# Theoretical and Practical Ramifications of Altering the Amount of Sorts Required from an Outbound Dock



by

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B.S. Materials Science and Engineering
Purdue University, 2008

SUBMITTED TO THE MIT SLOAN SCHOOL OF MANAGEMENT AND THE ENGINEERING SYSTEMS DIVISION IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREES OF

MASTER OF BUSINESS ADMINISTRATION
AND
MASTER OF SCIENCE IN ENGINEERING SYSTEMS

IN CONJUNCTION WITH THE LEADERS FOR GLOBAL OPERATIONS PROGRAM AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2013



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Submitted to the MIT Sloan School of Management
and the Department of Engineering Systems on May 10, 2013
in Partial Fulfillment of the Requirements for the Degrees of Master of Business Administration
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# Abstract

Amazon has been enjoying a rapid pace of growth over the last few years. One unfortunate side effect of this growth is the overall increased complexity of the network Amazon utilizes to deliver packages from the Amazon warehouses (coined "fulfillment centers" or "FCs") to the final customers. Specifically, Amazon now requires the outbound docks of the FCs to handle more volume that needs to be delivered to more locations. The increased number of outbound locations necessitates more package sorting operations on the dock. This thesis focuses on the operation of the outbound docks and performs time studies, capacity analyses, various warehouse case studies, and discrete event simulations to discover the ultimate bottleneck of a dock as more of these sorts are added. This sorting capacity analysis uncovers that the space available on a dock as an inventory buffer between the sorting and truck loading operations to ultimately be the source of constraint as more sorts are required from a building. This buffer constraint is then explored and quantified to create a mathematical formulation for estimating the ultimate outbound sorting capacity of an FC.

Given the max sorting capacity of an FC, this thesis then dives in to the practical applications of operations management principles for executing on a sort plan. The principles of minimizing non-value added work, optimizing the number of packages going through the most labor efficient process paths, worker interference on labor efficiencies, and employing flexible capacity will be explored and applied to the outbound dock.


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## Acknowledgements

I would like to begin by thanking the Amazon community for taking me in and exposing me to a truly wonderful and efficient operation. The many intelligent and dedicated people at Amazon make it easy to understand why the company has experienced such outstanding success since its inception in 1994. One of my leadership principles is also that no matter our success, we must believe that it is still Day 1. The enthusiasm and pace I see all employees at Amazon work with is truly what I would call a "Day 1" frame of mind.

I would also like to specifically thank my manager Andy Maruska for guiding and developing me throughout my internship. His timely feedback, good attitude, and willingness to throw me into various situations made the experience a rich one. Many thanks also go to my thesis advisors, Prof. Simchi-Levi and Prof. Spear, for their help and fantastic assistance over the course of this project. I would also like to thank my mentors Miriam Park and Mike Chrzanowski who not only gave me great guidance throughout my internship, but were also great friends. In addition, I would like to thank all of the dedicated and supportive operations managers I had the pleasure of working with while at Amazon. Specifically, the collaboration I was able to share with Dave Seitelman, Dennis Olvera, and Diego Mendez de la Luz created a learning experience unique among Amazon interns.

I would like to thank the incredible amount of social support I have received since arriving at MIT. During my short time at MIT, I have made countless lifelong friends from the Leaders for Global Operations program, Sloan program, and engineering programs. From these families, I have come to believe that through collaboration and having an optimistic attitude; we can truly change the world for the betterment of humanity. We just need to keep believing that it is only Day 1.

Finally, this thesis is dedicated to my wonderful, supporting wife Janet and my friends and family back in Indiana. When I have been asked during interviews, "What's your proudest accomplishment?" I have always responded with, "my friends and family." To this day, I have not received a job offer whenever I was asked this question. I am delighted for this since I would probably not have wanted to work for those companies anyway.

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## Note on Proprietary Information

Note that much of the data presented throughout this thesis has been modified in order to maintain confidentiality. The figures and results do not represent the actual values that were measured or calculated. Many numbers have been either skewed or scaled in an effort to disguise and preserve any proprietary information of Amazon.com while still representing the general trend or pattern the data is intended to represent.

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# 1 Introduction and Background

## 1.1 Welcome to Amazon!

We're all accustomed to placing an order with Amazon and, PRESTO!, two or three days later, our long anticipated copy of *The High Velocity Edge* arrives at our mailbox ready to read. With online retailing such a regular part of our daily experiences, we probably never wonder how that order actually arrives, especially with such reliability. After all, Amazon stocks tens of million individual items with the capability to make on demand any written or digital media that is out of print with Kindle Direct Publishing, holds these items in many separate locations in the United States and Canada, ships hundreds of millions of units in a year (with a peak of 13.7 million on cyber Monday 2011 – an astonishing 158 items per second (1) ), and sends these items anywhere there are roads and a carrier willing to take the packages. That many pieces moving through that many parts...it makes one wonder how anything ever gets to the right place at the right time let alone almost all of the time.

Here's what happens behind the scenes.

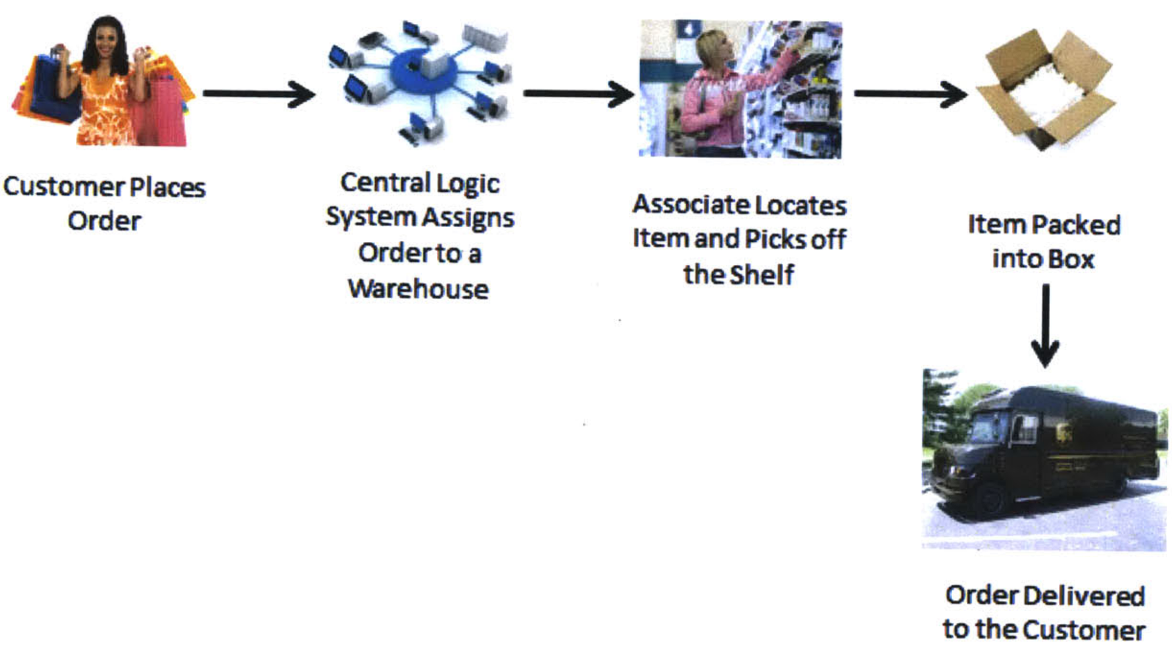
After you click "place your order," an electronic signal is sent to a central computer logic system responsible for assigning orders to a warehouse. Depending on what you ordered, it is forwarded to the appropriate fulfillment center (FC) where the item you want is stocked...for example a book in Kentucky or a shirt in Indiana.

When the order hits the fulfillment center, it is sent electronically to an Amazon employee (who we will call an "associate") who finds the item in the part of the warehouse that looks like giant supermarket isles. Once the associate finds the item, he or she "picks" the item off the shelf and sends it down a series of conveyor belts to the pack line. At the pack line, the item is put inside a box, the box is sealed, and a label is placed on the box which dictates through which carriers (i.e. FedEx, UPS, USPS, etc.) and downstream buildings (we will call these downstream buildings hubs) the package will go through in order to reach the final customer.

After the item is packed, it is sent down another series of conveyors, sorted, and loaded onto trucks where the package is transported to the next step of the process and out of Amazon's operation. It should be noted that although Amazon may not control the downstream parts of the operation run by the UPSs and FedExs of the world, Amazon keeps close metrics on these operations to ensure the package gets to the customer on time.

These carriers then make the actual delivery to the final destination, and we can begin reading *The High Velocity Edge* in less than 2 days after we ordered it! For a schematic outlining this overall process, refer to Figure 1.1.

*Figure 1.1: Illustration of how Amazon Fulfills Orders*

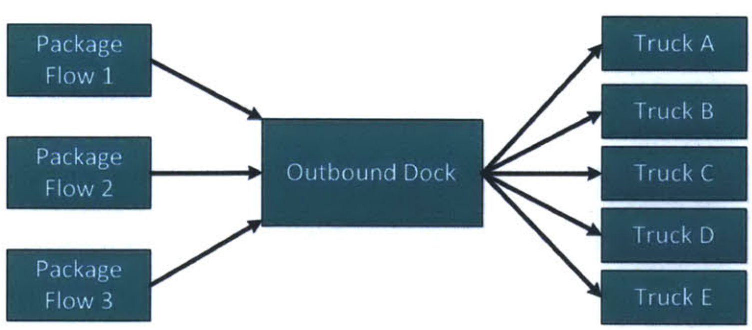



For the purposes of this thesis, we'll be focusing on the sort operations--the piece of the process after ordered items have been put in packages up to the point they are ready for shipment from the FC to the hub, and we'll do so first, by looking at the process through the eyes of "Diego," who is responsible for it.

## 1.2 The Situation

After receiving the most recent forecast, Diego sat with horrified concern over the response he knows his operation will give him this coming December. An unprecedented number of units will be processed out of Diego's building, FC1, on December 10th. Diego runs the operation responsible for putting the packages onto a truck and shipping them out the door. Diego knows it will be extremely hard to solely deal with the overall volume without any additional constraints complicating his operation. However, to add to his pain, the corporate transportation group has indicated that they will force Diego's operation to cope with two additional sorts as a cost savings and network capacity initiatives. "Sort" is a term used at Amazon to indicate the process of segregating packages at the outbound dock so that the packages are loaded onto their appropriate outbound trailers. This sorting process is performed since not all packages go to the same destination when leaving the FC due to either the final delivery location of the packages or the overall cost of the various shipping methods. Typically, the more sorts an FC can perform, the more in transportation cost savings is realized. The term "sort" can be used interchangeably with "outbound lane" when speaking internally at Amazon. A schematic outlining Diego's outbound dock operation is given by Figure 1.2.

*Figure 1.2: Overview of Outbound Dock Sorting Process*




"Saving on transportation costs is certainly something that is both good for the customer and Amazon," Diego thought. "However, those folks up in corporate have no idea what they are talking about when it comes to outbound docks. These savings will be nice up until the point when these extra sorts come to bottleneck my dock, increase queue sizes and overall process times, and ultimately lead to misses on customer promised deliveries. Ultimately, these misses will mean millions of dollars in concessions paid to customers. Not to mention the ill-will we will incur when Christmas presents don't reach customers on time for the holidays. This is something I won't live with, let alone have to explain to my boss."

The predicament Diego is facing is not a unique one at Amazon. Every year, the order volume across the Amazon network materially increases during the weeks between Thanksgiving and Christmas. This period of increased network order volume, coined "peak" in the Amazon community, is not surprising as this is the time where retailers are posting deals and families are buying presents for the holidays. The operational problem that Amazon then faces is how to cope with these increased volumes while still keeping the same speedy delivery service customers have come to expect and now rely upon for their holiday shopping needs. Every peak, this capacity problem must be addressed across the network as a whole, and at the individual process steps in the Amazon warehouses (called Fulfillment Centers or FCs).

## 1.3 Walking the Process

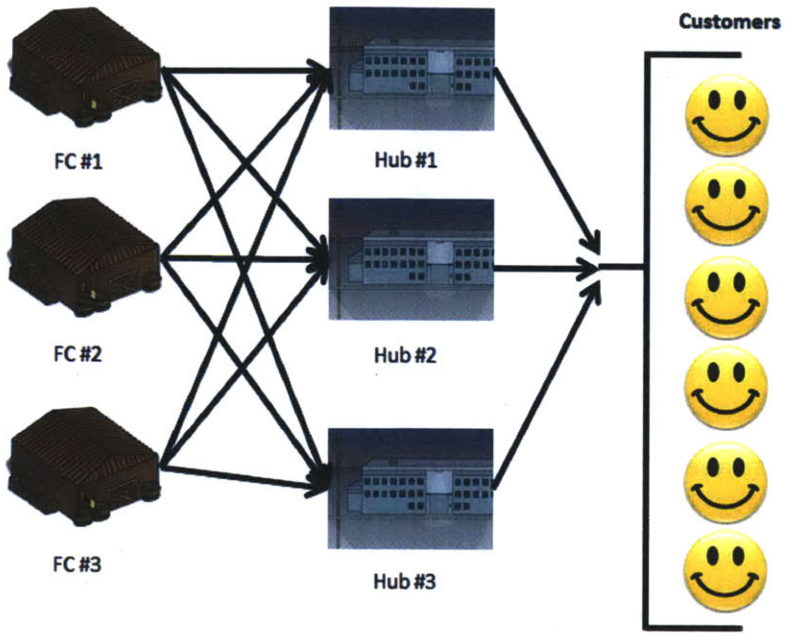
Now that the background of how orders are processed through Amazon and the operational troubles associated with peak have been described, this chapter will focus on walking though the operation of the outbound dock. The reason why this process is interesting is because it will provide insight into where capacity constraints exist on the dock and how Diego's preoccupations can be solved. By mapping the operation and measuring each individual process step, we find that the system has many moving parts; and we gain insight in terms of where exactly the dock operation could bottleneck the rest of the system.

Despite Diego's concerns of the outbound dock bottlenecking FC1's entire operation, Diego was not yet willing to throw in the towel even with corporate transportation muddling FC1's operations. Diego decided to again walk through his operation to see if there was any potential opportunity to force more volume and sorts through.

Diego's territory begins at what is called the pack line. The pack line is where boxes flow after the items customers have ordered are placed into boxes, stuffed with dunnage, and taped shut. A shipping label is then applied on top of these boxes. The pack line dictates the final destination of the packages. However, more specific to our issue; the pack line is the moment when it is known exactly which truck a given package will leave the FC on. This decision is delayed until so late in the process for two reasons:

- **Capacity constraints at the next step in the process:** A package typically goes to a hub or a package sorting center as the next step in the process after leaving the FC. These hubs can only handle a certain number of packages, and Amazon controls the number of packages traveling from the Amazon FCs to a given hub. This is done so as not to overwhelm the hub with volume and thereby missing customer promised delivery times. A high level view of the process flow of packages from FC to the customer is generally described by Figure 1.3. As can be understood from looking at Figure 1.3, the complex outbound network that Amazon operates in creates the need for FCs to process large numbers of sorts and compels tight coordination between Amazon and the downstream processors.

*Figure 1.3: High Level View of Package Flow from FCs to Customers*




- **Critical Pull Times (CPT):** Every sort at an Amazon outbound dock has a critical pull time (CPT) assigned to it. These CPTs indicate the latest moment that a package can leave the Amazon FC and still make the promised delivery to the customer for that shipping path. CPTs are dictated by the transit times between steps in the process and the timing of when the hubs will run the operation that processes the package (since many hubs do not run their operations continuously). If a package is packmed too late for a given lane's CPT, then that package will be assigned to a lane who's CPT allows the package to make the customer promised delivery.

After the pack line, a decision is made as to whether the package will go to the flat sorter or the ship sorter. This decision is dictated by the **physical size of the packages**. The current criterion for this decision at FC1 is smaller packages go to the flat sorter whereas all other packages are sent to the ship sorter. Since the first package Diego saw was a small package (also called a "jiffy"), he decided to follow this package through the flat sorting process.

From the various pack lines, the jiffies are automatically diverted to a series of conveyor belts that ultimately take the package to the flat sorter. The flat sorter at FC1 is a large oval conveyor that has many package diversion points. Packages are fed manually into this large oval conveyor at 8 different points by associates. This process of feeding packages into the flat sorter (also called induction) is manual to cope with the varying volume the building sees and so that the package label orientation is correct so the package is scanned and diverted properly once in the flat sorter. Diego knows through time studies that an associate should be able to induct at a rate of 1500 pkg./hr. After the package is inducted, the package is automatically scanned and then diverted down one of several chutes into a large cardboard box called a gaylord. A sensor placed right over the top of the gaylord will indicate when a gaylord is full. Once the gaylord is full, a blue light will go off above the gaylord and packages will not be diverted down this chute until an associate removes the full gaylord and replaces it with an empty one. During this gaylord replacement process, the packages meant for this sort will recirculate around the flat sorter until an empty gaylord is placed in position. Packages that recirculate the flat sorter for too long or packages that have labels that can't be scanned are sent down a deposit chute for associates to problem solve.

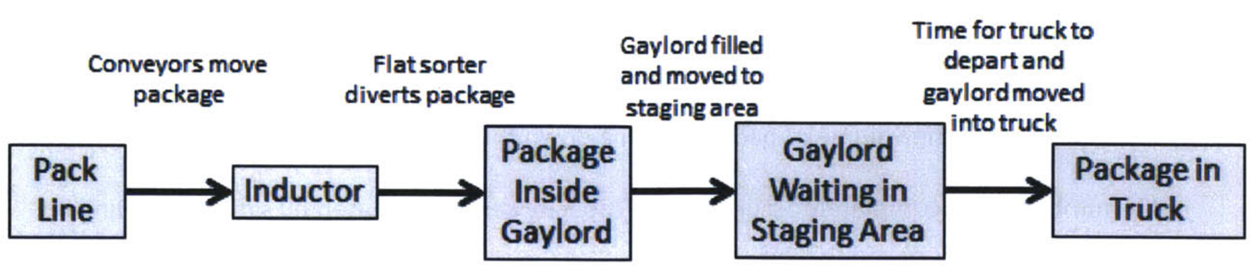
"It would really be nice if I could just sort everything at our flat sorter," Diego thought to himself. "Not only is this the fastest way to sort packages, but it also requires the least amount of manual labor." However, Diego knows that he will never get this wish for three reasons:

- **Capacity:** The theoretical maximum capacity of the flat sorter as given by engineering is much, much larger than the volume of packages going down this route. Furthermore, Diego knows that this number is not completely accurate since capacity can be increased by simply speeding up the belt. However, this maximum capacity must be considered when moving volume to the flat sorter.

- **Package quality:** In an empty gaylord, packages drop approximately 6 feet from the flat sorter belt to the bottom of the gaylord. If bigger, heavier packages were allowed to go into the flat sorter, the risk of crushing customer packages increases.
- **Truck utilization:** Certain trucks leaving the FC can cost thousands of dollars to move the packages to the next step in the process. Carefully stacking boxes in a truck to the ceiling will typically yield high degrees of utilization whereas haphazardly tossing boxes can cause this number to drop to significantly lower values. By diverting more and bigger boxes to the flat sorter, overall truck utilization will suffer.

Full gaylords from the flat sorter are kept in a staging area until the truck for these packages is ready to depart. Once truck departure is imminent, these gaylords are then moved into the back of the trailer so that the packages can go to the next step in the process. Virtual-physical matching is emphatically stressed so that full gaylords of customer packages are not mistakenly left on the dock after the lane's CPT. To better visualize, document, and analyze the process; Diego broke down the flat sorting process into its component activities via a process flowchart given in Figure 1.4. Figure 1.4 shows the component activities involved in the flat sorting process path and gives a comprehensive listing of activities that could be a source of bottlenecking the operation. (2)

*Figure 1.4: Flat Sorting Process*

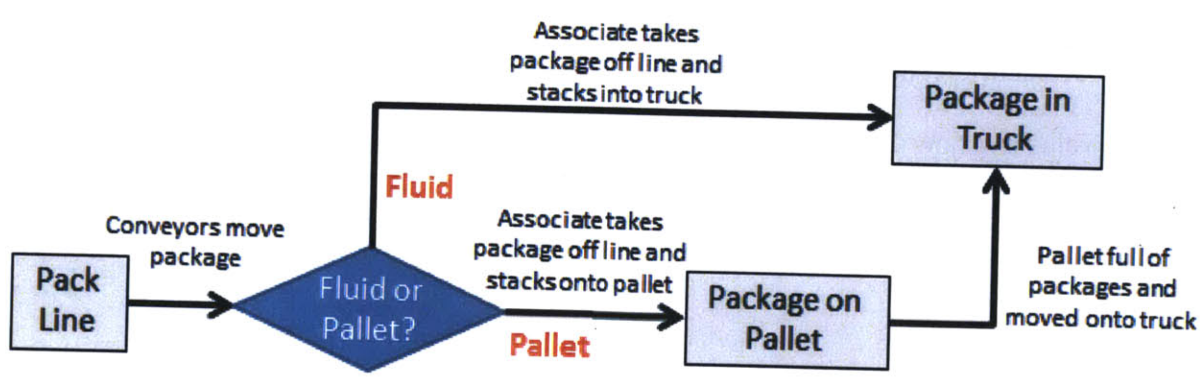


After reviewing the flat sorting part of his operation, Diego decided to walk the part of his process where the bigger packages go after the pack line: **the ship sorter**. Much like flat sorting, packages for the ship sorter are diverted after pack through a series of conveyor belts up to the second floor of the FC. Once on the second floor, packages are automatically diverted down either fluid sort diverts or pallet sort divert. A fluid sort is defined as the process where packages are automatically moved via conveyors directly into a trailer. An associate then takes the package off of the conveyor and stacks it into the truck much like a brick layer making a wall. A pallet sort is where a package is diverted off of the ship sorter and down a conveyor to a spot where a package is manually moved by an associate off of the conveyor line and onto a pallet. Packages are stacked onto the pallet until the pallet reaches a specified height. The associate then takes shrink wrap, wraps around the packages and the pallet, and moves the pallet either into a staging area or onto the back of a trailer (if a trailer and a dock door are available). If a pallet is moved to a staging area, it is "live loaded" onto the back of a trailer once the trailer and a door become available. The process of physically moving a box onto a pallet is a little bit slower than fluid loading. However, the non-value added activities of shrink wrapping and having to move the pallets from the pallet sort location to the trailer also add on labor time to this process. A non-value added activity is defined as an action that, while required by a firm's process, does no directly increase the value of a flow unit. (3) From a labor standpoint, it would be ideal for all packages to be fluid loaded. However, due to capital investment and space constraints, pallet loading is employed for some lanes.

The ship sorting area is what concerns Diego the most. Diego knows from his experience last peak that if packages are left on the line in either the pallet or fluid sort locations, the line can get backed up. Although a light and a siren will go off so that associates can see the problem immediately and clear off the line, the packages will begin to recirculate around the ship sorter until a given line is cleared off. The light and siren can be thought as a mechanism to help associates see problems at the problem's source, and then prompts the associates to swarm and solve these problems where and when they occur. Without these management mechanisms in place, recirculation can be excessive and back-up the upstream operations. These concepts of allowing a workforce to see problems at their source and then creating systems for swarming and immediately solving the problems are explored in the literature by S. Spear as two capabilities that help organizations perform at the highest levels. (4)

If recirculation on the ship sorter is extremely excessive, a condition of dock lock can occur where the ship sorter is shut down and packages have to be manually removed from the sorter. This manual removal of packages from the ship sorter can take a considerable amount of time and will not only put a halt to Diego's operation but also bottleneck FC1's entire operation. Again, to help Diego visualize this process; he created the process flow map given by Figure 1.5. Much like the flat sorting process flow map, the ship sorting process flow shows the component tasks involved and gives a comprehensive listing of activities that could be a source of bottlenecking the operation. (2)

*Figure 1.5: Ship Sorting Process*




To complicate matters, whenever a trailer is completely filled with packages; it associates some time to close up the truck, fill out the appropriate paperwork, and check in and check out the driver. During this time, packages are still flowing down the fluid sort lanes with nowhere to go.

Upon completion of walking this process, Diego heads back to his office to reflect on what he had seen. There are many ideas running through his head; however, Diego feels that if he can answer the following two questions, FC1 as well as the Amazon network will be in good shape this peak:

1. What is the theoretical sort capacity of an FC?
2. How does an FC most effectively and efficiently execute on the sort plan?

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# 2 Theoretical Sort Capacity of an FC

Now that the background of the outbound dock operation has been described along with why more sorts are important for the Amazon network, Chapter 2 will focus on how the sorting capacity for an outbound dock can be quantified. By understanding the ultimate sorting capacity of an FC and how to execute on a sort plan, the predicament that Diego is in can be solved. Chapter 2 will quantify the maximum sorting capacity of an FC through case studies, analytical models, and finally by discrete event simulation. We discover through these methods that the ultimate sorting capacity of an FC is dictated by the capacity of an inventory buffer in the process.

Currently, there is no universal metric used to evaluate the sort capacity of the various FCs. This lack of sort capacity understanding creates the organizational issue of the addition of sorts being a negotiation process between FC leadership and the transportation department (since additional sorts tend to complicate FC operations). In addition, there is a general fear that increasing the number of sorts can eventually bottleneck and lock up an outbound dock. Because there is no universal metric for the maximum number of sorts at an FC, monetary losses from thousands to millions of dollars in transportation costs annually can result if the sort is not accepted by an FC.

This situation leads to the question: What is the theoretical sort capacity of an FC?

## 2.1 Overview of Methods Used to Answer Theoretical Sort Capacity Question

Three methods will be utilized to answer the theoretical sort capacity question. First, 1) The case studies of the constrained buildings FC1 and FC2 will be given to provide initial insight into the outbound dock operation and the similar struggles buildings face even with drastically different package flows and dock set-ups. Then, 2) the sorting process will be generalized and package flow data will be analyzed to determine the potential bottleneck in the operation. Finally, 3) a simulation analysis will be performed to further mathematically define the bottleneck and better explain how more sorts will ultimately lock up the dock's operation.

## 2.2 Case Study: FC1's Outbound Operation

Chapter 2.2 attempts to find a bottleneck in the outbound dock operation so that this bottleneck can be used to quantify the ultimate sorting capacity of the dock. By mapping the process, performing time studies on the various process steps, knowing the operational capabilities of the FC, and understanding the volume distribution of how packages flow to the dock; it is discovered that the sorting operations themselves are not expected to limit the volume of packages that can be processed through the dock. This chapter leads to the questions of whether the findings discovered through this case study are generalizable to all other FCs and what the true bottleneck of the system is if the sorting operation will not bottleneck the dock.

### 2.2.1 Background on FC1

To help illustrate the idea behind the max sort criteria and illustrate methodology for planning dock layouts, the case of FC1's outbound peak planning will be analyzed. To obtain a step by step explanation of FC1's operation, please refer to Diego's story given in the Introduction and Background section.

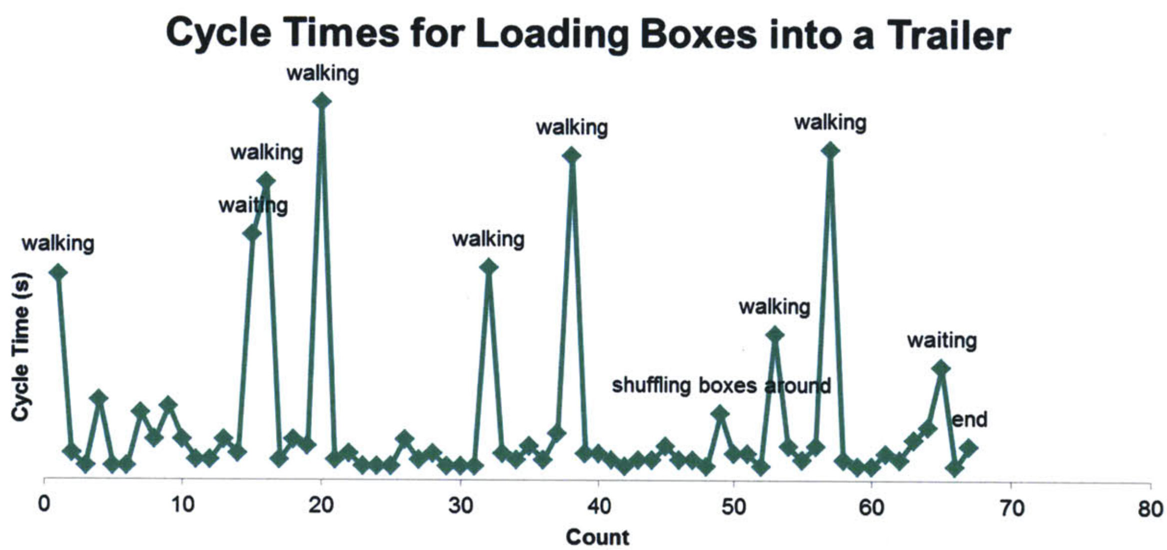
Consistently across FCs, what has been the failure point of dock operations in the past was the labor on the dock. There are constraints as to how quickly a person can physically stack packages into a truck or onto a pallet. To complicate matters, diminishing returns in terms of labor productivity exist as more associates are added to a particular sort (due to interference in a truck or on a pallet). Additionally, the changing over of trailers for fluid sorts poses a risk in that there is some time during this process where packages are not being loaded into a trailer. During this time, packages are either allowed to accumulate on the belt or stacked onto pallets to avoid recirculation on the ship sorter. As was previously mentioned, recirculation on the ship sorter needs to be avoided so as to not lock up the ship sorter and cause it to be down for an extended period of time. FC1 has a static length of conveyor outside of all of its fluid sorts which can accommodate a certain number of packages before recirculation is triggered on that lane.

The question that this situation then poses is: How will FC1 cope with the increased package volumes and sort requirements placed on the building this peak? Given that FC1 can cope with the increased volumes and sorts, under what conditions will FC1 not be able to handle the volumes and have gridlock on the dock?

### 2.2.2 Method and Data Collection for Figuring out the Dilemma at FC1: Work Time Studies with Forecast and Capacity Analyses

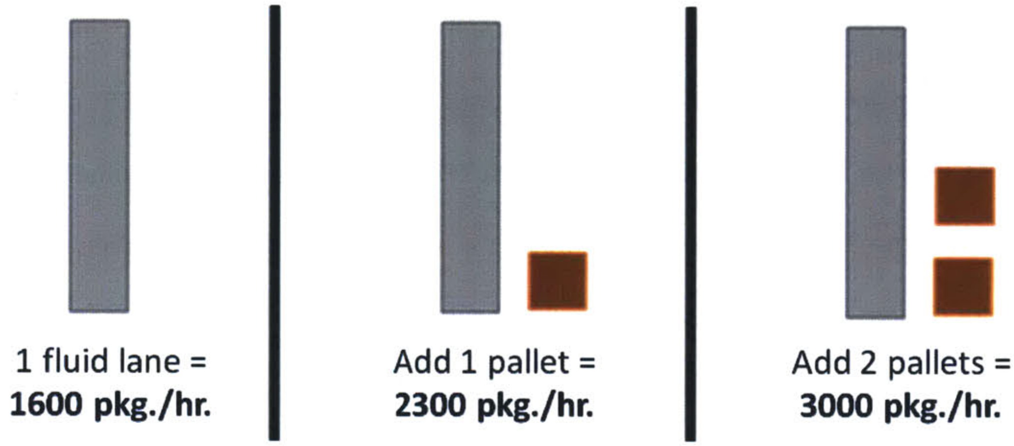
To establish theoretical limits for the various sorts, time studies were conducted for fluid loading and pallet sorting. These time studies were based upon the standards given by Meyer as the time given to complete a task given three criteria: 1.) a qualified, well trained operator, 2.) working at a normal pace, and 3.) doing a specific task. (9) These time studies were then repeated multiple times for one operator to account for variability in the individual worker's rates, across different operators to account for variability between workers, and at different times of day to account for variability in loading rates caused by differing package flow distributions. It should be noted that special cause variation occurred frequently in the loading rates of associates. Special cause variation is defined by Shewhart as variation that is inherently unpredictable and that can be given an assignable cause. Special cause variation is typically orders of magnitude different than what is considered to be the mean of what is measured. (10) This type of variation can be contrasted with that of common cause variation. Common cause variation is defined as variation that can be predictable probabilistically. Systems exhibiting only common cause variation are said to be in statistical control. (11) A few reasons for this special cause variation include associates waiting for packages to come down a line, associates having to walk from one conveyor line to the next to clear volume, and associates rearranging boxes already stacked so that space utilization is increased in a trailer. Although these are special causes of loading rate variation, these cases must be included in the overall calculation of loading rates as they occur regularly during the fluid loading and pallet sorting operations. Figure 2.1 gives an example of cycle time versus package count for one associate fluid loading packages to give an example of how the overall cycle times per task were estimated. Figure 2.1 further illustrates the frequency and magnitude of these special cause statistical variations in package loading cycle times.

*Figure 2.1: Cycle Time versus Package Count for an Associate Fluid Loading Packages into a Trailer*



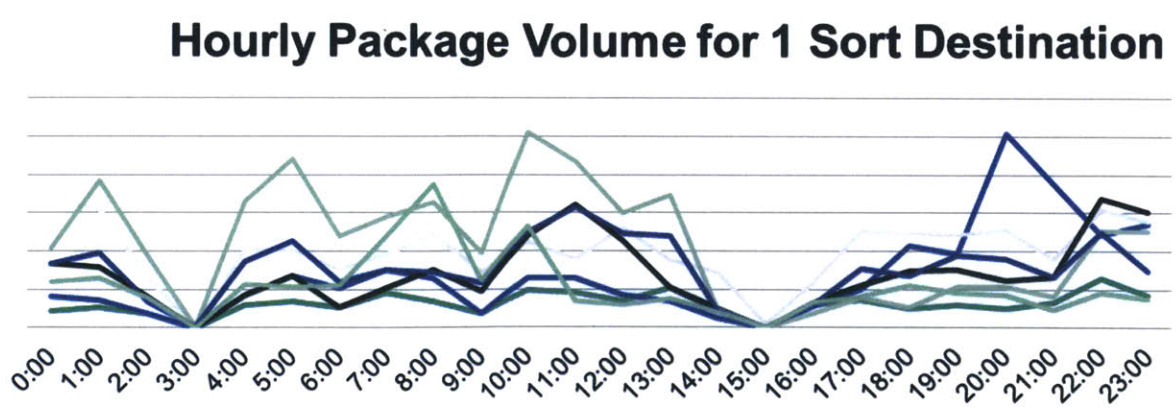

It was found that for fluid loading, a limit of 1600 pkg./hr. exists; whereas this limit is 700 pkg./hr. for pallet sort. It should be noted, however, that for any fluid lane; pallet sorting locations can be added along the sides of the conveyor which in turn will increase the capacity of the lane by 700 pkg./hr. per pallet sort location. This method of sorting is not preferable due to the inherent labor inefficiencies involved with pallet sorting, the reduced truck utilization, and the potential need for staging space for these pallets until the trailer is about to depart. However, creating this temporary pallet sort is better than having package recirculation backing up the ship sorter. Figure 2.2 illustrates how adding pallet positions alongside a conveyor can increase that conveyor's capacity for handling package volumes.

*Figure 2.2: Illustration of how Adding Pallet Positions Can Increase the Capacity of a Fluid Lane*




Although average package volume per sort is an important consideration, it is the spikes in volume that typically occur right before a lane's CPT that cause operational issues on the dock. Figure 2.3 illustrates how volumes will not only differ significantly by hour, but also by day of week. As you can see, drastic volume fluctuations from one hour to the next are not uncommon for a given sort.

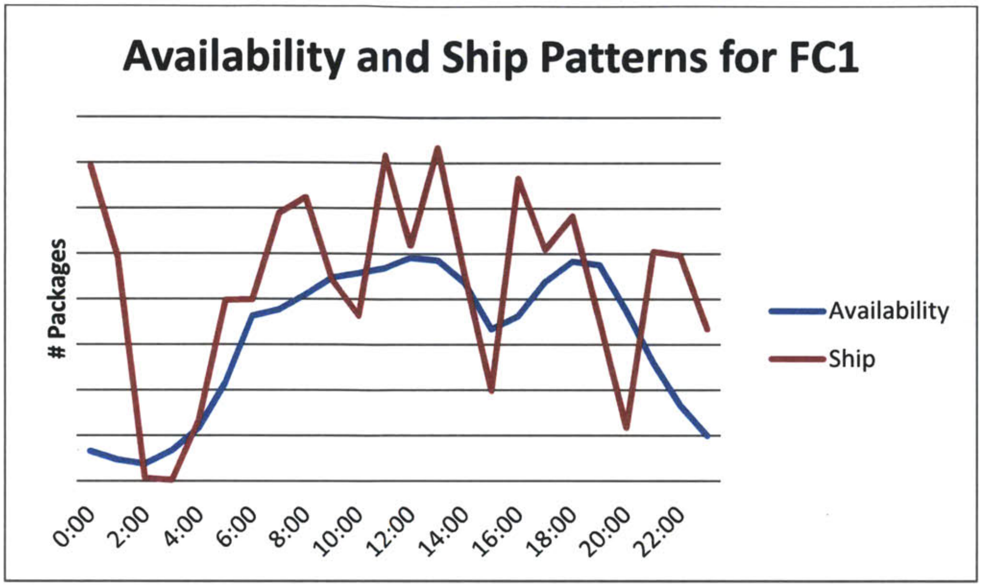
*Figure 2.3: Graph Illustrating how a Sort's Volume Differs Significantly with Time*



Fortunately, the timing of the volume spike and overall spike magnitude are relatively predictable per sort. The timing of the volume spike is typically right before the sort's critical pull time (CPT). The reason why the volume spike for a given lane occurs right before that lane's CPT is because the FC's usual pick settings will deprioritize packages assigned to a given lane until very soon before the lane's CPT. Once it is close to a lane's CPT, the pick settings will send all of the pickers upstream in the process on paths that pick mainly items for the nearest CPTs until all items assigned to that CPT are finally picked and processed. Picking all of the items for the soonest CPT will ensure as many customer orders as possible will make the promised ship date. However, by optimizing the pick settings based on the requirement of picking all items for the nearest CPT, an unfortunate side effect is that large package volumes jump from lane to lane on the outbound dock in coordination with the lane's CPT.

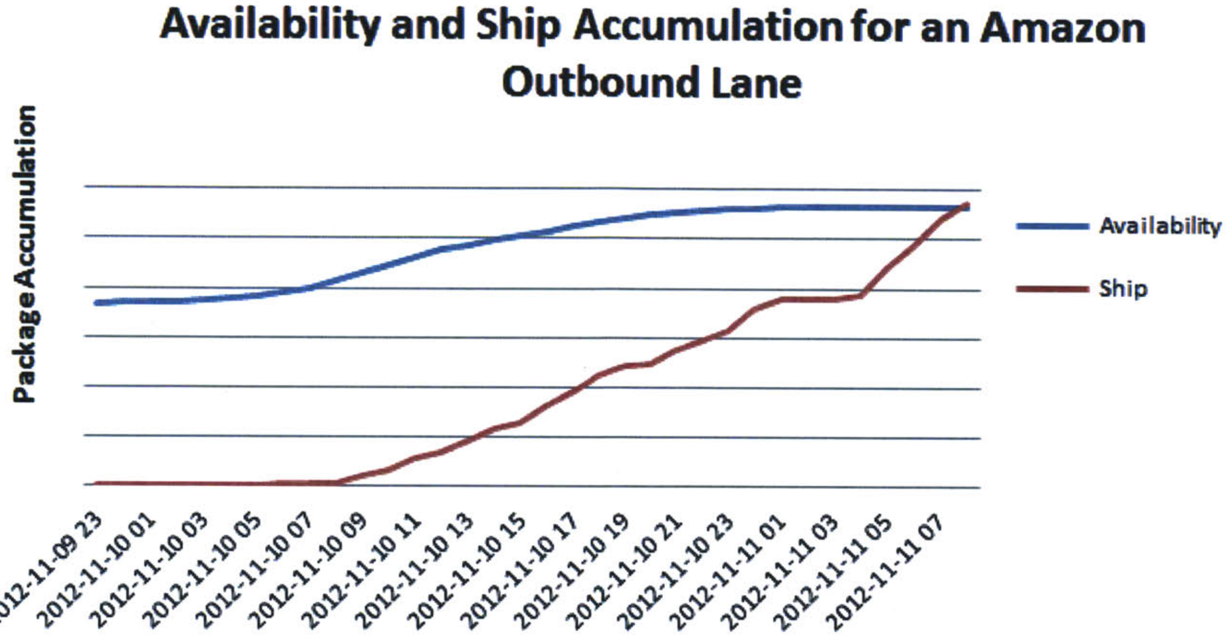
To better understand this phenomenon, it is helpful to look at the timing of when orders are assigned to an FC (also called "availability pattern") and compare this with when orders are processed by the FC and prepared to go onto trucks (called "ship pattern"). Figure 2.4 shows the overall availability and ship patterns by hour for FC1 over the same time frame. One aspect to note here is how relatively discontinuous the ship pattern is when compared to the availability pattern for a given FC. This discontinuity is caused by a combination upstream optimization and organizational constraints.

*Figure 2.4: Example of Charge and Pack Pattern for FC1*



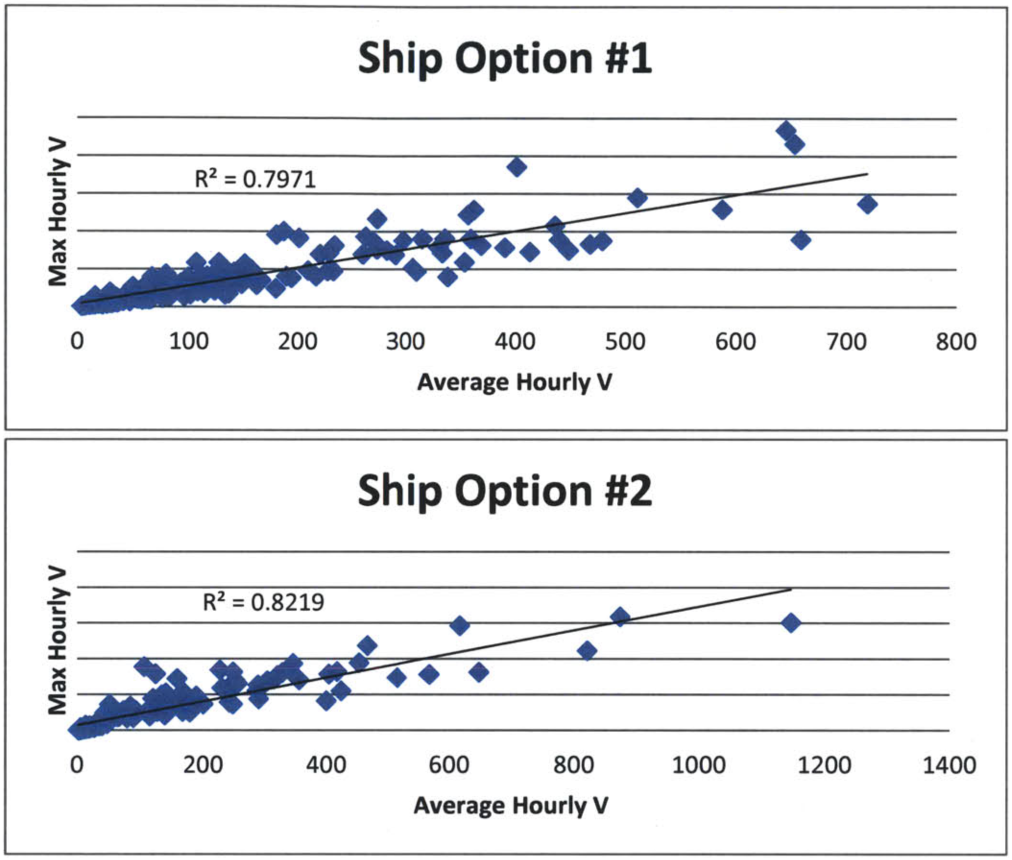

As a final illustration of these volume spikes and the potential influence of upstream operations on the dock, Figure 2.5 gives an example of the availability accumulation and ship accumulation of packages for an Amazon outbound lane. The slope on the accumulation trend gives the relative speed at which orders are coming into the FC. The slope on the ship trend gives the processing rate of orders. As can be observed in Figure 2.5, the ship curve has a steeper slope towards the end of processing as the pick settings are adjusted so that all packages get picked in time for the CPT. This increase in processing rate is especially pronounced over the 3 hours before CPT.

*Figure 2.5: Availability and Ship Accumulation of Packages for an Amazon Lane*



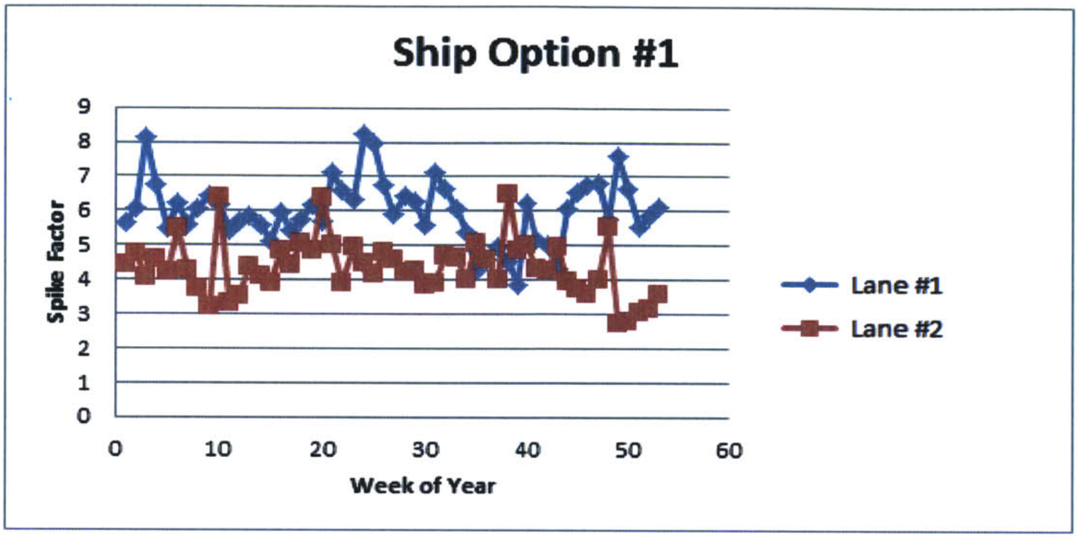

Once the volume spike timing is established for a given lane, the spike magnitude needs to be explored. The volume spike magnitude is dependent upon how quickly a customer wants a package after it is ordered. This speed of package delivery (i.e. next day shipping, 2 day shipping, etc.) is also called the "ship option." See Figure 2.6 for examples of the regressions performed on many of the lanes in the Amazon NA network separated by ship option to further quantify this spike factor. Figure 2.6 bases these spike factors off of one randomly sampled week of data separated by lane. Figure 2.6 shows that the spike factor by lane is relatively consistent across ship option (based on the high $R^2$ regression values). The coefficient of determination, $R^2$, gives us the proportion of total variability that is explained by the regression model. In our case, the two charts in Figure 2.6 indicate that approximately 80% of the variability in the max hourly volume can be explained by knowing the average hourly volume and ship option. (12)

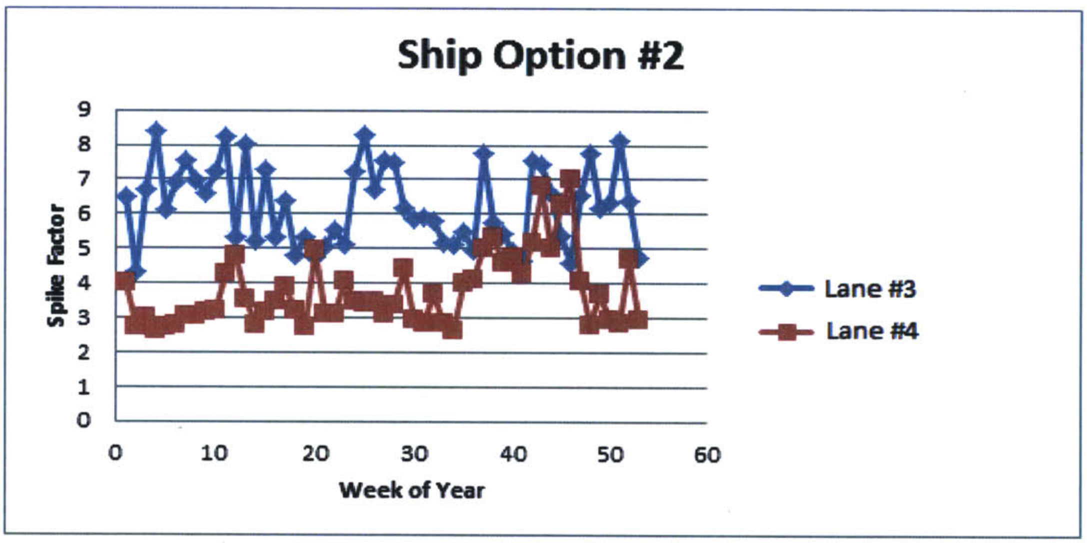
*Figure 2.6: Example of Spike Factor Quantification (each chart is a different ship option and every data point represents a different lane's spike factor over the week selected)*




These spikes in volume for a particular lane have also been seen to be relatively stable with time (see Figure 2.7). The fact that the trends are moderately constant as seen in Figure 2.7 emphasizes that these spike factors are a reliable way of estimating volume spikes given the average volume for a lane and the lane's ship option.

*Figure 2.7: Spike Factors Trends over Time (each data point is max hourly volume/average hourly volume for 1 week of data by lane)*




Although there are spikes in volume for the individual lanes (anywhere between 3x to 12x the average hourly volume), the overall volume processed by the FC does not shift as drastically throughout the course of the day. Therefore, the outbound dock can relatively easily cope with these shifts in volume as long as the labor on the dock moves in step with the volume shifts.

To ensure FC1 can cope with the excessive volume it is expected to process this peak, the forecasted lane volume along with lane volume spikes estimated using the spike factors determined by the ship option regressions were established. The analysis of expected average hourly volume with the hourly volume spikes by lane is summarized in Table 2.1.

### Table 2.1 Peak Volume Forecasts and Peak Spikes by Lane for FC1

| Sort | Ship Sorter Average Hourly V | Ship Sorter Spike |
|---|---|---|
| Sort #1 | 2000 | 4600 |
| Sort #2 | 1800 | 3600 |
| Sort #3 | 1700 | 7100 |
| Sort #4 | 1200 | 4400 |
| Sort #5 | 1100 | 3800 |
| Sort #6 | 1100 | 3300 |
| Sort #7 | 900 | 1800 |
| Sort #8 | 800 | 2100 |
| Sort #9 | 800 | 3600 |
| Sort #10 | 800 | 2600 |
| Sort #11 | 700 | 4400 |
| Sort #12 | 700 | 3000 |
| Sort #13 | 600 | 1500 |
| Sort #14 | 400 | 1000 |
| Sort #15 | 300 | 800 |
| Sort #16 | 320 | 900 |
| Sort #17 | 90 | 300 |
| Sort #18 | 70 | 400 |
| Sort #19 | 60 | 250 |
| Sort #20 | 30 | 150 |
| Sort #21 | 30 | 130 |
| Sort #22 | 10 | 20 |
| Sort #23 | 10 | 20 |

A capacity analysis was then performed for all of the different sorting areas at FC1 using the time study capacity data of 1600 pkg./hr. for each fluid loading position and 700 pkg./hr. for each pallet sorting position. This capacity analysis is given in Table 2.2.

### Table 2.2 Capacity Analysis for all of the Sorting Positions at FC1

| Sort Area | # Fluid Lanes | # Pallet Positions | Theoretical Max Capacity (pkg./hr.) |
|---|---|---|---|
| S1 | | 6 | 4200 |
| [redacted] | | | |
| S3 | | 3 | 2100 |
| S4 | | 3 | 2100 |
| [redacted] | | | |
| S6 | | 3 | 2100 |
| S7 | | 5 | 3500 |
| [redacted] | | | |
| S14 | | 4 | 2800 |
| S15 | | 3 | 2100 |
| S16 | | 7 | 4900 |
| S17 - Jackpot | | 6 | 4200 |
| [redacted] | | | |
| S20 | 1 | 3 | 3700 |
| S21 | 1 | 1 | 2300 |
| S22 | 1 | 1 | 2300 |
| S23 | 1 | 1 | 2300 |
| S24 | 1 | 1 | 2300 |
| S25 | 1 | 1 | 2300 |
| S26 | 1 | 1 | 2300 |
| S27 | 1 | 1 | 2300 |
| S28 | 1 | 1 | 2300 |
| S29 | 1 | 2 | 3000 |
| S30 | | 6 | 4200 |
| [redacted] | | | |
| S32 | 1 | 2 | 3000 |
| S33 | 1 | 1 | 2300 |
| S34 | 1 | 3 | 3700 |

This capacity analysis was then compared to the forecast by lane so that any potential operational issues can be predicted for the peak day at FC1. This analysis of comparing the capacity with the forecasted volume is given in Table 2.3. This analysis, called capacity utilization of a resource pool, measures the degree to which resources are effectively utilized by a process. Typically, no resource should have its utilization much greater than 90% since the relationship between wait times and utilization is highly nonlinear with wait times going to infinity as utilization reaches 1. (13)

### Table 2.3 Forecast Analysis Combined with Capacity Analysis to Determine Potential Bottlenecks in the System

| Forecast | | | Sort Area and Its Capacity Analysis | | Utilization Calculations | |
|---|---|---|---|---|---|---|
| Sort | Ship Sorter Average Hourly V | Ship Sorter Spike | Sort Area | Theoretical Max Capacity (pkg/hr) | Average % Utilization | Max % Utilization |
| Sort #1 | 2000 | 4600 | S20 & S21 | 6000 | 33% | 77% |
| Sort #2 | 1800 | 3600 | S33 & S34 | 6000 | 30% | 60% |
| Sort #3 | 1700 | 7100 | S29, **S28*, S27*** | 7600 | 22% | 93% |
| Sort #4 | 1200 | 4400 | S32, **S28*, S27*** | 7600 | 16% | 58% |
| Sort #5 | 1100 | 3800 | S26, **S28*, S27*** | 6900 | 16% | 55% |
| Sort #6 | 1100 | 3300 | S25, **S28*, S27*** | 6900 | 16% | 48% |
| Sort #7 | 900 | 1800 | S24 | 2300 | 39% | 78% |
| Sort #8 | 800 | 2100 | S23 | 2300 | 35% | 91% |
| Sort #9 | 800 | 3600 | S22, **S28*, S27*** | 6900 | 12% | 52% |
| Sort #10 | 800 | 2600 | S1 | 4200 | 19% | 62% |
| Sort #11 | 700 | 4400 | S16 | 4900 | 14% | 90% |
| Sort #12 | 700 | 3000 | S7 | 3500 | 20% | 86% |
| Sort #13 | 600 | 1500 | S14 | 2800 | 21% | 54% |
| Sort #14 | 400 | 1000 | S15 | 2100 | 19% | 48% |
| Sort #15 | 300 | 800 | S6 | 2100 | 14% | 38% |
| Sort #16 | 320 | 900 | S4 | 2100 | 15% | 43% |
| Sort #17-18** | 160 | 700 | S3 | 2100 | 8% | 33% |
| Sorts # 19-23** | 140 | 570 | S30 | 4200 | 3% | 14% |

*Note: Sorts S27 and S28 are known as "flex doors." These sorting areas are left unassigned to cope with the volume surges for these particular sorts that typically occur right before the sort's CPT. Although the utilization calculations are admittedly underestimates of the true value for these lanes, the lanes will not blow out the capacity of the operation since the volume through an FC remains relatively constant throughout the day and a surge in one lane typically leads to volume drops in other lanes.
** The average and max volume for these lanes was figured by summing together the values for the individual sorts. Although this will be accurate for the total average volume, the maximum volume is an overestimate since it is very unlikely that the lanes will see their volume spikes at exactly the same time.

Two things to note here are the **grouping of the low volume sorts in one sorting area** and the use of "**flex doors**." The grouping of low volume sorts in one sorting area has the benefit of helping to balance the flow of packages to one sorting area such that the magnitude of the volume spikes when compared to the average package flow is mitigated across sorts. This practice has the same effect as the risk pooling concept seen in supply chain literature. Risk pooling suggests that demand variability is reduced if one aggregates demand across locations. This is true since, as we aggregate demand across different locations, it becomes more likely that high demand from one customer will be offset by low demand from another. In our case, we are aggregating sorts so that a volume spike by one sort may be offset by a lull in volume from another sort. (14)

Additionally, the grouping of low volume sorts to one sorting area can also better utilize capacity on a sort lane that would not otherwise be used. One drawback of this practice is that it requires a manual sortation step as associates must take packages off of the line and sort them onto different pallet locations.

Flex doors are also used to balance the overall capacity of the outbound dock. Flex doors are defined as fluid sorting locations that are not assigned any particular sort. However, sorts are dynamically assigned to these sorting areas during the periods of time when the lanes experience the aforementioned spikes in volume that occur throughout the course of the day. The concept of flex doors are a practical application of the operations management principle of flexible capacity. Flexible capacity is defined in the literature as capacity that can be utilized to serve demand across several products. In our specific case, the different products can be thought of as different sort destinations. As incoming package volume spikes get to be more intense; the techniques of flexing the capacity of the various sorting areas must be employed to a greater extent to cope with the variations in volumes. This flexing of sorting capacity is currently done on the fly by operations managers. However, flexing capacity can ideally be predicted and planned for in advance for running an operation. (15)

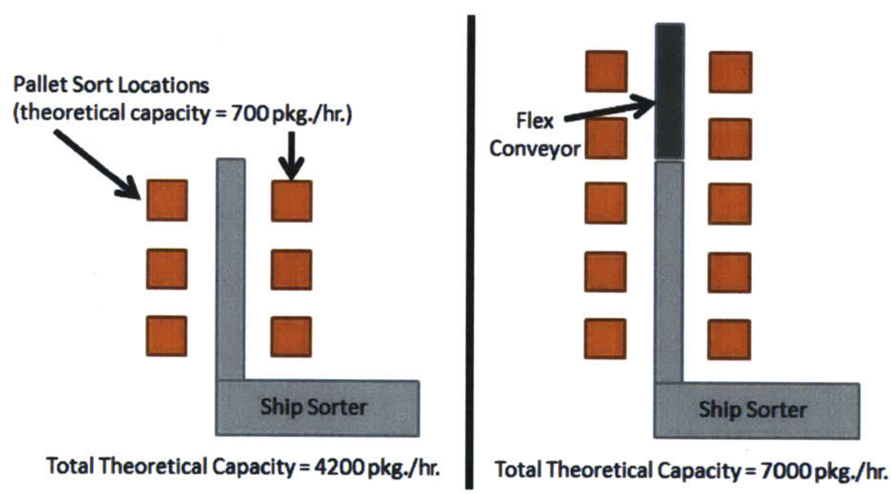
A similar analysis to Table 2.3 was performed for the flat sorter process path and significantly smaller percent utilizations were found. Smaller percent utilizations were found because the capacity along this route is limited by the actual sorting machine as opposed to the manual labor involved.

### 2.2.3 Discussion and Conclusions Reached through Case Study of FC1

The analysis performed for FC1 shows that although additional sorts tend to complicate FC operations, these added sorts themselves pose no threat to the ship sorting or flat sorting operations at FC1. Even for peak day at FC1, the most stressed sorting area has an average utilization of only 39%. Although there are significant spikes in volume for all of the lanes throughout the course of the day, these spikes can be accommodated via such practices as **1. flex doors, 2. grouping of low volume sorts in one sorting area, 3. release valve sorting areas**, and in extreme cases by **4. adding flex conveyors to any given sorting area**. The concepts of flex doors and the grouping of low volume sorts in one sorting area were explored in the previous section. Release valve sorting areas are an additional way of coping with large package volumes and are defined as pallet sorting locations that will take the volume away from any overburdened sorting area. For example, sorting area S30 has an average utilization of 3% with a spike utilization of 13%. At any time, volume can be moved from a sorting area that is at capacity to S30. A manual sort will then be performed here to a pallet location for whatever sort is experiencing the high volumes. The concept of release valve sorting areas is just a practical application of the concept of operations risk management. Operations risk management is defined as a process that includes risk assessment, risk decision making, and the implementation of controls as a reaction to risk. These controls result in the elimination, mitigation, or avoidance of risk. In our case, a contingency for mitigating excessive volumes down a particular sorting lane via diversion to a release valve sorting area is built into the decision making of the associates and operations managers working on the dock. (16)

Figure 2.8 shows a schematic of how adding flex conveyors to any sorting area will increase the capacity of that sorting area. Essentially, the capacity of any sorting area can be increased by adding conveyor length, labor, and pallet sorting locations. Although the increase in sorting area capacity is not expected to scale exactly linearly as portrayed in Figure 2.8 due to package and worker interference, the concept of being able to gain capacity with the additions of conveyor length, labor, and pallet sorting locations still applies. This worker interference is analogous to the economic concept of the law of diminishing marginal returns. The law of diminishing marginal returns states that as one factor of production is increased (in this case labor) while other important resources remain constant (in this case space) the output per unit of the variable factor will eventually diminish. In our specific example, as more associates are added to the sorting process, these associates begin to interfere with one another during the sorting and moving operations. This interference (specifically associates getting in the way of one another while doing work) will cause the variable rate per associate to decrease. (17) Although the law of diminishing marginal returns will be a factor while increasing the sorting capacity of a lane, this way of increasing capacity is a cheap (since flex conveyors and labor are relatively cheap), quick (since flex conveyors are on wheels and can easily be added to any point in the operation on a whim), and effective way of increasing the sorting capacity of any FC outbound operation.

*Figure 2.8: Schematic Showing how a Flex Conveyor with Additional Pallet Locations Can Increase the Overall Capacity of a Sorting Area*




This case study at FC1 shows that the operations of ship sorting and flat sorting packages are not expected to be the points of bottlenecking FC1's operation as more sorts are added.

### 2.2.4 Limitations of the Analysis at FC1 and Future Work

Although the case study at FC1 provided some insight into the intricacies of the outbound operation and the limitations inherent in this operation, there are still questions that need answering in order to establish the maximum sort capacity of an FC. Specifically, these questions are as follows:

- The outbound dock of FC1 is just one example of the many types of outbound docks in the Amazon network. Are the insights gleaned from FC1 generalizable to all FC outbound docks in the Amazon network?
- Given that the sorting operations themselves are not expected to ultimately bottleneck the outbound operation as increasing numbers of sorts are added to a building, where will this bottleneck occur as more sorts are added?

To answer the question of generalizability of the lessons learned from the FC1 outbound operation, an outbound dock that is very different from FC1's will be analyzed. This analysis will take the form of another case study for a building we will call FC2.

## 2.3 Case Study 2: FC2's Dock Operation

Chapter 2.3 focuses on whether the conclusions reached in the case study performed for FC1 can be generalizable to all other FCs. The reason why this is relevant and interesting is because if the conclusions for sorting capacity are generalizable across FCs, then a simple metric for evaluating sort capacity across the Amazon network can be formulated. Again, by mapping the process, performing time studies on the various process steps, knowing the operational capabilities of FC2, and understanding the volume distribution of how packages flow to the dock; it is discovered that the sorting operations themselves are not expected to limit the volume of packages that can be processed through the dock. Through this exercise, we find that the lessons learned from FC1 are indeed generalizable to FC2. Additionally, what we discover through the case studies at FC1 and FC2 is that the capacity of an inventory buffer used to store packages on the dock after the packages have been sorted will be the ultimate limit of sorting capacity. Moreover, this capacity limit is also generalizable across FCs in the Amazon network.

### 2.3.1 Background on FC2

An analysis similar to the one employed for the FC1 peak plan was crafted for FC2 to understand how differences in outbound dock operations may impact the maximum number of sorts a building can handle. The reason why FC2 is selected as a comparison case study is due to the numerous differences between the two buildings. For one, FC1 and FC2 are different building types with different product shipping capabilities (we'll call FC1 Type 1 and FC2 Type 2). Furthermore, whereas FC1 has an automated ship sorter and flat sorter, all of the sorting done at FC2 is a manual operation. Additionally, FC2 has process paths to the shipping dock that are unique when compared with FC1. FC1 has ship sorting and flat sorting. FC2 does contain the ship sorting process path. However, instead of flat sorting, FC2 has a process path for specialty items.

Finally, the overall flow of packages from FC2's pack lines to the outbound dock poses additional challenges that aren't faced by FC1. Instead of one line coming from all of the pack stations to the outbound dock, FC2 has two pack lines feeding volume to the various doors of the outbound dock. Once the line hits the outbound dock, it makes a left hand turn so that the line is parallel with the dock doors. Associates then perform an in-line manual sort where packages are removed from the main conveyor and fed down flex conveyors. These flex conveyors then move the packages into the back of a trailer where the packages are then fluid loaded. Based on volume data from last peak, 63% of the total volume is expected to come from the North Side Pack Line and 47% of the total volume is expected to flow from the South Side Pack Line. The issue that comes into play with this dock layout is that any volume that comes from the South Side pack line currently has no way of getting to the North Side Dock Doors. In order to remedy this issue either 1.) sort locations that exist for the North Side Dock Doors need to be repeated for the South Side Dock Doors or 2.) a series of flex conveyors and associates performing manual sorts need to be added to the process to ensure volume coming from the South Side Pack Line can make it to the North Side Doors. Figure 2.9 gives a commented schematic of FC2's outbound dock layout to help visually explain the dock layout and flow of packages to the dock. Table 2.4 summarizes the differences between FC1 and FC2.

*Figure 2.9: Schematic of FC2's Outbound Operation*

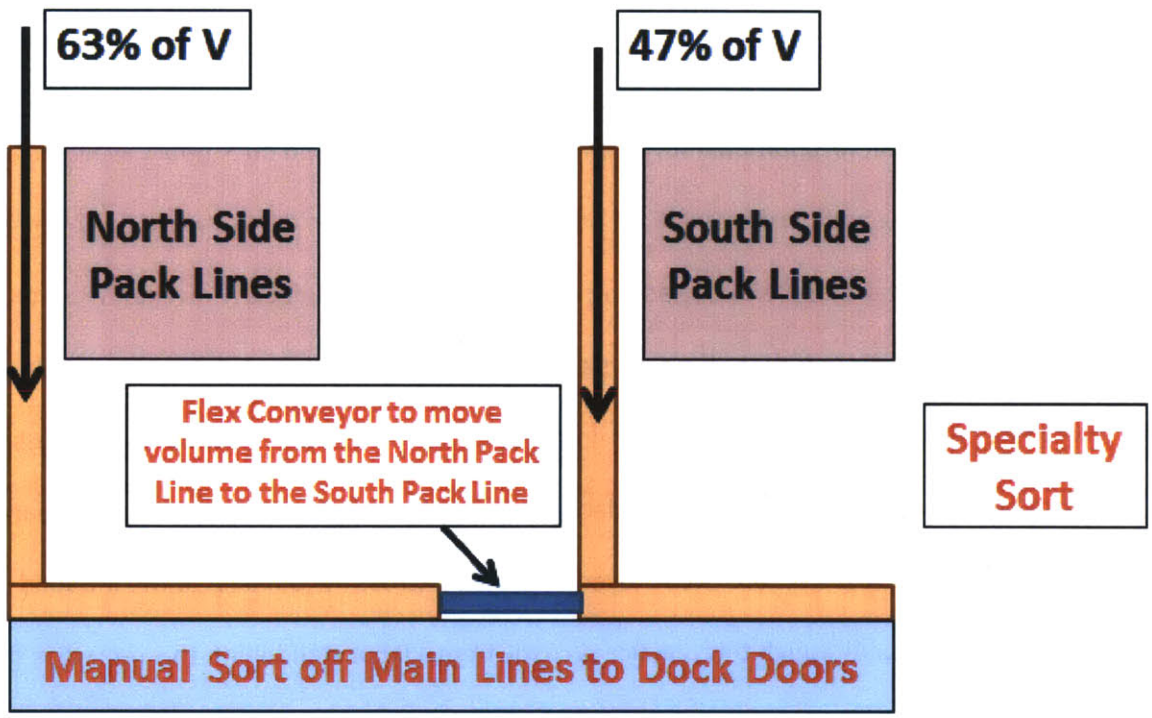



**Table 2.4 Summary of Operational Differences between FC1 and FC2**

| Operational Facet | FC1 | | FC2 | |
|---|---|---|---|---|
| **Building Type** | Type 1 | | Type 2 | |
| **Method of Sorting** | Automated | | Manual | |
| **Process Paths to Dock** | Ship Sorting | Flat Sorting | Ship Sorting | Specialty Sorting |
| **Package Flow to Dock** | All pack lines feeding 1 conveyor | | All pack lines feeding 2 conveyors | |

### 2.3.2 Method, Data Collection, and Discussion for Crafting a Peak Plan for FC2

Similar to FC1, capacity and forecast analyses were crafted for the volumes FC2 is expected to see during peak. It should be noted that time studies had to again be performed on the various labor steps due to the significant difference in the size and weight of the packages in a Type 2 building when compared to that of a Type 1 building. Without going into the details, these analyses again showed that the manual sorting and package loading operations will not be a source of bottlenecking the dock for both the ship sorting and specialty sorting process paths. Although the multiple package flow paths do complicate the operation, practices such as flex conveyors routing packages to both docks or replicating sorting areas between the North and South docks remedies this complication (although there are labor costs associated with these practices). Additionally, the space along the conveyors at the dock can be better utilized by adding pallet sort locations if sorting capacity ever becomes a concern for FC2.

The concern in accommodating additional sorts came down to the outbound dock doors available and skid staging space. Moving additional volume off of the pack lines and into a truck while performing a manual sort can always be accomplished by adding extra associates to the dock. However, a condition of locking up the dock will occur if there is no physical place to put the packages. FC2 accommodated for this risk during peak by taking additional dock doors from the inbound operation located across the building. Extra pallet sorting locations are then placed at the end of the conveyor lines that are parallel to the dock. Once full, these pallets are then moved all the way across the building to the inbound doors using pit equipment. Although this practice is costly from a labor standpoint, this remedies the concern of having no physical place to put the packages once they come down the line.

### 2.3.3 Conclusions and Limitations from Case Studies at FC1 and FC2

Studying the operations at FC1 and FC2 provided the insights that the sorting operations are not expected to bottleneck the dock as increasing number of sorts are required out of a building. Although there are volume spikes that regularly occur on lanes throughout the course of the day, the overall volume that an Amazon dock sees remains relatively constant. The fact that overall volume remains relatively constant indicates that the FC can cope with these individual lane volume spikes through effective capacity management of the operational facets of the dock. Even during peak when an FC is expected to see double the volume it sees throughout the course of the rest of the year, the sorting operations generally run under capacity. Comparing FC1 to FC2 showed that although these two FCs have drastically different outbound operations, the sorting capacity bottleneck appeared to be constant across the buildings.

Studying the operation at FC2 indicated that the bottleneck in adding sorts to any outbound operation is a space constraint where space is defined as the number of dock doors plus the amount of available staging space on the dock. If dock doors and staging space truly constrain the outbound operation as more sorts are added, the following questions appear:

- Exactly when does this space constraint become an issue?
- How can we measure available "space" at an FC?
- How can we gauge the effect of lane volume and volume fluctuations over time against the sorting capacity of a building?
- Exactly how costly is increasing the number of sorts from a labor standpoint?

In an effort to answer these questions, operations management principles were applied to a generalized FC dock process to quantify how dock doors and staging space can be used to figure the maximum sorting capacity of an FC.

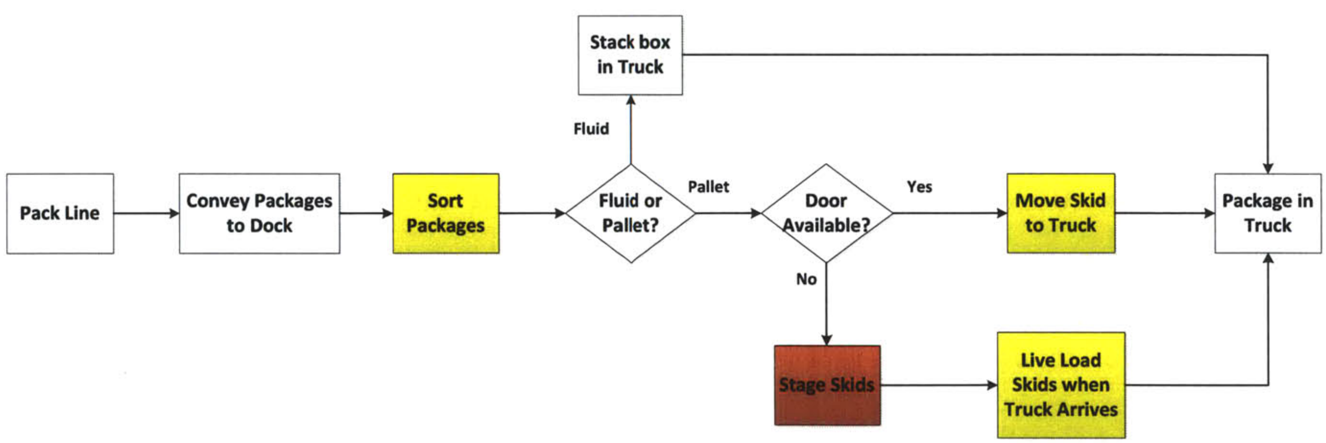
## 2.4 Generalization of Outbound Dock Operation and Insights Gained towards Max Sort Criteria

Chapter 2.4 focuses on creating a general dock process map and evaluating how the maximum number of sorts an FC can accommodate can be quantified given the operational capabilities of an FC. This quantification is important because it will directly lead to a simple method of evaluating the maximum sorting capacity of an FC. This evaluation is performed via operational observations, labor time studies, and package volume data analysis. A method for quantifying the sorting capacity of an FC is formulated along with the effects additional sorts have on labor productivity. However, this maximum sorting capacity formulation has the shortfall of not accounting for the timing of package flows. This shortcoming is explored later in this thesis with the information developed in this section as the foundation for this future work.

### 2.4.1 Background of Generalized Process Flow and Classification of Sort Types at an FC

From the case studies of FC1 and FC2, a high level process flow was created generalizing the steps involved in taking packages from the pack line, sorting the packages on the outbound dock, and moving these packages onto trailers. This process flow is given by Figure 2.10. The outbound dock process was then evaluated to determine which steps along the process change when more sorts are introduced. There are potentially two resources that increase in utilization as more sorts are required out of a building: 1. labor and 2. space. The steps marked in yellow in Figure 2.10 indicate areas where the labor is increased as the sort type changes from the most labor efficient sort type (fluid load). The step in red indicates an area where both labor and space are utilized to an increased extent by introducing a sort.

*Figure 2.10: Generalized Process Flow of Outbound Dock Operations*




There are 3 ways a sort can be handled: 1. **fluid load**, 2. **pallet load**, and 3. pallet load with staging (a.k.a. **live load**). As more sorts are required out of a given FC, increasing amounts of fluid sort locations are taken by these sorts. Fluid loading locations are used first as this sort type is the most efficient from a labor standpoint. Once all of the fluid loading locations are occupied by sorts, the lower volume sorts then must be allocated to pallet sorting areas. Once a pallet or skid is completed for these sorts, this skid can be directly loaded onto a trailer assuming a door is available exclusively for that sort. Pallet loading increases the labor cost of a particular sort as it adds on the non-value added steps of wrapping the packages to the pallet with shrink wrap, moving the completed skid to the trailer, having to find a new pallet once the previous pallet is completed, and moving the new pallet to the sorting location to continue the sorting process.

As even more sorts are required out of a building, the number of doors that can be exclusively dedicated to one sort decrease. Once there are enough sorts such that each sort cannot have its own dedicated dock door, the process of live loading the sort must occur. "Live loading" is defined as the process of accumulating skids in staging space on the dock until a door and a trailer become available for that particular sort. Once a door and a trailer are available, the skids are immediately loaded into the trailer. The trailer is then departed once all of the skids are loaded into it. Live loading has all of the non-value added steps that pallet sorting contains with the addition of having to move the skids to a staging area and then moving the skids from the staging area to the trailer once the trailer becomes available at a dock door. The question that then arises is: how do increasing numbers of pallet and live load sorts affect FC operations and where is the theoretical breaking point of the outbound dock?

### 2.4.2 Methods of Dock Door Capacity Analysis, Sort Volumes, and Staging Space Evaluation

The effect of increased pallet sorts and live loads on **1. dock door capacity**, **2. labor cost**, and **3. space cost** will now be evaluated. The effect on **dock door capacity** will be gauged by determining the critical path of loading packages onto a trailer and evaluating whether this will risk bottlenecking FC operations under any scenario. This critical path will be figured by performing time studies on the component jobs necessary for the live load operation and summing those that exist on a live load's critical path. The

**labor cost** of adding more sorts will be determined by performing time studies of the individual component jobs comprising each sort type. The times of these component jobs will then be summed for each sort type and compared across these three different sort types (fluid sort, pallet sort, and live load). A relative labor percent efficiency will then be figured comparing all sort types to the most labor efficient sort type (fluid load). Finally, the concept of **space cost** will be explored and a method will be presented for quantifying how space can be used to determine skid capacity.

### 2.4.3 Data Collection and Discussion of Dock Door Capacity Analysis, Sort Volumes, and Staging Space Evaluation

To begin the process of the **dock door capacity analysis**, a critical path of loading trailers with the associated job times needs to be performed. The critical path method is a project management concept where the times to perform every job in a project are estimated and the network of activities are mapped out along with the activities' interdependencies. Given the job times and the interdependencies of the tasks in the system, the longest path of planned activities to complete the project will be the rate limiting path for project completion. The time to complete a set of tasks can therefore not be shorter than the time it takes to complete all tasks on the critical path. (18)

Figure 2.11 provides this critical path analysis. Given that the number of dock doors and dock staging space ultimately limit the number of sorts a building can handle, understanding how long a dock door is needed to depart one live loaded sort will lead to a better understanding of the utilization of a door for live loaded sorts. Figure 2.11 will also provide insight into how many live loads one dock door can theoretically accommodate.

### *Figure 2.11: Truck Departure Critical Path*

| Deadlines for each Critical Task | CPT minus 12 minutes minus # of pallets*1.5 minutes | CPT minus 24 minutes | CPT minus 15 minutes' | CPT minus 14 minutes | CPT minus 13 minutes' | CPT minus 12 minutes | CPT minus 11 minute | CPT minus 10 minutes | CPT | CPT + 1 minute |
|---|---|---|---|---|---|---|---|---|---|---|
| **Task #10** | | | | | | | | | Begin | Completed |
| **Task #9** | | | | | | | | | Begin | Completed |
| **Task #8** | | | | | | | | Begin | Completed | |
| **Task #7** | | | | | | | Begin | Completed | | |
| **Task #6** | | | | | | Begin | Completed | | | |
| **Task #5** | | | Begin | | | Completed | | | | |
| **Task #4** | | | | | Begin | Completed | | | | |
| **Task #3** | | | | Begin | | Completed | | | | |
| **Task #2** | Begin | | | | Completed | | | | | |
| **Task #1** | | Begin | Completed | | | | | | | |

Let's say the maximum number of pallets that can fit into a trailer is 25, Figure 2.11 shows that the maximum expected time for a live loaded sort to occupy a dock door is 50 minutes. This means that a dock door at 100% utilization used only for live loaded sorts with a volume of 25 pallets can accommodate approximately 28 live loads in one day. Of course, no piece of equipment can be run at 100% utilization without having infinite queues due to variability in job arrival times. (19) However, this analysis still provides an estimate of the maximum number of sorts one door can handle.

To begin figuring the cost of labor for each sort type, Figure 2.12 breaks down the individual steps involved for each sorting type and gives the average time needed for each step in the process. The total time to load 100 packages into a trailer was then compared for each sorting method to quantify the labor efficiency of each sort type. This analysis is similar to the Boothroyd Method of gauging the relative efficiency of parts designed for assembly where each process step is timed individually and the sum of the times of the assembly operations gives an approximation of the total assembly cycle time. (20)

*Figure 2.12: Efficiency Comparison of the Three Different Sort Types*

| | | | | | | Time to Load 100 pkg (hr.) | % Efficiency |
|---|---|---|---|---|---|---|---|
| **Fluid Load** | Fluid Load 800 pkg/hr | | | | | 0.156 | 100% |
| **Pallet Load no Staging** | Pallet Load 700 pkg/hr | Wrap Pallet 60 s/pallet | Move Pallet to Trailer 90 s/pallet | Get New Pallet 90 s/pallet | | 0.245 | 64% |
| **Pallet Load with Staging** | Pallet Load 700 pkg/hr | Wrap Pallet 60 s/pallet | Move Pallet to Stage 90 s/pallet | Move Pallet to Trailer 180 s/pallet | Get New Pallet 90 s/pallet | 0.295 | 53% |

Figure 2.12 can be used to quantify the labor cost of adding more sorts to a building. This labor cost calculation is expressed mathematically as follows:

$$\text{Labor cost of sort} = \frac{E[V]}{Fluid\ rate}\ x\ (\frac{L}{\%\ eff} - L)$$

where: E[V] = expected hourly volume of sort changing sort types (pkg./hr.)

fluid rate = fluid load rate (pkg./hr.)

L = hourly associate labor cost

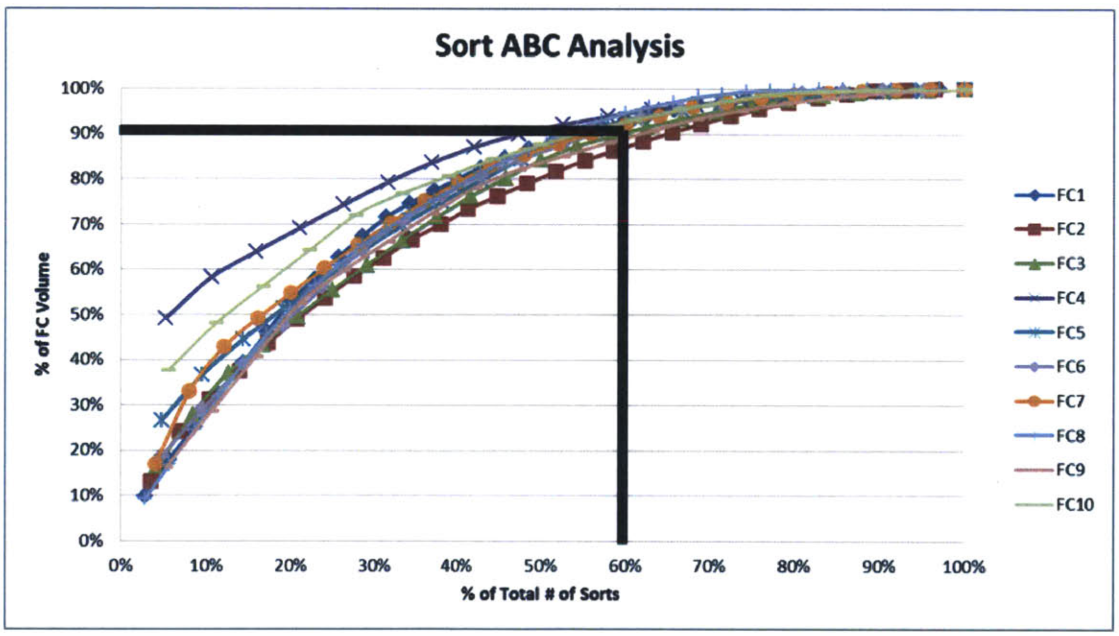
% eff = Efficiency of sort given by Figure 2.12

Although the **cost of labor** increases as more sorts are given to an FC, it will be assumed in this analysis that labor capacity will not limit the number of sorts an FC is able to execute. Because labor can be and is scalable at Amazon, this will not bottleneck dock operations.

However, one resource that will eventually bottleneck the dock as more sorts are added is **dock space**. Dock space bottlenecks the outbound operation as an FC is forced to cope with increasing amounts of live loaded sorts. In addition to the dock space constraining the live loading operation, the amount of time it physically takes to load skids onto a trailer can potentially bottleneck the overall flow as was explained in the critical path analysis of loading a trailer given by Figure 2.11.

To begin the analysis of how live loaded sorts affects space, the volume magnitude of sorts across the network was analyzed. Figure 2.13 shows that consistently across FCs, 90% of the total package volume goes to only 60% of the sorts. The analysis performed in Figure 2.13 is similar conceptually to ABC inventory classifications as a way to aggregate stock-keeping units (or SKUs) for decision models. The literature asserts via these ABC classifications that typically somewhere on the order of 20% of the SKUs account for 80% of the total annual dollar usage across businesses. (21) In a similar fashion, a relatively small number of outbound sorts account for a large volume of the package flows. Figure 2.13 indicates that FCs across the Amazon network regardless of location perform many low volume sorts. Since these low volume sorts are typically the ones that are live loaded, it can be safely assumed that the live loaded sorts in an FC have volumes requiring less than one trailer per day to ship packages on these sorts from an FC.

*Figure 2.13: ABC Analysis of Volume Distribution of Sorts across Different Buildings in the Amazon Network*




### 2.4.4 Conclusions of Dock Door Capacity Analysis and FC Staging Space Evaluation

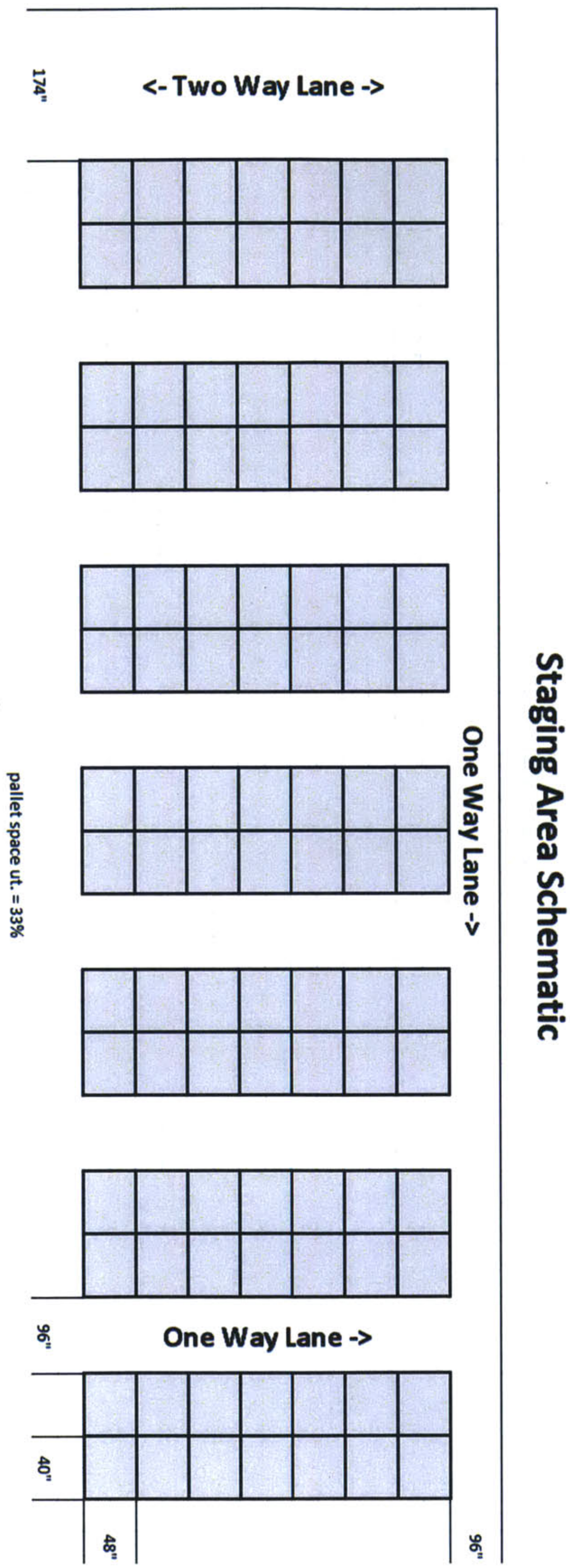
Let's say a typical Amazon FC has x dock doors. This means that it would take somewhere around the order of 28x sorts for dock door capacity to bottleneck the sorting operation in a typical FC. Since the most sorts an FC is currently accomplishing in the Amazon network is significantly less than 28x, dock door capacity is not expected to bottleneck the outbound operation. However, staging space for live loaded sorts is usually scarce at FCs. Outbound dock staging space is ordinarily not factored into the operational layout when an FC is originally designed. Therefore, any staging space that an outbound dock has is purely coincidental. Table 2.5 shows the amount of staging space by a sampling of FCs in terms of the number of skids that the staging space can accommodate. This is done to give a better understanding of the capacity of this buffer.

### Table 2.5 Staging Area by FC Given in Terms of Skid Capacity

| FC | Staging Area (# skids) |
|---|---|
| FC1 | 250 |
| FC2 | 100 |
| FC3 | 275 |
| FC4 | 150 |
| FC5 | 250 |
| FC6 | 100 |
| FC7 | 100 |
| FC8 | 117 |
| FC9 | 254 |
| FC10 | 100 |
| FC11 | 100 |
| FC12 | 50 |
| FC13 | 50 |
| FC14 | 100 |

The logic behind how the staging space skid capacity was estimated is outlined in Figure 2.14. A pallet's dimensions are 40" by 48". Due to safety concerns, any one-way pit lane must be at least 96" in width. Additionally, a two-way pit lane needs to be at least 174" wide. It will be assumed in this analysis that any staging space will be set up with 7 sets of 2 skid by 7 skid grids (as shown in Figure 2.14). Between the rows are one way pit lanes, and bordering the 7 set unit is a two way lane and a one way lane. It will be assumed that the structure in Figure 2.14 will regularly repeat for the staging space similar to the materials science concept of unit cells. Much like how figuring out the density of a material can be done by determining the density of that material's unit cell, the space utilization of this entire layout can be determined by taking the smallest repeating layout and finding out that repeating structure's space utilization. (22) Performing this analysis for the layout in Figure 2.14 shows that a space utilization of 33% exists for any staging area.

*Figure 2.14: Assumption of How the Staging Area of an Outbound Dock is Set-up*



Therefore, to determine the amount of skid staging space in an FC, the subsequent steps should be followed:

- Determine the square footage of available staging space in an FC
- Divide this square footage by the area of a pallet (40 in x 48 in = 1920 $in^2$)
- Multiply the result by 33% (per Figure 2.14)

### 2.4.5 Limitations of Dock Door Capacity and Staging Space Analysis

Although this analysis gives the staging space capacity in skids for an FC, it provides no insight into how much space is actually needed to accommodate increasing numbers of sorts. Additionally, it is not usual for two sorts to have the same CPT and therefore accumulate their total daily volume at the same time. In other words, just because an FC has two live loaded sorts that have a volume large enough to take up 26 skids, the FC does not necessarily have to have 52 skids available in its staging area. This is because one sort may depart the FC with 26 skids at a time in the day when the other sort has only accumulated 13 skids. If this is the time when the maximum number of total skids exists in the staging area between the two sorts, the maximum amount of staging space this particular FC needs is only 39 skids and not 52 skids. This fact yields the question: Given that dock staging space will ultimately limit how many sorts an FC is able to accommodate, how can one mathematically relate the amount of dock doors and staging space with the number of sorts that FC is able to ultimately handle?

## 2.5 Discrete Event Simulation Modeling to Determine the Relationship between Number of Live Loaded Sorts and Staging Space Required

Chapter 2.5 focuses on factoring how the timing of package flows to the dock can influence the sorting capacity of an FC. The reason why this is interesting is because it allows for a more accurate description of the outbound dock operation and provides for a more precise maximum sorting formulation. The influence of the timing of package flows is explored via discrete event simulation and we discover how the number of dock doors and the area of staging space work to dictate the ultimate number of sorts an FC is able to accommodate.

### 2.5.1 Simulation Model and Live Loading Background

Given that space will ultimately limit the FC's ability to sort packages, a simulation model was developed to determine how increasing levels of live loaded sorts command more dock space. Simulation models are used widely in industry to create a simplified representation of a system under study. These representations are then studied with the goal of being able to predict the system's future performance under differing scenarios. Since it is both time consuming and impractical to perform physical simulations on the many different parameters that can influence the amount of staging space needed on the dock (number of sorts, sort volume, sort volume distributions, etc.), the outbound dock process was modeled using discrete event Monte Carlo computer simulations. (23)

The skid staging, truck loading, and truck departing processes can essentially be thought of as a batch operation where entities are accumulated until the transfer batch size is reached and the entities are then removed from the system. To put this in terms of the outbound dock: skids for live loaded sorts are accumulated in staging areas until the truck is scheduled to depart. These skids are then moved onto the trailer and removed from the dock.

Hopp and Spearman illustrated the effects of their buffering law which they termed, "pay me now or pay me later" via employment of discrete event simulation. Their theory was that if production volumes could be predicted perfectly, there would be no waste in terms of lost throughput, wasted capacity, inflated cycle times, larger inventory levels, or long lead times. However, due to the negative effects of variability; some degree of buffering in terms of excess inventory, time, or capacity is necessary. (24) In our case, if the exact number of skids per sort at any given time could be predicted, the exact amount of staging space on the dock could be figured. Although a reasonable estimate can be made of package volume by sort by time of day, multiple simulation runs with different package arrival distribution functions were performed to gauge a worst case scenario for staging needed by number of live loaded sorts.

A literature review of the effect of batching on operations showed that studies on batching tend to focus on 1. the effect of batch size on the perceived variability of job flow in the next step of the process and 2. determining an appropriate transfer and process batch size such that the overall cycle time of a system is minimized. The main arguments given as the purpose of batching are either to mitigate the change-over costs for a process (such as change-over times required from going from one product family to another) or to lower the material handling costs when batches are not used (such as the amount of labor needed when using a forklift that moves 500 packages in one operation versus having to manually move each package). (25) In the case of the outbound dock, the added material handling costs of transfer batches certainly apply when it comes to moving skids of packages versus moving the packages individually. However, there are other considerations that ultimately determine the batch size of packages in a given skid and the batch size of skids in a trailer. For one, there is a safety concern of stacking packages over 6 feet tall on a pallet. This safety concern stems from the ergonomic apprehensions of taking heavy packages and continually placing them high over one's head. Additionally, stacking packages over 6 feet tall and shrink wrapping them eventually becomes impossible simply due to the height of an associate. The other consideration which coordinates well with minimizing transfer batching costs is truck utilization. Shipping a trailer with empty space can be a major source of cost for an outbound operation. Therefore, stacking packages on pallets as high as possible and loading as many skids onto a trailer as possible to maximize truck utilization is stressed at the FCs. For this analysis the effect of package batch size on skids will not be explored. However, the batch size of skids onto a truck will be varied to see the effect this has on staging area needed on the outbound dock. Ideally, 26 skids would be loaded onto each truck to maximize truck utilization.

However, waiting until each sort has 26 skids is not operationally practical as the low volume sorts in the FCs cannot fill 26 skids in one day. These packages must still go out on their daily CPTs in order to make customer promise. This process therefore causes less than optimal truck utilization.

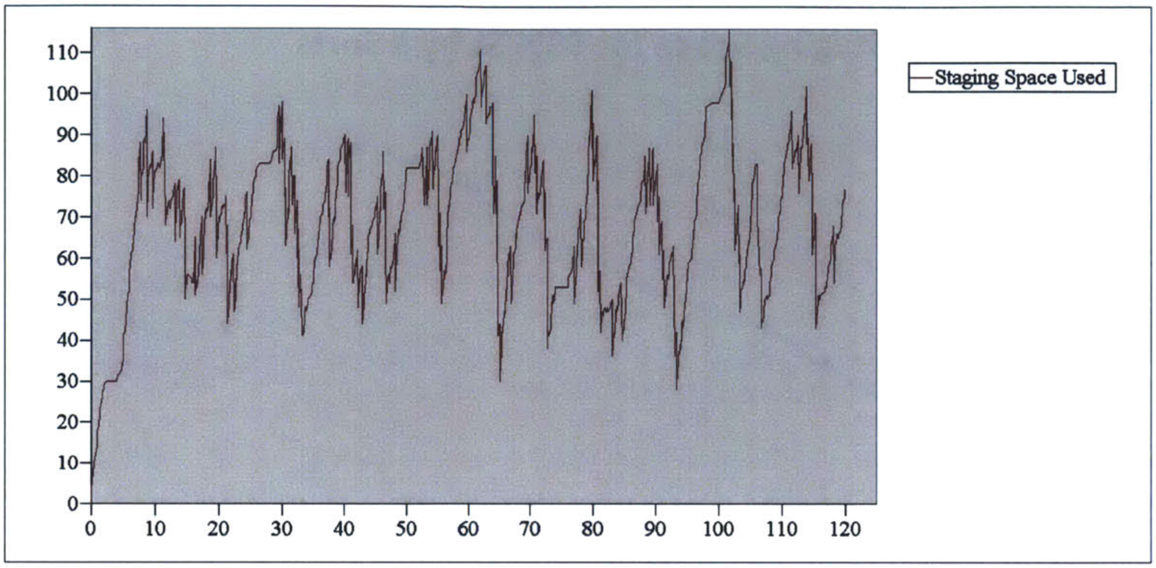
### 2.5.2 Explanation of Modeling Methods Used to Create Simulation Analysis

A simulation model was built to analyze the process of assigning a sort to a package, batching these packages into skids, moving these skids into a staging area, and then moving the skids into a trailer. As was previously stated, the batching operation that will be studied in this analysis will be the process of taking completed skids and batching them into trailer loads. This simulation was run for different sizes of batched skids, sort volumes, and package arrival distribution functions. The model simulates the processes of packming packages (package interarrival times based on a Poisson distribution), assigning a sort type based on a uniform probability function divided amongst the number of sorts, accumulating the skids in a staging area, loading the skids into a trailer, and finally departing the trailer. Throughout the simulation, the queues are continually monitored. The maximum queue experienced through the simulation period is then estimated as the space needed for 99% service level for staging space in the system. To obtain a more in depth explanation of the particulars surrounding how the simulations were formulated, refer to Appendix 1.

### 2.5.3 Overview of Simulations Run and Data Collected from Simulations

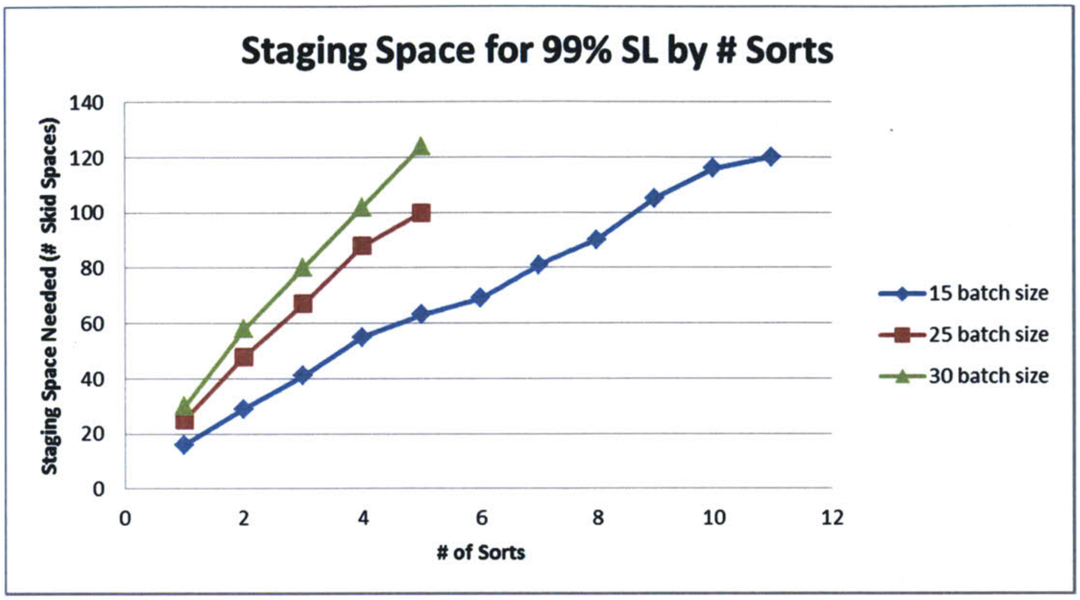
Figure 2.15 shows the staging space needed (in terms of # of skids) as a function of time for a simulation run where there are 10 sorts with equal volume, the same arrival distribution functions, an expected daily volume of 50,000 pkg./day, and a batch size of 15. Figure 2.15 shows that the variability in staging space needed throughout the simulation run is large with a spread as wide as 80 skids once the system hits steady state.

*Figure 2.15: Staging Space Needed as a Function of Simulated Time (parameters: 10 sorts, equal expected volume per sort, equal distributions, a batch size of 15, total expected volume = 50,000 packages)*



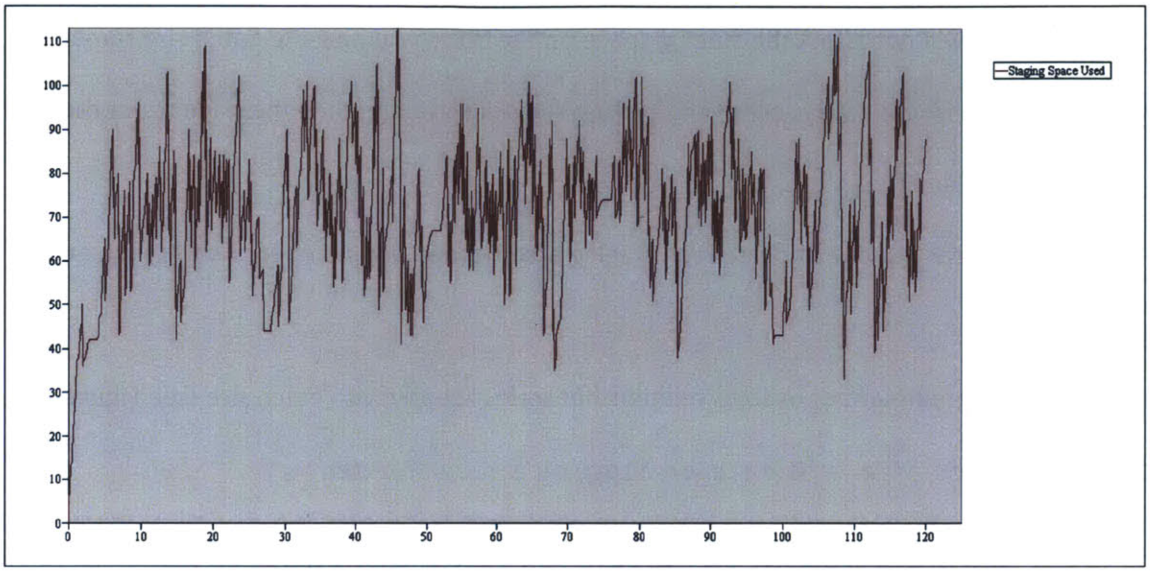

The simulation run in Figure 2.15 was then repeated for various batch sizes and varying numbers of sorts. The staging space needed as a function of the number of sorts under the scenarios of equal volume sorts and same arrival distributions is illustrated in Figure 2.16 based on these simulation runs. As can be observed from Figure 2.16, there appears to be a linear relationship between staging space needed and number of sorts for a given batch size. This linear relationship is significant because if there is a linear relationship for simulation scenarios with different sort volume and non-uniform arrival distributions, then a simple mathematical formulation for the maximum sorting capacity can be derived and applied across FCs.

*Figure 2.16: Staging Space Needed for 99% SL by Number of Sorts and Batch Size (parameters: equal expected volume per sort, equal distributions, a batch size of 15, total volume = 50,000 packages)*



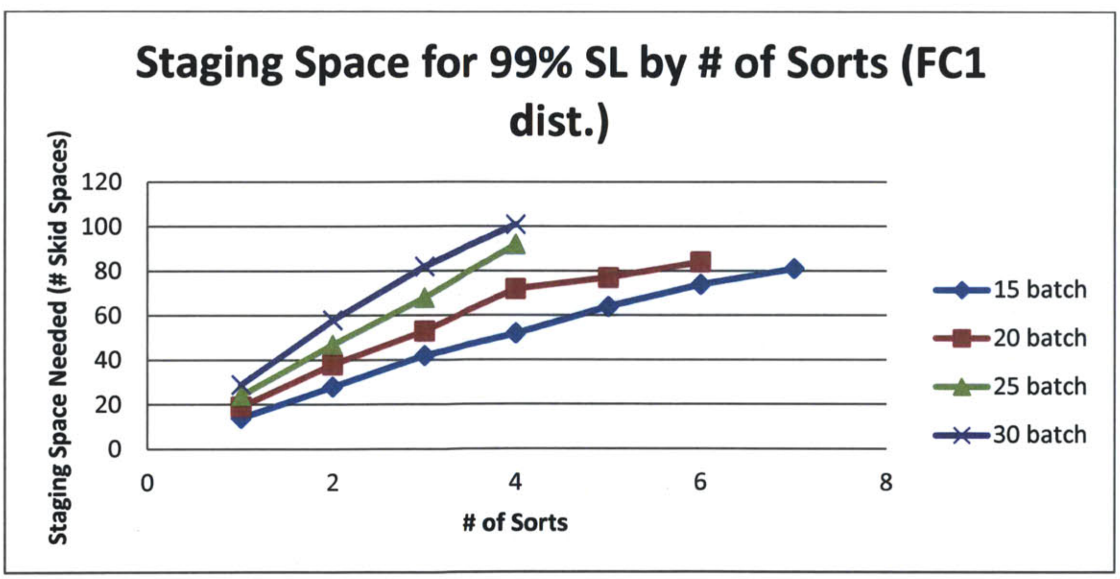

To gauge the effect of sort volume and arrival distribution patterns on the total staging space needed, the same analysis was performed for 10 sorts with different volumes, arrival distributions mirroring that of FC1's heaviest volume sorts, and an overall daily volume close to the capacity of the loading and departing operation (90,000 pkg./day). Figure 2.17 shows the staging space needed (in terms of # of skids) as a function of time for this simulation run. Although the staging space needed as described by Figure 2.17 varies more rapidly with respect to time when compared to the simulation parameters described in Figure 2.15, it should be noted that the maximum space used in either scenario was approximately 110 skid spaces. This is significant because it indicates that the total sort volume and the sort volume distributions have no effect on the amount of staging space needed at an FC for a given batch size and number of live loaded sorts.

*Figure 2.17: Staging Space Needed as a Function of Simulated Time (parameters: 10 sorts, non-equal expected volume per sort, distributions mirroring FC1's heaviest volume sorts, a batch size of 15, total expected volume = 90,000 pkg.)*




The staging space needed as a function of batch size and number of sorts under this simulation scenario is given in Figure 2.18. Similar to Figure 2.16, Figure 2.18 shows that a linear relationship is observed between the staging space needed and number of sorts for a given batch size.

*Figure 2.18: Staging Space Needed for 99% SL by Number of Sorts and Batch Size (parameters: non-equal expected volume per sort, distributions mirroring FC1's heaviest volume sorts, a batch size of 15, total expected volume = 90,000 pkg.)*

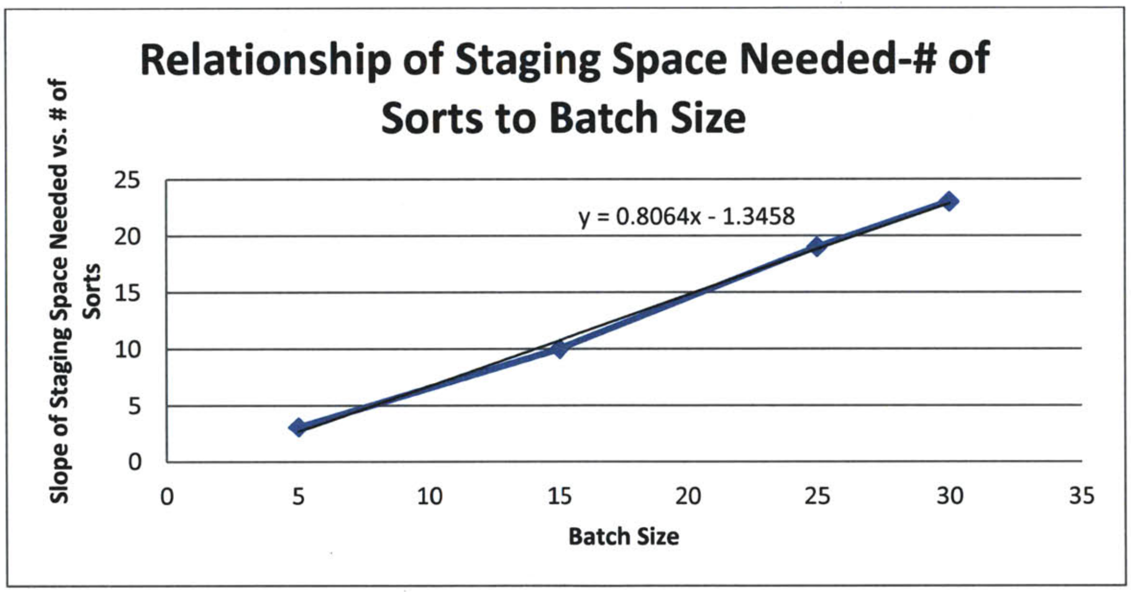


### 2.5.4 Discussion and Conclusions Gain from Simulation Runs

In summary, these simulations give a few insights:

- The overall volume of the sort will ultimately bottleneck the truck loading and departing process, but will not affect the staging space on the dock assuming the batch size remains constant (i.e. trucks always come and pick up the skids exactly when the skids count reaches the proper batch size)
- There is a linear relationship between staging area needed and number of sorts for a given batch size
- This staging area-number of sorts relationship scales linearly with batch size (see Figure 2.19)

*Figure 2.19: Batch Size Influence on Staging Space Needed*




Because there is a linear relationship between the slopes of the lines shown in Figure 2.18 and the batch size associated with these slopes (as illustrated by Figure 2.19), this relationship can be mathematically generalized by the following **Buffer-Batch Size Theory:**

$$B_U = 0.8 \times B_A \times S$$

Where: $B_U$ = Buffer size (a.k.a. skid floor spaces needed) required for 99% service level (SL)

$B_A$ = Batch size (i.e. how many skids are assumed to leave on a truck)

S = # of live loaded sorts

0.8 = factor determined experimentally via simulation (Figure 2.19)

In other words, the Buffer-Batch Size Theory argues that the capacity of a buffer needed for a batch operation with batch size $B_A$ can be determined via the following steps:

- Take the number of unique products or batches (labeled as S in the previous equation)
- Multiply the number of unique products by the batch size
- The product of the first two steps are then multiplied by 0.8 (0.8 is determined experimentally via the results of discrete event simulation analysis as illustrated in Figure 2.19)

Of course, this analysis assumes that the buffer step in the operation cannot have its capacity exceeded and hold up the preceding steps in the operation. This requirement is true for the Amazon FC outbound dock operation because if there is no place to put skids full of packages, the packages must remain on the conveyor belt. Although there is some place for the packages to accumulate on the ship sorters and flat sorters at the FCs, these machines were not designed to be a buffer and can very quickly lock up if excessive amounts of packages remain in the system. More generally, if exceeding a buffer's capacity does not pose the significant operational malignancies as is the case with an Amazon outbound dock; then designing a buffer with appropriate capacity given in the Buffer-Batch Size Theory is not necessary.

Finally, it should be noted that although the Buffer-Batch Size Theory gives the maximum volume that a buffer is expected to experience; thought should be given as to whether the buffer should be designed such that the buffer's capacity exceeds that of the capacity suggested by the Buffer-Batch Size Theory. In the case of the outbound dock: if all skid staging space is taken up by pallets, not only can it become hard to find the pallets when it is time for them to depart (since there will be many pallets in a small area), but it also becomes a chore to find a spot to place a skid full of pallets once the skid is completed. This will add the non-value added steps of spending extra time finding pallets when it is time for them to depart and finding spots to place skids when the buffer is close to capacity. These issues can eventually be remedied via technology giving associates exact locations of where skids are and where to place skids. However, since this technology is not yet an integral part of the operation; the ramifications of this must be considered when designing an outbound dock operation.

The Buffer-Batch Size Theory can be expanded and applied to the specific question posed in this thesis of determining the maximum number of sorts an FC is capable of handling given the FC's operational capabilities. This maximum sort criterion is defined mathematically as follows:

$$M_S = D_{OB} - D_{LL} + \frac{B_U}{0.8\, B_A}$$

Where: $M_S$ = max sorts

$D_{OB}$ = OB doors

$D_{LL}$ = Doors needed for live loads = $roundup(0.9\, x \frac{250\, pkg}{1\, skid}\, x \frac{25\, skids}{1\, truckload}\, x \frac{1\, truckload}{\frac{5}{6} hr.}\, x\, V_{LL})$, where $V_{LL}$ = live loaded volume (pkg./hr.), 0.9 = assumed maximum capacity at a door before queue size issues occur

The maximum sort criterion equations provide a way to universally calculate sort capacity across FCs. These equations indicate that the number of outbound doors and available outbound staging space are what ultimately limit the number of sorts a building can successfully accomplish.

### 2.5.5 Limitations of Max Sort Criteria

Although a theoretical method of calculating the maximum number of sorts an FC can accommodate has been explored in this thesis, practical guidance for dock layout and labor allocation for optimally executing a sort plan has not been given. This fact leads to the questions:

- What are the best practices for efficiently executing on a sort plan?
- What is the best way to lay out a dock given a sort scheme?

# 3 Methodology and Practices for Executing on a Sort Plan

Chapter 3 focuses on the best practices that should be employed for the proper operational execution of a given sort plan. The reason why focusing on sort plan execution is important is because although formulating the theoretical sorting capacity of an FC is necessary for saving cost in the Amazon network, this maximum sorting formulation is practically useless if the FC does not employ the practices that allow it to execute on the plan. Proper sort plan execution is explored by taking the case study of FC3 and generalizing the lessons from this case study to be applicable to all FCs in the Amazon network. What we discover is that there are a few practices that can be employed by FC leadership that will optimize labor while providing for more capacity to handle sorts.

## 3.1 Background on Sort Plan Execution

The previous chapters focused on calculating the theoretical maximum sorting capacity of an outbound dock and discovered via case studies, operations management principles, and discrete event simulation that the skid staging areas and dock doors create the eventual space bottleneck in the operation as more sorts are added to an FC. This space bottleneck will be the point of failure at the FC **assuming the dock is properly managed.** However, #1: what if management decides to make all sorts a live loading operation? Turning all sorts an FC has into live loads will impact the space bottleneck and will artificially set a lower limit on the number of sorts a building is able to accommodate. In addition, #2 how does one spatially set-up a dock given a sort plan with forecasted volumes? A methodology for dock set-up will be explored based on the previously explored concept of value added steps vs. non-value added steps while factoring in the position of dock leadership and package flows into the outbound dock. Finally, #3: image labor isn't properly planned on the dock such that packages cannot be taken off the ship sorter conveyors in time and the dock locks up. Historically, this condition has led to the false conclusion that the FC simply cannot take on additional sorts even though the problem is a labor planning problem and not a dock capacity problem.

While the previous chapters focused on sort capacity theoretical calculations, the ensuing chapters will focus on establishing and explaining practices for running the dock.

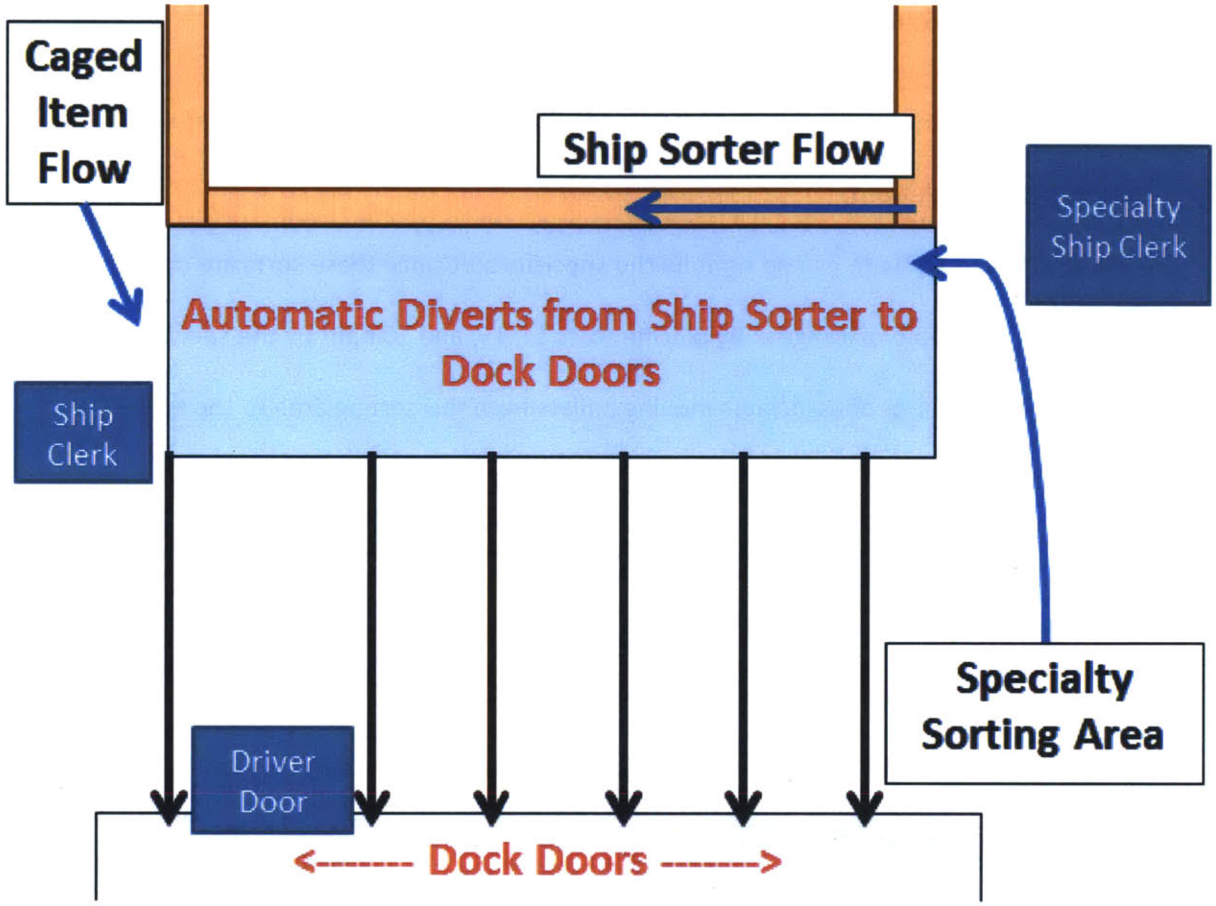
## 3.2 Methodologies Employed to Establish Best Practices for Sort Plan Execution

Executing on a sort plan is an exercise in matching incoming package volumes to a dock's sorting and package moving capacity while maximizing the number of packages flowing to the most labor efficient sort types. The case study of setting up the outbound dock of one of Amazon's newer FC's (which we will call FC3) for its startup will be explored. Additionally, the effect of increasing package volumes (which typically occur during the ramp-up of an FC) on FC3's outbound dock configuration will be studied to garner greater insights. These insights will then be generalized into best practices that can be used to manage an outbound dock.

## 3.3 Data and Discussion for Effective Sort Plan Execution

To aid in understanding the spatial movement of packages to the outbound dock, a dock layout schematic for FC3 is given in Figure 3.1. FC3 contains specialty items much like FC2. However, one difference between FC3 and FC2 is that FC3 has an automatic ship sorter whereas sorting at FC2 is a manual process. Additionally, FC3 has three separate package flows into the dock: 1. ship sorter, 2. caged items, and 3. specialty items. The **ship sorter** is a single line that is fed by all of the pack lines. Packages are automatically diverted off of this sorter to either one of several fluid lanes or to one long pallet sorting area. The **caged items** are packages that are too big to fit down the chutes of the automatic ship sorter, but are light and small enough such that these packages do not need to go to the specialty sorting area. These packages are loaded onto large carts and manually fed into the various conveyors for ship sorter diverts. These "caged items" packages are then either fluid loaded into a truck or sorted onto a pallet to eventually go onto a truck. The **specialty** sort is the same process as in FC2. An associate sorts these packages using equipment into the specified sorts.

*Figure 3.1: Layout and Various Package Flows of FC3's Outbound Dock*




An analysis similar to that performed in Table 2.3 was done to match incoming package volume forecasts with sorting area capacity for the start-up of FC3. This analysis yielded the dock layout shown in Figure 3.2. The layout given in Figure 3.2 is a result of the application of a few rules that showed to be useful in the set-up of FC3's dock upon its start-up, but can also be generalized across FCs. These rules will be reviewed specifically for the case of FC3's start-up and will be generalized in the ensuing "Conclusions and Generalized Best Practices for Executing on a Sort Plan" section.

The first step that was performed when creating a layout for FC3's dock was to perform a capacity analysis for each sorting position and matching this capacity analysis with the forecasted hourly volume of each sort. Since each of FC3's volume by sort are well under the ultimate lane capacity for fluid loading and pallet loading packages, every sort that could be performed with fluid loading was given a fluid load lane. There are four things to note with this:

1. Sort 10 could not be given a fluid load lane since the next step in the process requires all packages to be palletized.
2. Sorts 11, 15, and 16 were placed right by the specialty sort since these sorts are entirely comprised of specialty packages. By placing sorts 11, 15, and 16 right by the specialty sort; the non-value added labor of associates moving pallets from this sorting area to the trailers is minimized.
3. Some sorts require live loading. Typically, these live loads are low volume sorts that are palletized, staged, and then live loaded to the back of a box truck or 5 ton truck. Since the volumes are so low for these sorts (typically less than 4 pallets per day), it does not make sense for Amazon or the carrier to have a trailer and a dock door taken up by this sort. Door 24 is allocated for these low volume live loads.
4. Not all fluid lanes are utilized. There are two reasons as to why not all fluid lanes are used: #1 if one sort took up more than one fluid lane, the non-value added step of associates having to walk between trailers once the volume dries up would be increased in frequency; and #2 there is not enough volume in any of these sorts to fill up one entire trailer. Truck utilization is an important driver of cost for an outbound dock. Consistently shipping two half-full trailers instead of shipping packages on one full trailer would be a source of waste that should be minimized.

Once the fluid door allocations per sort were chosen, assigning the exact location of each sort was done. The heaviest volume sorts were placed in doors 4, 6, and 7 in order to minimize any non-value added steps on the dock, place potentially problematic lanes in full view of dock leadership, and avoid potential congestion in the lot. These principles are specifically applied to FC3's layout as follows:

1. **Minimize non-value added steps on the dock:** the two manual package flows to the dock are the caged item flows and the specialty flows. Although no data could be ascertained for the amount of packages flowing down the caged item path, it was assumed given FC experience that this flow was greater in volume than the specialty flow (except for Sort 8 which has 10% of its volume going through the specialty process path). Therefore, the manual transport of packages would be minimized if the heaviest volume sorts were placed closest to the origin of the caged item flow. Additionally, when a trailer needs to depart, two associates need to perform various steps requiring movement between the ship clerk's desk and the driver door. The closer a sort is to these two locations, the less non-value added walking occurs.
2. **Place potentially problematic lanes in full view of dock leadership:** The ship clerk is one of the most senior associates on the dock. The ship clerk is in charge of keeping track of package volumes to ensure sufficient trucks and drivers are scheduled for a given lane (especially important if there are large unforeseen spikes in volume), coordinating labor on the dock, and directing drivers as they check into and out of the building. The ship clerk also lends a hand in stacking packages and removing volume off of the conveyor belts if the volumes get to be too extreme. Since heavier volume lanes tend to need increased oversight in these areas, efforts need to be made to ensure the heavy volume lanes are in full view of the shipping clerk. Although the benefit of this practice is intangible, FC leadership considers this as a general best practice in laying out a dock. This practice again incorporates the theory of Spear introduced earlier in this thesis of ensuring problems are immediately seen at the problem's source. (3)
3. **Avoiding potential congestion in the outside lot:** Finally, the critical pull times (CPT) of the sorts should be examined to ensure congestion in the outside lot is minimized. The CPT signifies the

time that a trailer will be picked up by a carrier to ensure the packages will reach the next step and ultimately the final customer on time. If many doors with the same CPTs are stacked next to one another, experience has shown that the drivers coming in to pull the loads can experience interference between one another. This driver interference can be a source of disruption for the outside lot.

**FC3 Layout - Start-up**

| | | | Fluid Load | | | | | | | | | | | | | | | Pallet Sort | | | | | | Specialty Doors | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 9 | 10 | 11 | 13 | 14 | 15 | 16 | 17 | 18 | 20 | 21 | 22 | 23 | 24 | 25 | 27 | 28 | 29 | 30 | 31 |
| | | | Sort 6 | Sort 3 | Sort 1 | Sort 2 | Sort 4 | Sort 5 | Sort 12 | Sort 7 | Sort 9 | Sort 8 | | | | | | | | | Live Loads | Sort 10 | Sort 11 | Sort 15 | Sort 16 | | |
| Avg. Hrly V | | | 9 | 25 | 49 | 26 | 22 | 10 | 2 | 6 | 5 | 6 | | | | | | | | | | 3 | 2 | 1 | 1 | | |
| V Spike Multiplier | | | 6.9 | 2.9 | 4.2 | 4.4 | 4.0 | 7.7 | 4.8 | 4.3 | 3.0 | 4.3 | | | | | | | | | | 3.1 | 7.6 | 7.8 | 6.5 | | |
| % of Total | | | 6% | 15% | 30% | 16% | 13% | 6% | 1% | 4% | 3% | 4% | | | | | | | | | | 2% | 1% | 0% | 0% | | |
| % Specialty Item | | | 2% | 0% | 2% | 2% | 2% | 2% | 0% | 2% | 2% | 10% | | | | | | | | | | 0% | 100% | 100% | 100% | | |
| CPT | | | 18:00 | 15:00 | 18:00 | 18:00 | 5:00 | 18:00 | 13:30 | 18:00 | #### | 16:00 | | | | | | | | | | 16:00 | 18:00 | 15:00 | 15:00 | | |

*Figure 3.2: Dock Layout for FC3's Startup*

As package volumes increased for FC3 after the start-up of this facility, a new dock layout had to be created to cope with these volumes. Figure 3.3 shows the next dock layout for FC3 after the volume in the building ramps up to full production. Again, there are a couple of takeaways that can be gleaned from this analysis:

1. **Sort 1 is allocated additional fluid doors:** Since the volume spikes of sort 1 are now greater than the capacity of fluid loading non-sort packages for one lane, this sort now gets 2 fluid load doors. It should be noted that these volume spikes can also be remedied by placing pallet sorting locations alongside the conveyor going into the trailer to remove volume from the conveyor. However, since there are additional fluid lanes available, it is preferable to use these lanes as opposed to the less efficient pallet sorting method.
2. **Sort 1 is also given a door by the specialty sort:** The volumes experienced by Sort 1 also dictate that a door and trailer are given to it in the specialty sorting area. The reason for this is because the typical number of specialty packages that fit on one pallet is approximately 4 due to the sheer size and weight of objects sent to the specialty sorting area. Using this number, sort 1 will fill up approximately 25 pallets per day of specialty material which will fill close to an entire trailer. By allocating a door to Sort 1 in this area, the non-value added steps of transporting these pallets across the dock is minimized.

| FC3 Layout - After Ramp-up | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fluid Load | | | | | | | | | | | | | | Pallet Sort | | | | | | Specialty Doors | | | | |
| | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 9 | 10 | 11 | 13 | 14 | 15 | 16 | 17 | 18 | 20 | 21 | 22 | 23 | 24 | 25 | 27 | 28 | 29 | 30 | 31 |
| | | | Sort 6 | Sort 1 | Sort 1 | Sort 2 | Sort 3 | Sort 4 | Sort 5 | Sort 12 | Sort 7 | Sort 9 | Sort 8 | | | | | | | | Live Loads | Sort 10 | Sort 11 | Sort 15 | Sort 16 | Sort 1 | |
| Avg. Hrly V | | | 36 | 196 | 196 | 102 | 98 | 87 | 41 | 7 | 25 | 19 | 24 | | | | | | | | | 14 | 7 | 4 | 3 | 196 | |
| V Spike Multiplier | | | 6.9 | 4.2 | 4.2 | 4.4 | 2.9 | 4.0 | 7.7 | 4.8 | 4.3 | 3.0 | 4.3 | | | | | | | | | 3.1 | 7.6 | 7.8 | 6.5 | 4.2 | |
| % of Total | | | 6% | 30% | 30% | 16% | 15% | 13% | 6% | 1% | 4% | 3% | 4% | | | | | | | | | 2% | 1% | 0% | 0% | 30% | |
| % Specialty Item | | | 2% | 2% | 2% | 2% | 0% | 2% | 2% | 0% | 2% | 2% | 10% | | | | | | | | | 0% | 100% | 100% | 100% | 2% | |
| CPT | | | 18:00 | 18:00 | 18:00 | 18:00 | 15:00 | 5:00 | 18:00 | 13:30 | #### | 18:00 | 16:00 | | | | | | | | | 16:00 | 18:00 | 15:00 | 15:00 | 18:00 | |

*Figure 3.3: Layout of FC3's Dock after Ramp-up of Volume*

An additional complication with the increase in volumes FC3 is now experiencing is that labor planning may not be as straightforward as it previously was. Although dock leadership does know the total volume to be expected during a shift at an FC, these total volumes do not necessarily help with the planning of labor on the dock. The reason for this is because the total volume experienced in a shift does not reflect the variability in overall package flows that occur throughout the course of the day. As was previously explored and illustrated in Figure 2.4, package flows (or pack patterns as it is termed in Figure 2.4) do vary significantly throughout the course of the day. If labor was planned only off of average package volumes, there would be times where the volume spikes will cause package queuing to occur on the dock. As this queuing can cause the dock to lock up, this situation must be avoided. A way to avoid this is via hour by hour labor planning. The package volumes by hour must be figured and compared with the labor needed to accommodate these volumes. Once this is done, labor on the dock can either be scheduled on an hourly basis (which is optimal from labor cost and utilization standpoints) or the hour when the most labor is needed can be used to dictate the labor needed during the entire shift. Using the latter method, the labor calculation for total associates needed can be expressed as follows:

$$\#\, associates = \text{roundup}\left[max\left(\sum_{sort\ 1}^{sort\ n} \frac{V_{ip}}{r_p\ x\ h_i}\right)\right] \text{ for all hours in a shift}$$

Where: n = total number of sorts

$V_{ip}$ = total package volume during hour i for sort p

$r_p$ = hourly rate of one associate for sort p (based on whether sort is fluid, pallet, or live load)

$h_i$ = percentage of time actually worked during hour i (to factor in breaks)

An example of the output for this formulation is given in Figure 3.4 where the rates by sort type are assumed to be 800 pkg./hr. for one associate performing fluid loading. The volumes by hour are forecasted on a percent of total volume per shift. For simplicity, all sorts will be assumed to be fluid loads. The output of Figure 3.4 indicates that hour 12 during the shift needs the greatest number of associates at 7 in order to accommodate the volumes heading to the dock. The recommended labor on the dock for this shift will therefore be 7 associates.

*Figure 3.4: Example of Dock Labor Planning by Hour of Day*

| **Hour of Day** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **% of Hour Worked** | **100%** | **38%** | **100%** | **100%** | **100%** | **100%** | **50%** | **100%** | **100%** | **100%** | **100%** | **100%** |
| **% of Total Package Volume by Sort** | | | | | | | | | | | | |
| **Sort #1** | 0.2% | 0.4% | 0.7% | 0.7% | 0.9% | 1.0% | 0.7% | 0.6% | 0.7% | 0.6% | 0.6% | 0.4% |
| **Sort #2** | 0.0% | 0.6% | 2.1% | 1.9% | 2.6% | 2.0% | 1.4% | 0.9% | 1.6% | 1.0% | 1.4% | 1.9% |
| **Sort #3** | 0.2% | 0.3% | 0.7% | 0.5% | 0.5% | 0.4% | 0.4% | 0.3% | 0.4% | 0.3% | 0.4% | 0.7% |
| **Sort #4** | 0.2% | 0.4% | 0.7% | 0.6% | 0.7% | 0.7% | 0.5% | 0.7% | 0.9% | 1.0% | 1.0% | 0.5% |
| **Sort #5** | 0.2% | 0.2% | 0.5% | 0.4% | 0.5% | 0.4% | 0.3% | 0.3% | 0.6% | 0.5% | 0.7% | 0.3% |
| **Sort #6** | 0.3% | 1.3% | 2.9% | 2.8% | 3.1% | 3.0% | 1.8% | 1.8% | 2.7% | 2.8% | 3.7% | 1.5% |
| **Sort #7** | 0.1% | 0.2% | 0.5% | 0.4% | 0.5% | 1.0% | 0.8% | 0.6% | 0.8% | 0.6% | 0.6% | 0.8% |
| **Sort #8** | 0.0% | 0.0% | 0.1% | 0.1% | 0.1% | 0.2% | 0.1% | 0.1% | 0.3% | 0.3% | 0.4% | 0.6% |
| **Sort #9** | 0.0% | 0.2% | 0.7% | 0.5% | 0.5% | 0.5% | 0.7% | 0.5% | 0.6% | 0.5% | 0.7% | 0.9% |
| **Sort #10** | 0.1% | 0.4% | 1.0% | 0.9% | 1.1% | 0.9% | 0.5% | 0.7% | 1.3% | 1.2% | 1.3% | 0.4% |
| **Sort #11** | 0.2% | 0.2% | 0.4% | 0.4% | 0.4% | 0.4% | 0.3% | 0.3% | 0.5% | 0.5% | 0.7% | 0.3% |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **# Associates Needed** | 1 | 5 | 5 | 4 | 5 | 5 | 7 | 3 | 5 | 4 | 5 | 4 |

The lessons learned from setting up FC3 can now be generalized and applied to set up other outbound docks. These generalizations are discussed in the ensuing conclusions section.

## 3.4 Conclusions and Generalized Best Practices for Executing on a Sort Plan

When setting up the configuration of an outbound dock, certain rules can be followed to ensure good dock execution. These rules are incorporated into FC3's layout established in Figures 3.2 and 3.3 and can be generalized as follows:

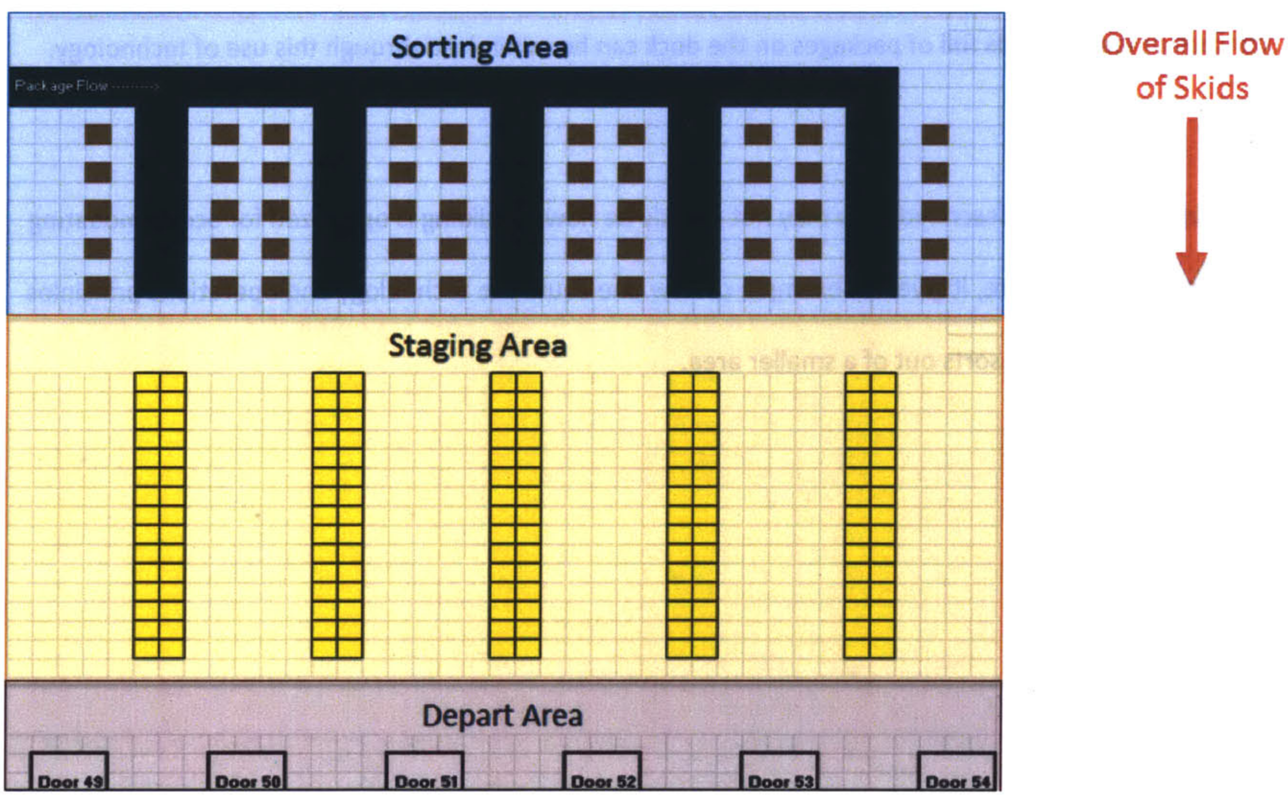
1. Evaluate max capacity of all sort positions. This analysis is outlined using the case study of FC1 in Table 2.2.

2. Forecast average hourly volumes plus volume spikes for each individual sort.
3. Plan dock based on average volumes. Put the highest volume sorts on fluid lanes while palletizing the remaining lower volume sorts. If volume spikes go over lane max capacity, plan a contingency to handle excess volume in the form of either flex doors or additional pallet positions alongside the fluid conveyor.
4. Establish truck change-over practices for the removal of packages for lanes that experience heavy volumes. The reason why this must be done is because truck change-overs cause a door to be out of commission for several minutes while volume is still coming down for the sort. These practices can involve 1) having 1 flex door available to accommodate truck swapping so that volume for a sort can still be removed from the line or 2) placing pallet locations next to the conveyor and removing volume via pallet stacking during the change-over.
5. Minimize the amount of non-value added labor on the dock. Specifically, the following can be done to ensure these non-value added steps are minimized:
    a. Direct as much volume as possible through the most labor efficient sort type (fluid loading).
    b. Understand the various process paths to the dock and direct the most volume possible to the path that is the most efficient from labor, truck utilization, and quality standpoints. For sortable buildings, this includes diverting as much volume as possible through the flat sorter without causing very large packages to go to the flat sorter (see section "1.2 Walking the Process" for a more in depth explanation of this concept).
    c. Place the heaviest volume sorts that will have the most truck change overs near the trucker cage and ship clerk's desk.
6. Incorporate the effect of leadership on the dock's operation. Placing sorts closest to the ship clerk can help ensure that problems are seen as they occur.

7. Ensure labor is planned properly for the incoming package flows recognizing that volume can vary significantly throughout the course of the shift.

It should be noted that these rules do not constitute a comprehensive list of all aspects that can be considered when managing a dock. However, these guidelines are meant to provide practical direction as to the various aspects that should be considered when setting up dock operations given the current dock management technologies and outbound transportation schemes. One can imagine that future technologies (such as automation) can transform and revolutionize both the future of outbound operations and warehouse management in general. Attempts at automating warehouse operations are already being employed in other processes at Amazon, but it is not hard to imagine how they could be utilized on the dock. An example of a future outbound dock proposed by the author is illustrated in Figure 3.5.

*Figure 3.5: Proposed Future Layout of Outbound Docks*



The process in Figure 3.5 begins with packages flowing down a conveyor belt from the pack line. These packages are then taken to an area where the packages are sorted onto various pallet locations by associates. Upon completion of pallets during this sorting process, a transporting mechanism can come in and move the completed pallets to a staging area. The movement of pallets from the sorting area to the staging area can be thought of as an outbound process analogous to the stowing operation performed at most warehousing operations. These pallets can then be removed from the staging area and loaded onto a trailer when it is time for the packages to depart. This movement of pallets onto a truck in time for departure can be thought of as a process similar to that of the picking operation at Amazon. By having proper synchronization of skid moving automation loading skids onto trailers, more volume can then be put through a given dock door. This can create the situation where fewer dock doors are needed to handle the same amount of volume. Also, the non-value added processes of walking and having to look for skids can be minimized as the robots can be set to optimize the shortest path distance for skid moving and will have a complete record of skid location. Additionally, the quality concern of leaving skids full of packages on the dock can be minimized through this use of technology. (26)

Although the system described here may not exactly be how a building is optimized for accommodating more sorts in the future, it gives an example of how one could use technology and operations principles for getting even more sorts out of a smaller area.

# 4 Conclusions: Logic Used to Formulate Max Sort Criterion and Guidance for Sort Plan Execution

This thesis focused on the main question of: **Given the fixed operational capabilities of an Amazon Fulfillment Center (FC), what is the maximum number of ways packages can be sorted on the FC outbound dock?** This main question was answered via the following stream of experiments and logic:

1. Case studies of various FC sizes, products, and age of the Fulfillment Center itself were performed. All case studies led to the conclusion that it is the package skid staging and truck loading operations that will ultimately limit the number of sorts an FC is able to perform. This conclusion was reached by first creating a process flow map of the various outbound dock operations. Then, the time to perform each step was measured via time studies. Each process step was also mapped to the resources needed to perform the given operation. These resources were found to be either dock space or manual labor. Finally, the incoming flows of packages by sort were measured with the package flow distributions characterized and quantified. The various methods that these packages flowed to the dock (i.e. via conveyor vs. manual movement) were also considered when performing this analysis. The package flows were then compared with the maximum capacity of the different operations to figure a resource's utilization at each step in the process. Average utilizations and maximum utilizations were quantified and used to evaluate exactly where the bottleneck would occur in the system. **The end result of these case studies led to the aforementioned conclusion of dock space and/or the truck loading operation as being the potential bottlenecks for adding more sorts.**
2. Once these two steps were identified as potential areas of bottlenecking the dock as more sorts are added, a generalized, high-level view of the dock operation was created emphasizing the resources that get utilized to an increased extent at the different process steps as increasing

numbers of sorts are added (see Figure 2.10). It was found that labor is used to an increased extent at various process steps as more sorts are added to a building. However, because labor is scalable at Amazon (through the practice of hiring permanent or temporary workers), this increase in labor needed will not bottleneck the dock. **Instead, the increased utilization of staging space as more live loaded sorts are required out of a building was found to be the ultimate constraint as more sorts are required.** To rule out the truck loading operation, a critical path of live loading 25 skids into a truck was performed to determine the process time of this operation. This critical path showed that one door can theoretically accommodate 28 sorts in one day. Given the average number of dock doors at an FC and the current number of sorts FCs are typically performing, staging space will constrain a dock long before dock door utilization will.

3. Given that staging space for live loaded sorts ultimately limits an FC's sorting capacity, relating staging space to sorting capacity was necessary. This relationship was formulated via a Monte Carlo discrete event simulation that **showed a linear relationship between the buffer size needed and the number of live loaded sorts for a given batch size of skids.** This relationship was coined as the Buffer-Batch Size Theory and has the following formulation:

$$B_U = 0.8 \times B_A \times S$$

Where: $B_U$ = Buffer size (a.k.a. skid floor spaces needed) required for 99% service level
$B_A$ = Batch size (i.e. how many skids are assumed to leave on a truck)
S = # of live loaded sorts
0.8 = factor determined experimentally via simulation (Figure 2.19)

4. The Buffer-Batch Size Theory was then applied to the specific question posed by this thesis of determining the maximum sorting capacity of a given FC. This application was performed via **the formulation of the maximum sort criterion that could be used to dictate the maximum**

**number of sorts for any FC in the Amazon network.** This maximum sort criterion is described mathematically as follows:

$$M_S = D_{OB} - D_{LL} + \frac{B_U}{0.8\, B_A}$$

Where: $M_S$ = max sorts

$D_{OB}$ = OB doors

$D_{LL}$ = Doors needed for live loads = $roundup(0.9\, x \frac{250\, pkg}{1\, skid} x \frac{25\, skids}{1\, truckload} x \frac{1\, truckload}{\frac{5}{6} hr.} x\, V_{LL})$, where $V_{LL}$ = live loaded volume (pkg./hr.), 0.9 = assumed maximum capacity at a door before queue size issues occur

5. Finally, practical guidance was given in terms of establishing the dock layout, labor plan, leadership interaction, and contingencies in the case of unexpectedly high volumes flowing into a dock. This guidance was simply the practical application of the theory of minimizing non-value added work, utilizing flexible capacity, and planning for average package flows while ensuring maximum flows do not at any time blow out the capacity of any given resource.

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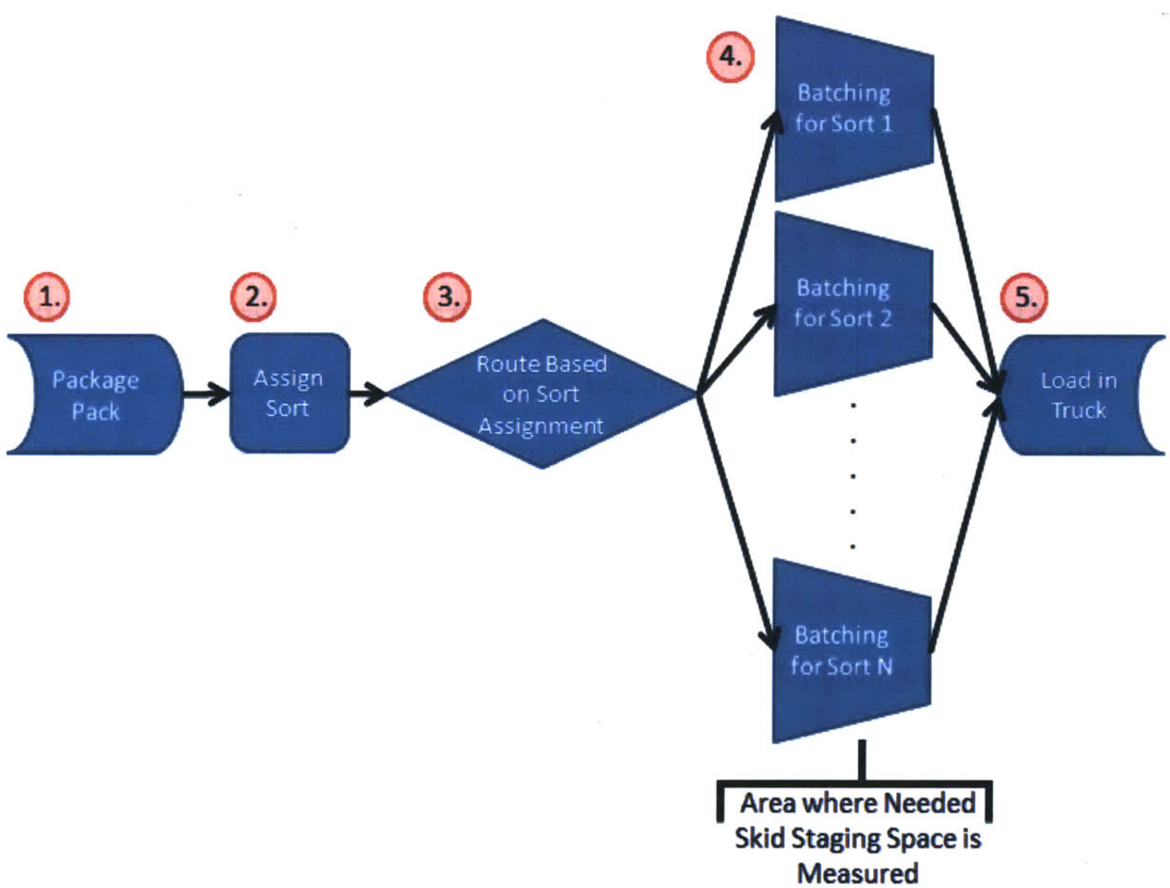
# Appendix 1: Formulation of Monte Carlo Discrete Event Simulation

This appendix outlines the particulars of how the discrete event simulation as described in section 2.5 was formulated. Essentially two main architectures were used for all simulation runs depending on whether the function of assigning entities to a sort was based on a uniform distribution or a user-defined distribution that varied considerably with respect to time. The former architecture was easier to create whereas the latter provided a more accurate representation of package flows to the outbound dock. Both architectures were employed to gauge the robustness of the eventual formulation of the Buffer-Batch Size Theory. Figure A.1 gives a high level view of the simulation used for assigning entities based on the uniform distribution.

*Figure A.1: Flowchart Showing the Discrete Event Simulation Formulation for Assigning Entities Based on a Uniform Distribution*



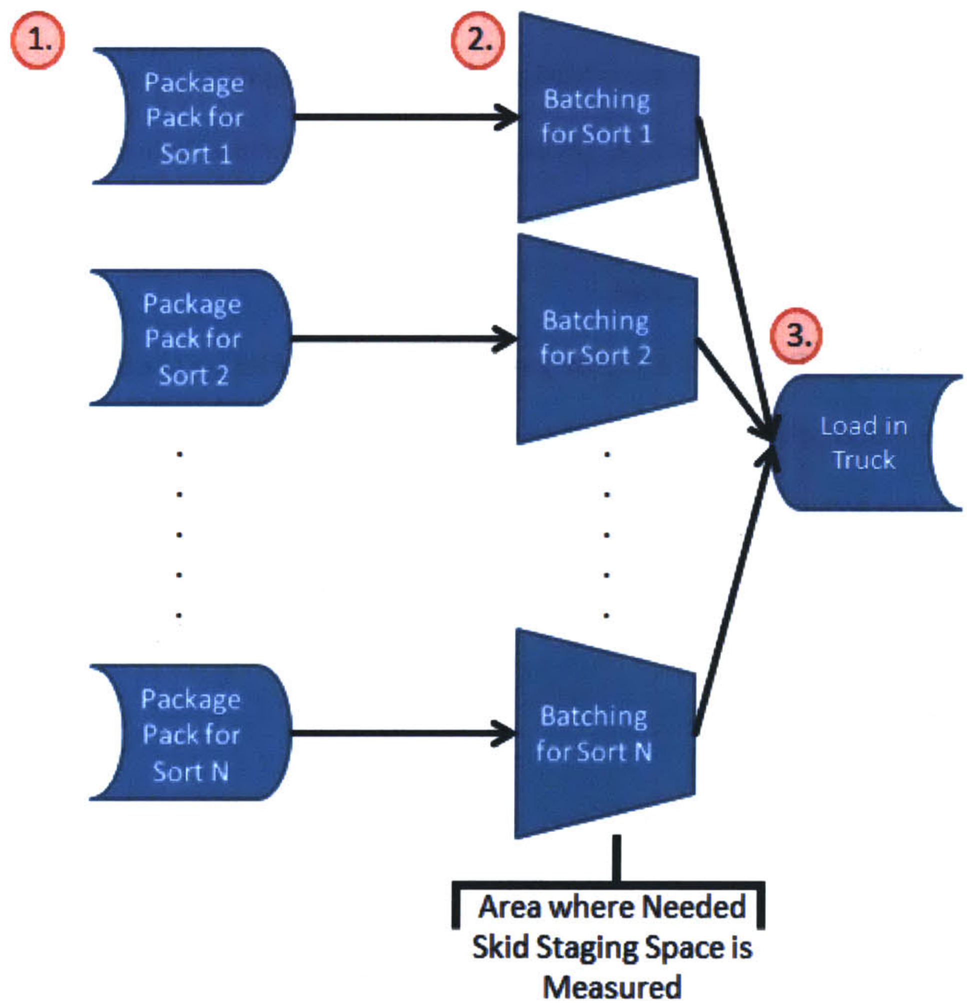
The particulars of the simulation corresponding to the step numbers shown in Figure A.1 are as follows:

1. **"Package Pack"** – This step is an entity creation process that generates entities based on any user-defined arrival distribution function. In the context of this project, this step essentially determines the arrival of packages to the dock. The entities in the model were defined as skids of a fixed number of packages as opposed to individual packages in order to reduce the computational load required by the simulation.
2. **"Assign Sort"** – This step is an assign process where the entities are assigned to a particular sort based on a user-defined uniform distribution function for each sort. One shortcoming of this formulation is that it does not mimic the package volume spikes for a given sort observed on a typical dock.
3. **"Route Based on Sort Assignment"** – This step is a decide process that routes the entities to the various batching processes based on the assign value given to the entities during the "Assign Sort" step. This step can essentially be thought of as the actual sorting process that occurs in the FCs.
4. **"Batching for Sorts 1-N"** – This step is a batching process where the entities are accumulated until the user-specified batch size is reached. This step is the part of the logic where both the number of sorts (by increasing the number of batching processes) and the batch size per sort (by editing the batching operation) can be varied. It is at this step where entities are summed across the batching operations and recorded as the simulated time advances throughout the run. This summation gives the amount of staging space needed throughout the simulation, and the maximum value obtained here is assumed to be the 99% service level of space needed to accommodate the live loaded skids. This process can be thought of as the part of the outbound operation where skids are staged on the dock until a trailer becomes available to remove the skids from the dock.

5. **"Load in Truck"** – This step is a dispose process where the entities are removed from the system after the critical batch size in the previous step is reached. This step can be thought of as the actual process of taking skids from the staging area, loading the skids onto a trailer, and departing the trailer from the FC.

As was previously alluded to in this appendix, a separate simulation architecture needed to be created to more accurately simulate the package flows by sort that are regularly seen at an FC. This simulation architecture is illustrated in Figure A.2.

*Figure A.2: Flowchart Showing the Discrete Event Simulation Formulation for Assigning Entities Based on User-Defined Arrival Distribution Functions*



The particulars of the simulation corresponding to the step numbers shown in Figure A.2 are as follows:

1. **"Package Pack for Sorts 1-N"** – This step is an entity creation process where the arrival functions for each entity are user-defined. In the case of the simulation performed for this thesis, these arrival distributions were formulated based on actual package pack data for a given sort by hour of day. Much like the previous architecture, entities are defined as skids of a set number of packages, and this step can be thought of as the package flow to the outbound dock. Unlike the previous architecture, this process also serves the purposes of assigning sorts to entities and routing the entities to the various sorting locations. In essence this step combines steps 1-3 in the previous architecture.
2. **"Batching for Sorts 1-N"** – This step is a batching process where the entities are accumulated until the user-specified batch size is reached. This step has essentially the same functionality as step 4 in the previous architecture. Unlike the previous architecture, both this step and the "Package Pack for Sorts 1-N" step will have to be replicated to see the effect that increasing the number of sorts has on the system.
3. **"Load in Truck"** – This step is a dispose process where the entities are removed from the system after the critical batch size in the previous step is reached. This is the same process as step 5 in the previous architecture.

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