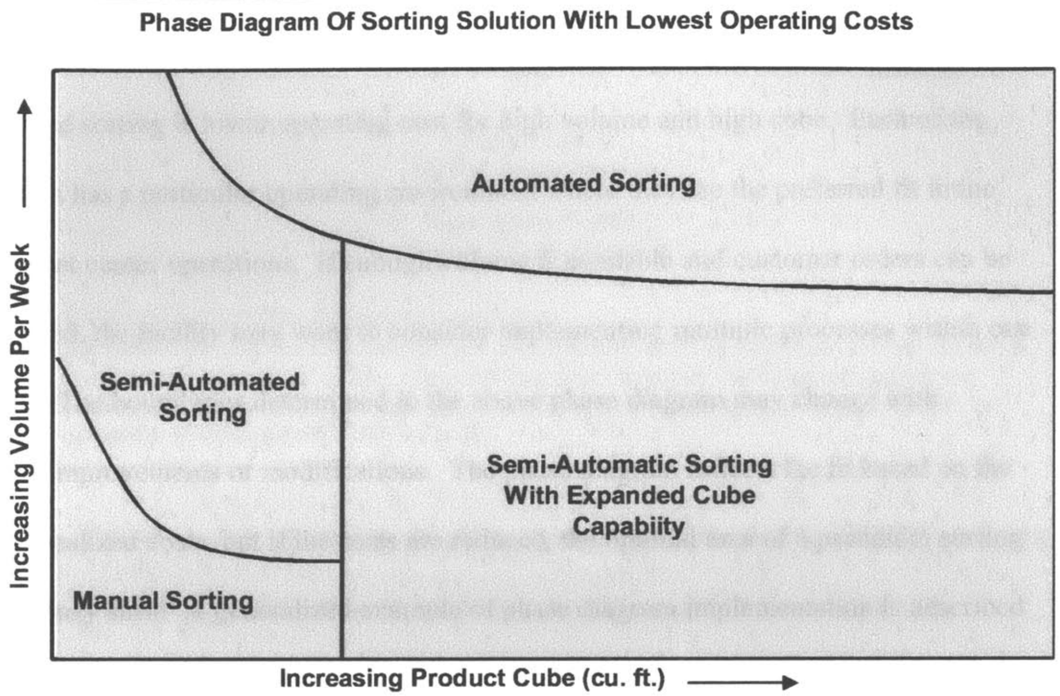

Figure 9.6 Sorting Process Optimal Phase Diagram.
This figure shows the least operating cost sorting solution for given product cube dimensions and volumes per week. The partitioning of the phase diagram is based on the intersection of the operating cost planes for each sorting techniques. The phase diagram is a projection of the least operating cost plane and the intersections between the developed cost planes. The actual volumes per week and the product cube have been withheld to maintain information confidentiality.

As shown in the diagram and discussed earlier in the process description, the manual and semi-automated sorting process break at a given product cube. However, the semi-automated sorting system can be modified to accommodate a larger cube product. The manual sorting is the optimal fit for small cube and low weekly volume products because of the low fixed costs and productivity rates lead to the least operating costs compared with the alternatives. If the cube stays constant, but the volume per week ramps up, then the facility will want to consider introducing semi-automatic sorting. The semi-automated sorting is preferred over manual sorting at higher volumes because of higher labor productivity rates achieved with this process implementation. The expanded semi-automated sorting is low cost for lower volume and high cube products. Finally, the automated sorting is lower operating cost for high volume and high cube. Each of the processes has a particular operating environment where they are the preferred fit in the fulfillment center operations. If enough volume is available and customer orders can be segmented, the facility may want to consider implementing multiple processes within one facility. The boundaries determined in the above phase diagram may change with process improvements or modifications. The phase diagram reflects the fit based on the current realized costs, but if the costs are reduced, the optimal area of a particular sorting process may shift. A generalized example of phase diagram implementation is described in section A.5 in the appendix.

9.5 Sortable Product Profiling and Segmentation

Based on the phase diagram results described in section 9.4, the optimal sorting system can be determined based on the facility volume and the product cube characteristics. As a result, a potential exists to further segment sortable products to reduce fulfillment center costs. A given customer order should be profiled based on the largest product in the order. Based on that product's dimensions, the sorting system chosen to process that order should be determined based on the phase diagram and the proposed sortable product segmentation described in Figure 9.7.

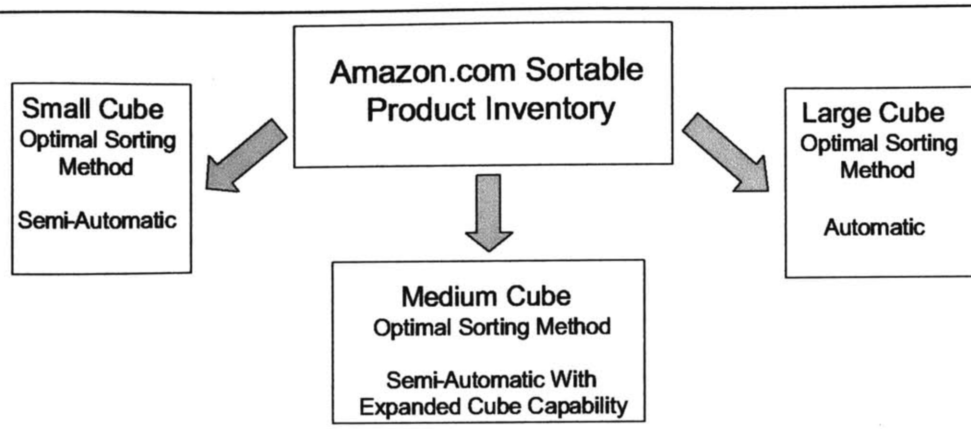

Figure 9.7 Proposed Sortable Product Segmentation.
This figure shows one potential way that Amazon.com in particular could implement and use the phase diagram to make process path decisions. The sortable current inventory can be segmented and the processes chosen to match each of the segments. These partitions of the optimal sorting methods are assuming that the volumes requirements are met.

The automated equipment should be used for products that are profiled as having a large product cube. Orders not containing a large item should be profiled and redirected from the automatic tilt tray equipment to semi-automatic processing. There is a potential opportunity to aggregate sortable inventory at one fulfillment center and to provide multiple sorting process paths within a single fulfillment center. Based on the customer order patterns, the orders should be stratified over multiple processes within a single fulfillment center. A move to this type of fulfillment center will normalize or create uniformity with sorting processes and overall sortable fulfillment center operations. Basically, the segmented order profiling and sorting processing helps the fulfillment center to find the least cost fulfillment method for a given order segment versus a single overarching sorting solution that may be more costly than required for the types of products ordered.

Chapter 10: Sorting Analysis Conclusions

When choosing a sorting process application for a particular customer fulfillment center, it is critical to understand the business environment in which the fulfillment center is operating. The key characteristics for determining the sorting solution for a facility are the volume of customer orders, the size of products and the number of items per customer order. These general characteristics can be used as a first pass indicator to qualitatively eliminate the sorting alternatives that are not a suitable match for the business environment. Once the strategic sorting alternative choices have been made, the details of the alternative system costs, responsiveness and quality can be further evaluated to determine the best match with the fulfillment center customer requirements. The analysis provided in this document focuses on the costs and the labor productivity of sorting choices in practice.

10.1 Key Thesis Results

The key results that are developed in this thesis are:

- A sorting phase diagram shows the least operating cost sorting solution for given product cube dimensions and volumes per week. The partitioning of the phase diagram is based on the intersection of the developed operating cost planes for each sorting technique.
- The manual sorting is the optimal fit for small cube and low weekly volume products. The semi-automated sorting is preferred over manual sorting at increased volumes because of higher labor productivity rates achieved. The

semi-automated sorting with expanded product cube capability is low cost for lower volume and high cube products. Finally, the automated sorting exhibits lower operating cost for high volume and high cube.

10.2 General Recommendations

The following are the recommendations generated from this thesis work:

- Understanding the fulfillment center position in the supply chain and the specific fulfillment center business environment are critical to sorting process choice and implementation.
- Opportunities can exist within a fulfillment center to segment products so that sorting solutions can be matched to the physical characteristics of each product segment using the process phase diagram introduced in section 9.4.
- Industry and supplier benchmarking was a useful technique to understanding the potential applications and implementation choices for sorting equipment and techniques.

10.3 Future Opportunities for Analysis

This analysis focuses on a local optimization of the sorting process step. This type of analysis work can be conducted for the other key process steps in the fulfillment center work flow. The localized optimization can be helpful and fruitful to the understanding of the fulfillment center operations and how they can be improved or changed, but the boundary determination for cross-site comparison can be difficult. Looking at the global operations and, in particular, the interactions in the downstream and upstream processes is also an important analysis for fulfillment center management. Usually, a decision in one process results in a change downstream, as a result an improvement in one process can result in an inefficiency somewhere else in the process. The fulfillment center is a system of productivity trade-offs and each fulfillment center is looking for the least overall cost position for their business. In addition to conducting both local and global comparison analyses, the sorting processes should be evaluated thoroughly on the other important process characteristics of quality and responsiveness.

Glossary of Terms

BMVD Product: A type of product that fall into the category of books, music, video and DVDs.

Full-Case Product: A product that can fit on conveyor, but not in the sorting system.

Full-Path Picking: The picking system in which the picker must visit each location for an item in a customer order.

Hardline Product: A type of product that does not fall in the BMVD product category.

Induct: A task in which an associate scans the barcode of an item, places it on an automated conveyor and it is moved onto the tilt tray for travel to the chute.

Non-Conveyable Product: A product that has dimensions that do not fit on the conveyor system.

P-slip: A packing slip that is included in a customer shipment.

Presort Process: A primary sorting process required to separate waves into individual batches.

Rebin Process: A process in which the personnel sort ordered items into separate containers.

Router: A conveyor system that delivers and directs totes for processing at the induct stations.

Sortable Product: A product that has dimensions that can be accommodated in the sorting equipment or system.

Sorting Phase Diagram: A diagram providing the least operating cost sorting method for a given operating volume and product cube characteristic.

Stacking Process: A process involving stacking ordered items on a cardboard footprint in preparation for downstream processing.

Tilt Tray: An automatic sorting system that carries the items around the machine to the proper chute assigned to a given order.

Tote: A large plastic container in which items are placed for movement within the fulfillment center.

Zone Picking: A picking technique in which the picking area is partitioned into separated picking areas.

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Appendix

A.1 Time Study Labor Productivity Formulation

The labor productivity of the picking processes can be calculated and modeled as follows with time study data:

Manual Picking

T_b = Time that occurs per batch (hours)
T_i = Time that occurs per item (hours)
N_i = Number of items per order
N_o = Number of orders per batch

$$\text{Manual Picking Labor Productivity} = \frac{N_i N_o}{T_b + T_i * (N_i N_o)}$$

Equation A.1 Manual Picking Labor Productivity Equation.

The time per batch for manual picking includes getting an empty pick cart, pick list and traveling to the first location within the pick module and the return travel to the pick operating point from the last pick location. The time per batch also includes the amount of time for return trips to the pick cart to unload arms. The time per item includes the travel time between picks and the search and extraction time for each pick.

The affect of increasing product size can impact the manual picking process in the following ways:

- ***Increase T_b – Time Per Batch –*** If the items are large, they might not be able to fit on a single pick cart. As a result, return trips for empty carts will need to be added to the Tb figure.

- ***Increase T_i Time Per Item*** – If the items are bulky or heavy, the process of lifting and moving the items into a cart may take longer per item. The larger items will most likely require more shelf or pick space per product generally increasing the pick area size and as a result the time to travel to each item location.

The number of items per order is generally fixed and not a controllable variable that can not be used by operations to improve productivity metrics. In order to offset the increasing time per batch and time per item, operations may consider changing the number of order per batch, but decisions on batch size directly relate to order lead-time.

Zone Picking[4]

T_b = Time that occurs per batch (hours)
T_i = Time that occurs per item (hours)
T_w = Time that occurs per wave (hours)
N_i = Number of items per order
N_o= Number of orders per batch
N_b= Number of batches per wave
N_z= Number of zones that items are stored

$$\text{Zone Picking Labor Productivity} = \frac{N_i N_o N_b}{N_z T_w + T_i (N_i N_o N_b)}$$

Equation A.2 Zone Picking Productivity Equation.

The time per wave for zone picking includes getting an empty pick cart, pick list and traveling to the first location within the zone and the return travel to the zone operating point from the last pick location. The time per wave also includes the amount

[4] Assuming that items for picking are uniformly distributed over all zones in the pick area.

of time for return trips to the pick cart to unload arms. The time per item includes, as above, the travel time between picks and the search and extraction time for each pick.

The affect of increasing product size can impact the zone picking process in the following ways:

- ***Increase T_w (Time Per Wave)*** - As discussed in the manual pick environment, if the items are large, they might not be able to fit on a pick cart. As a result, return trips for empty carts will need to be added to the Tw figure.
- ***Increase Ti (Time Per Item)*** – As discussed in the manual pick environment, heavier items might require a two-hand pick and increase the time needed to traverse to the pick location.

In order to offset the increasing time per wave and time per item, operations may consider changing the number of order per batch and the number of batches per wave or the number of zones in the pick area.

Automated Picking

T_t = Time that occurs per tote (hours)[5]
T_i = Time that occurs per item (hours)
N_t = Number of items per tote

$$\text{Automated Picking Labor Productivity} = \frac{N_t}{T_t + T_i N_t}$$

Equation A.3 Automated Picking Productivity Equation.

The automated pick time includes a minor tote set-up time as the tote is retrieved and scanned into the system and eventually placed on the conveyor system when full.

[5] The time per tote refers to the time to activate the next tote, scan the tote and remove the empty tote from the active workspace. This is set-up time for each tote and not tote travel time from the pick area.

The majority of the time for automated picking involves the travel between items and the search and retrieval time.

The affect of increasing product size can impact the automated picking process in the following ways:

- ***Decrease N_t (Number of items per tote)*** – If the items are large, only a few items will fit per tote.
- ***Increase T_i (Time Per Item)*** – As above, the heavier items might require a two-hand pick and increase the time needed to traverse to the pick location.

Manual Sorting (Rebin Process)

T_b, T_i, N_i, N_o have the same definitions as above.
T_o=Time that occurs per order (hours)

$$\text{Manual Sorting Labor Productivity} = \frac{N_i N_o}{T_b + T_o N_o + T_i (N_o N_i)}$$

Equation A.4 Manual Sorting Productivity Equation

The manual sorting labor productivity can be calculated with a similar equation as the manual picking labor productivity. The key differences between the sorting and picking labor productivity formulation are that the T_b and T_i numbers for both picking and sorting activities will be different and there is additional sorting time per order (T_o) in the sorting formulation. The time per batch in the sorting process includes the workstation set-up time, the processing of problem orders and staging of the full cart for downstream processing. The time per item for the sorting process includes the scanning and placement of each item in its respective location. Finally, the time per order is the amount of time required to associate the packing slips with the each slot or customer order. This process step is done as a staging step for the downstream stacking as the packing slip for the order is then readily available and the items in an order can be verified against it.

Semi-Automatic PreSort

T_w, T_i, T_b, N_i, N_o, N_b, N_z have the same definitions as above.

$$\text{Semi - Automatic Presort Labor Productivity} = \frac{N_i N_o N_b}{N_z(T_w + T_b N_b) + T_i(N_i N_o N_b)}$$

Equation A.5 Semi-Automatic Presort Productivity Equation

The semi-automatic presort labor productivity is a very similar formulation to the zone picking labor productivity. There are some activities in the process that are based on the number of batches in the wave, so a time that occurs per batch was added to the formulation. The time per batch for the pre-sort step are the tote management and tote scanning that occurs for each batch in the wave. The time per item involves the scanning and placing of each item into the respective tote. The time per wave involves the set-up of empty totes, the time to get the next pick cart for processing and the time to log in the batch for processing.

Semi-Automatic Sort[6]

The semi-automatic final sort is very similar to the manual sorting accept that the product is delivered to the sorting station via totes versus in a cart. As a result, there is some tote management time as in the automatic sorting process. However, as in the manual process, there is still some batch time. The batch time in the semi-automatic sort

[6] Assumes that the average number of totes per batch shows little variation and that the average is representative of the load experienced at the final sort step.

involves setting up the internal containers for each batch as well as the order time of associating the packing slips with each order before passing the containers through the slots for downstream processing by the packing labor.

T_i, T_t, T_b, T_o, N_b, N_i, N_o have the same definitions as above.

$$\text{Semi - Automatic Sort Labor Productivity} = \frac{N_i N_o}{T_b + T_t N_b + T_o N_o + T_i (N_i N_o)}$$

Equation A.6 Semi-Automatic Sorting Productivity Equation

Automatic Induction

The automatic induction step is the exact same formulation as the automatic picking formulation. The key difference is that the time per item and the time per tote are different for the sorting process. The time per item for the sorting step involves removing items from the totes and scanning them and placing them on conveyor that feeds into the tilt-tray system. The time per tote involves both the tote activation time as well as the tote removal time once the tote is empty of items.

$$\text{Automated Sort Labor Productivity} = \frac{N_t}{T_t + T_i N_t}$$

Equation A.7 Automated Sorting Productivity Equation

Manual Stacking

T_b, N_o, N_i, T_o have the same definitions as above.

$$\text{Manual Stacking Labor Productivity} = \frac{N_i N_o}{T_b + T_o N_o}$$

Equation A.8 Manual Stacking Productivity Equation

The manual stacking process includes a batch set-up time as the stack labor must retrieve a completed rebin cart from the buffer. The stacking labor involves removing all of the items from the rebin slot and stacking them on cardboard footprints. Most of the items can be removed from the slot in one motion, so that is why a time per item is not included in the formulation. If a scanning step is added, then there will be a touch to each item and the time to scan each individual item will need to be added. The following term would need to be added to the denominator above $(T_i(N_iN_o))$.

Semi-Automatic Process: Packing

The semi-automated packing process involves removing the interior container from the completed rebin slots with all of the sorted items. The items are packed into the box and sent on conveyor to the final outbound process. For the semi-automatic process, there is a small batch time associated with stacking and removing all of the interior slot containers and there is no time per item as all items are removed together and none of the individual items are scanned. If the items are not packed in a single stack and require arranging, there may be a small, but mostly negligible time per item.

$$\text{Semi - Automated Packing Labor Productivity} = \frac{N_i N_o}{T_b + T_o N_o}$$

Equation A.9 Semi-Automated Packing Productivity Equation

Automatic Process: Packing

The automatic packing labor involves removing the items from the completed chute, scanning them and placing them into a selected box which conveys them for final packing and labeling. There is no batch time as any set-up time occurs for each individual chute which translates to a single customer order.

$$\text{Automatic Packing Productivity Equation} = \frac{N_i}{T_o + T_i N_i}$$

Equation A.10 Automatic Packing Productivity Equation

A.2 Manual Rebin Time Study Sensitivity

The manual sort labor productivity can be depicted in the following plot (Figure A.1) showing the slope of the labor productivity versus the number of items per order and the number of orders in a batch. In Figure A.1, the actual time associated per batch is the largest and the time per order the smallest, $T_b > T_i > T_o$. The sensitivity of labor productivity to the average number of items per order is greater than the sensitivity to the number of orders per batch. Unfortunately, the batch size is more easily controlled than the number of items per customer order. Batch size can be used as a lever to improve the manual sorting labor productivity. The function shows that labor productivity increases with increasing order size and increasing batch size, but that the increase in labor productivity shows diminishing returns on both axes. Larger batches can incrementally improve the sort labor productivity, but can reduce system responsiveness. The gains in increased number of orders per batch can easily be outweighed by increased order lead-time.

As the time per batch approaches zero $(T_b \rightarrow 0)$, the impact of increasing the number of orders per batch reduces, so that there really is no benefit in a larger batch size at that point. If the time per batch is decreased, the benefit of a batch system to the sorting labor productivity is decreased. If the batch time is diminished, the process strategic focus can be on greater responsiveness or throughput.

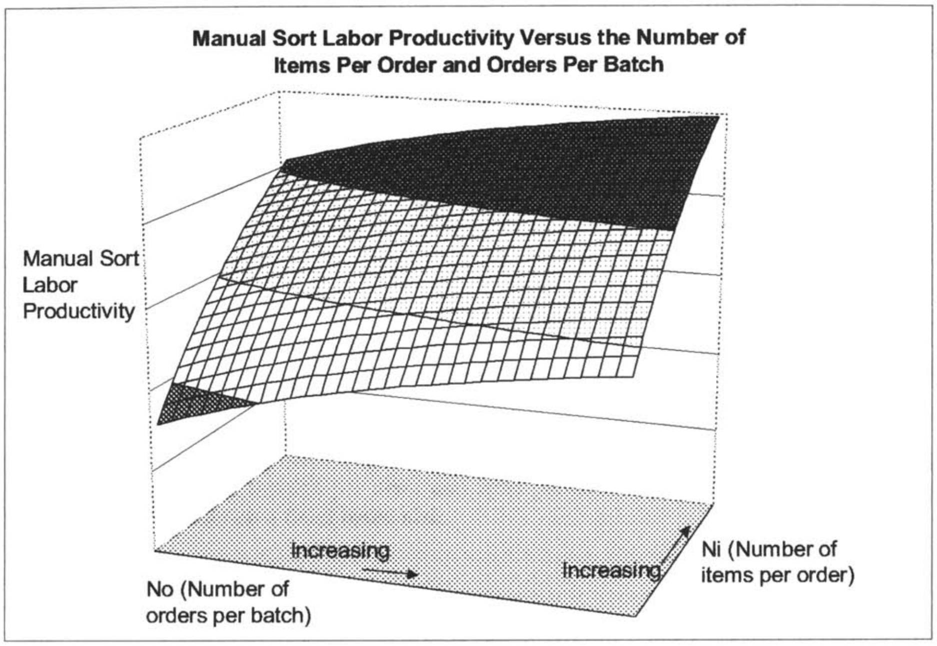

Figure A.1 Plot of Sort Labor Productivity Versus Order and Batch Size.
This figure shows an extrapolated curve based on varying order and batch sizes. The figure extrapolation is based on empirical data collected from the manual sorting processing times at Amazon.com. The actual manual labor productivity numbers have been removed to protect information confidentiality.

The sensitivity of labor productivity to the time per item and the time per batch is depicted in Figure A.2. The sort labor productivity is much more sensitive to the time per item than the time per batch. If the time per item can be reduced, then the impact to labor productivity is significant. When attempting to improve the labor productivity, the greatest impact will come from reducing the time per item.

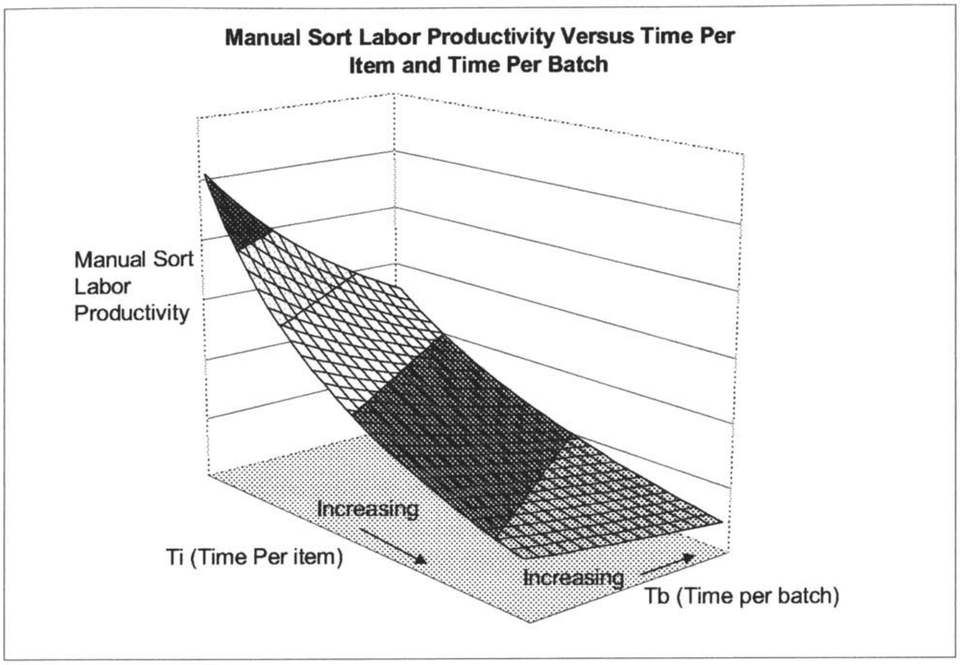

Figure A.2 Plot of Sort Labor Productivity Versus Item and Batch Time.
This figure shows hypothetical sensitivity curve based on varying order and batch sizes. The figure extrapolation is based on fixed number per items and order per batch. The time per batch and time per item were varied to see the impact on a fixed batch size.

The manual rebin sensitivity methodology can be used to determine the impact of perspective process improvement projects that will help to increase labor productivity and likewise reduce process costs. In the end, the time study results can be simplified for each of the process steps as follows:

$$\text{Labor Productivity} = \frac{\text{Batch Size}}{\text{Processing Time}}$$

Equation A.11 General Labor Productivity Equation

In order to improve labor productivity benchmarks, management can either look to reduce the required processing time or to increase the batch size processed.

Considering that batch size reduces responsiveness, it is probably best to find ways to reduce processing time. The opportunities for improving processing time are harder to find and often do not result in as significant of an impact as desired.

A.3 Realized Labor Productivity

In addition to the time study method described above for calculated process labor productivity, the actual realized labor productivity for the various sorting center operations can be calculated by taking the volume of items run through a process step and dividing by the number of hours that were direct billed to that process step over a given time horizon. This method of calculating labor productivity was used to determine the realized operating cost structure of the various sorting centers. The realized labor productivity includes any non-productive time that is realized throughout daily operations that is not captured in the time study model.

$$\text{Realized Labor Productivity} = \frac{\text{Volume}}{\text{Labor Hours}} = (1 - \text{Loss Factor})(\text{Time Study Labor Productivity})$$

Equation A.12 Realized Labor Productivity Equation

Closing the gap between the time study resulting labor productivity and the actual realized productivity is a potential opportunity. There is a lost factor associated with non-productive time that causes the time study benchmark labor productivity to not be met in the actual daily operations. In order to improve, the realized labor productivity at each process step, the efforts can be made to either reduce the loss factor by removing roadblocks that tend to reduce the time that the employees are doing direct task related work or the efforts for improvement can be focused around task and workstation design that will improve the time study benchmark results.

A.4 Combined Labor Productivity and Labor Costs

The labor productivity of the picking, sorting and packing labor can be combined in series to determine an overall labor productivity for the three outbound processes. The equation used to combine the individual process productivities:

$$\text{Combined Labor Productivity} = \frac{1}{\frac{1}{\text{Pick Productivity}} + \frac{1}{\text{Sort Productivity}} + \frac{1}{\text{Pack Productivity}}}$$

Equation A.13 Combined Labor Productivity Equation

The equation above is derived by figuring out the number of hours required to pick the item, sort it and pack it. Because the productivity equation is the number of items per labor hour, the inverse is taken to determine the number of hours to process one item. The process is in series, so the hours for each process step can be added. In order to determine the labor productivity from the number of hours required to pick, sort and pack an item, the inverse of the sum is taken. The inverse of the total hours is required to turn the result into the labor productivity metric. The equation development is similar to the series addition used for circuits with elements in series.

The translation of the labor productivity into actual costs numbers can be formulated as follows:

$$\text{Process Labor Cost Per Unit} = \frac{\text{Hourly Wage Rate}}{\text{Process Labor Productivity}}$$

Equation A.14 Labor Cost Equation

A.5 Generic Phase Diagram Implementation

In order to get a better sense of how the process phase diagram is developed a generalized example is formulated and presented in this section of the appendix. The purpose of the generalized example is to demonstrate the details of the process phase diagram implementation as well as how the process boundaries shift when the process cost distribution changes. For this example, four generic processes are evaluated. The cost structure of the various processes are given the following percentages of fixed and variable costs. The fixed and variable costs distribution is Figure A.3.

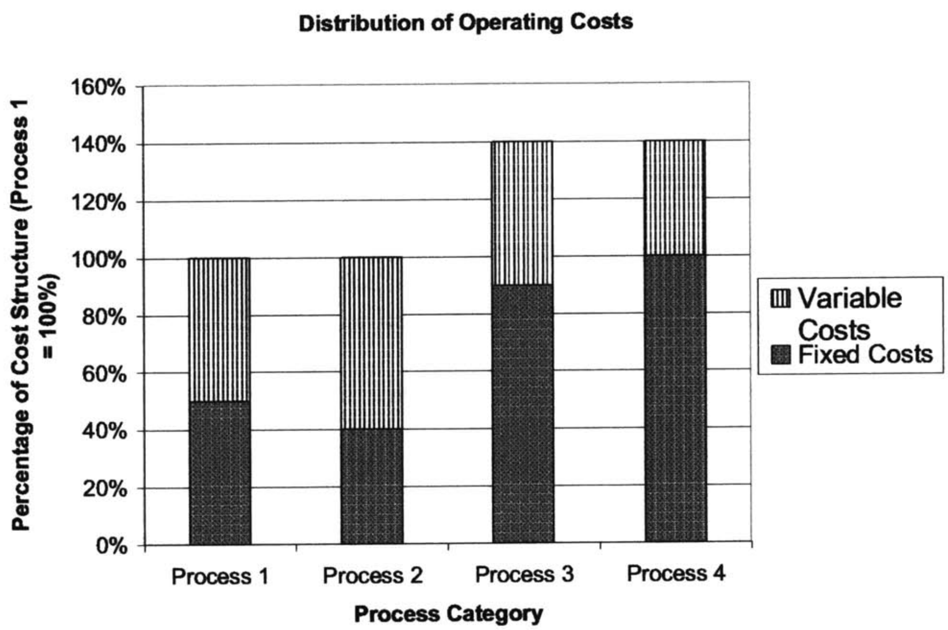

Figure A.3 Distribution of Costs for Generalized Process Phase Diagram.
The figure shows the representative cost distribution used for this process phase diagram

The nominal volume for each of the cost distributions is given in Table 9.1. The cost planes are extrapolated from the nominal data point. The cost structures are assumed to be invariant over the area that the phase diagram is developed. The variable costs are assumed to be primarily composed of direct labor costs. Some of the fixed costs may vary with dramatic shifts in the volume experienced, but for the purposes of this example they are assumed to be invariant with volume changes for the range investigated.

	Volume Per Week	Cube (Cubic Feet)	Cube Break Point
Process 1	500,000	2.0	5.0
Process 2	500,000	2.0	5.0
Process 3	600,000	4.0	20.0
Process 4	600,000	4.0	20.0

Table A.1 Distribution of Costs for Generalized Process Phase Diagram.
This table shows the nominal conditions upon which the costs in Figure A.3 are determined. The cost planes will be extrapolated from these nominal values.

The cost structure is extrapolated on one axis in relation to product cube and along the other axis in relation to weekly volume. The extrapolation with relation to increased cube size was completed using the empirical relationship between productivity and cube determined in section 5.4. The extrapolation with respect to the facility volumes assumes that the direct labor scales linearly. The fixed operating costs are assumed to be invariant for the given system capacity. As the volumes increase the burden of carrying the fixed operating costs diminishes because these costs are divided by higher volumes.

Based on the costs given in Figure A.3 and the points given in Table A.1, the phase diagram in Figure A.4 is developed. Process 1 and 2 break at 5 cubic feet. Process 1 is the optimal operating cost for very low cubic products. Process 2 is better equipped to process higher cube and higher volume items. Process 3 and 4 are a better fit for higher cube products. Process 4 is more suited for very high volume processing.

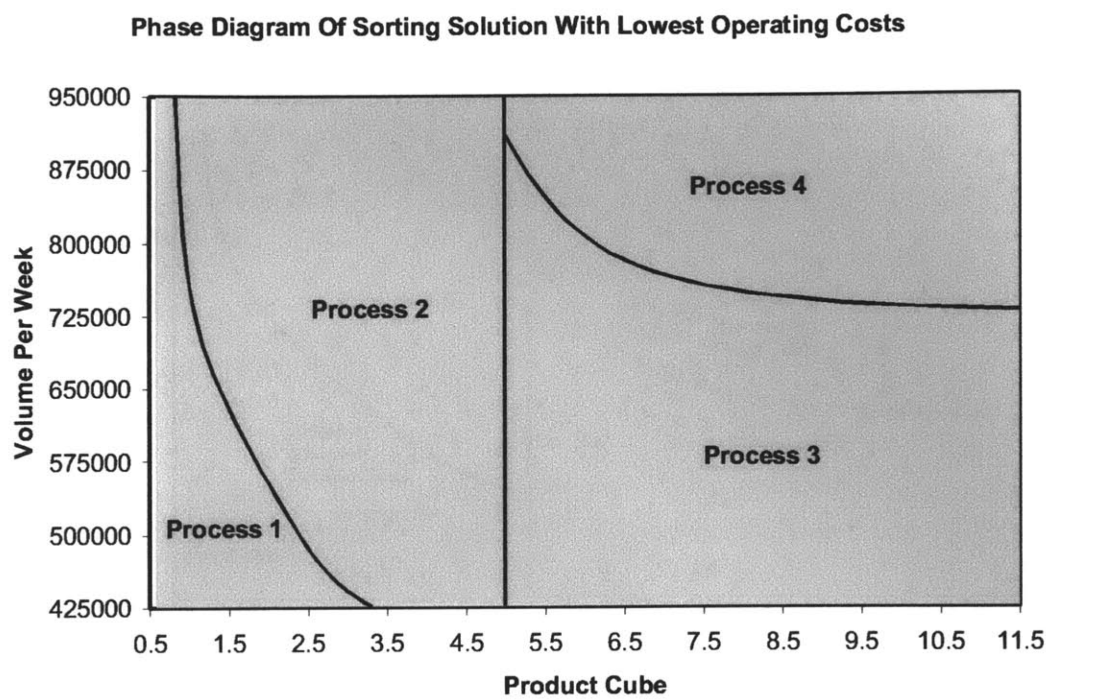

Figure A.4 Generalized Process Phase Diagram Example.
This figure shows the least operating cost process solution for given product cube dimensions and volumes per week. The partitioning of the phase diagram is based on the intersection of the operating cost planes for each process. The phase diagram is a projection of the least operating cost plane and the intersections between the developed cost planes.

In order to understand the sensitivity of the process phase diagram, the variable costs of process 1 are changed and the fixed costs of process 3 are modified. The results of the modified phase diagram are depicted in Figure A.5. With a reduction in the process 1 variable costs, process 1 assumes part of the area that was originally assigned to process 2 under the original conditions. Likewise, with increased fixed costs assigned to process 3, a larger area of the high cube processing is given to process 4.

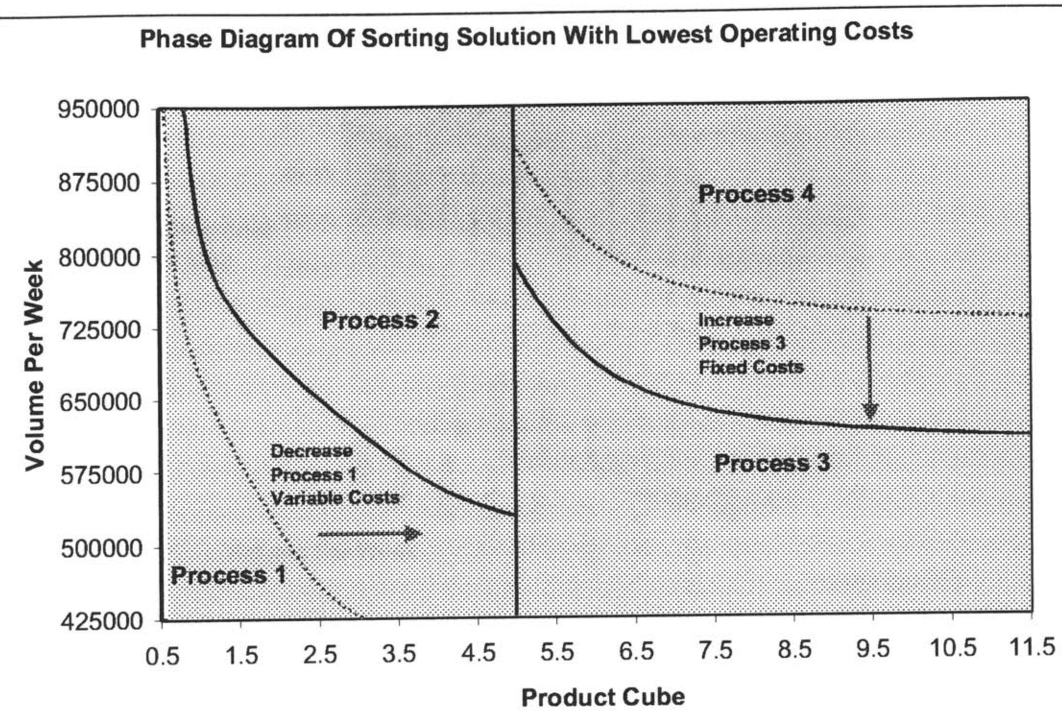

Figure A.5 Sensitivity of Generalized Process Phase Diagram Example.
This modified phase diagram shows the sensitivity of the phase diagram to changes or improvements of the process costs structure. With a reduction in the process 1 variable costs (5% decrease), process 1 assumes part of the area that was originally assigned to process 2. Likewise, with increased fixed costs assigned to process 3 (5% increase), a larger area of the high cube processing is given to process 4.

An example of the developed costs planes for this generalized and hypothetical example is shown in Figure A.6. The cost plane for process 1 is displayed in Figure A.6. The costs decrease with lower product cube and higher volumes. The fixed costs are better absorbed at the higher volumes. The cost plane for process 1 does not extend beyond product cube of 5 cubic feet because that is the process break point. Figure A.7 shows the combined cost plane for the least operating cost over all processes evaluated. The cost plane in Figure A.7 is projected onto the cube-volume plane in order to create the process phase diagram.

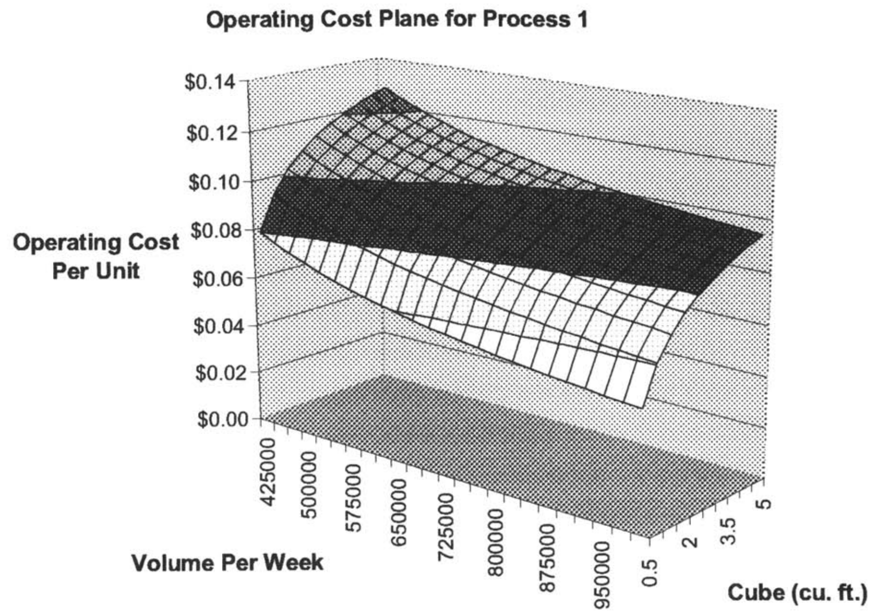

Figure A.6 Operating Cost Plane for Process 1.
The figure shows the actual cost plane for Process 1 versus product cube and volume per week with total operating cost of \$0.10/unit for the nominal volume and cube given in Table A.1.

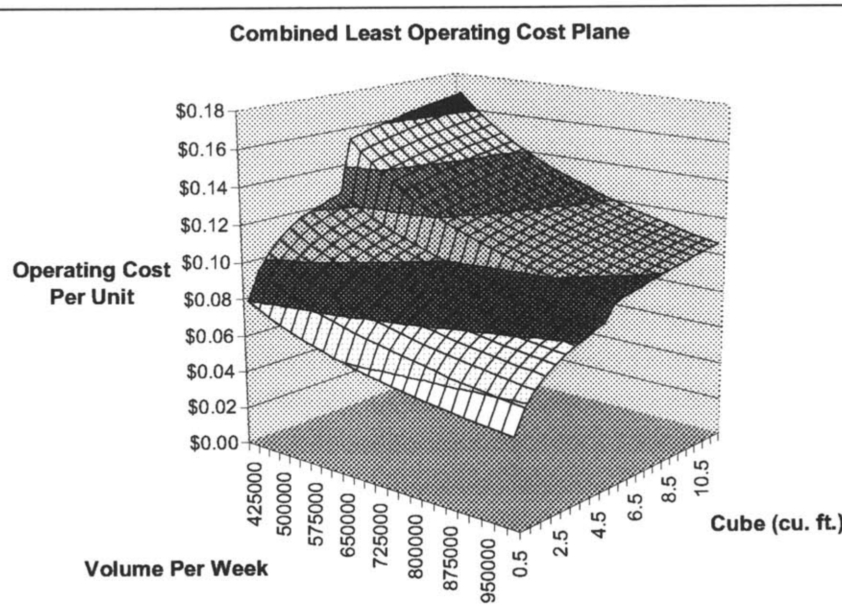

Figure A.7 Least Operating Cost Plane.
The figure shows the combined least cost plane for all of the processes evaluated. This combined plane is projected to the cube and volume plane in order to create the phase diagram in Figure A.4.