ISYE 6202 Supply Chain Facilities
Casework 3.1 Report
SwiftHelper Distribution and Fulfillment Centers Design
Group: 11

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Task 3.1.1 - Demand Analysis

3.1.1 Data Source

As part of its strategic capability plan, SwiftHelper directed a careful study and review of the consumer appliance market in order to forecast future demand requirements. Given the assumption that demand will return to pre-pandemic levels following 2022, order data from 2019 was used as representative of 2023 customer orders. In the absence of demand specific data, order data was substituted to estimate demand with an implicit understanding that sales values are not exhaustive and fail to capture unsatisfied demand.

The 2019 orders dataset contains 713,573 data points broken down by date, product number, ZIP code, and quantity sold. Orders were placed for 585 unique products purchased in 890 ZIP codes across each of the 50 states throughout all 365 days of the year. SwiftHelper experienced demand for less than 75% of its product portfolio, with zero order data on 211 products (see Figure 1.1). The absence of order data for such a large portion of the portfolio significantly reduces the accuracy of the forecasts and simulations in this report since these products are not represented. Areas of expansion in future analysis could include the addition of historical data from 2018 or earlier to determine the demand share for these 211 products.

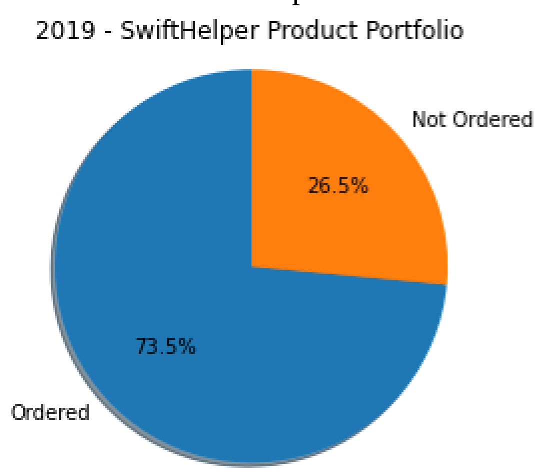


Figure 1.1: SwiftHelper Product Portfolio Pie Chart

From the total number of orders, over 99.9% are for a quantity less than 500 and 89.6% are for a quantity less than 100. Figure 1.2 illustrates a histogram of the order quantities less than 500, with the overwhelming majority centered around the quantity 50 order minimum. Additionally, Figure 1.3 depicts the distribution of orders greater than a quantity of 500. From this illustration, large orders span a range of 500 to 15,00 units but the majority are clustered at a quantity of 500. Of note, there were 4 orders placed that were greater than 10,000 units, representing 0.09% of the total units demanded in 4 single orders.

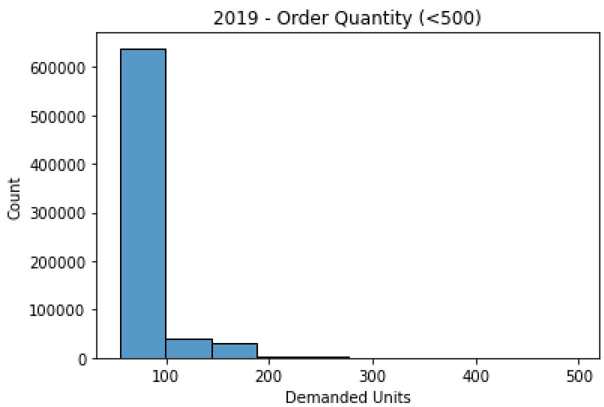


Figure 1.2: Small Order Frequency

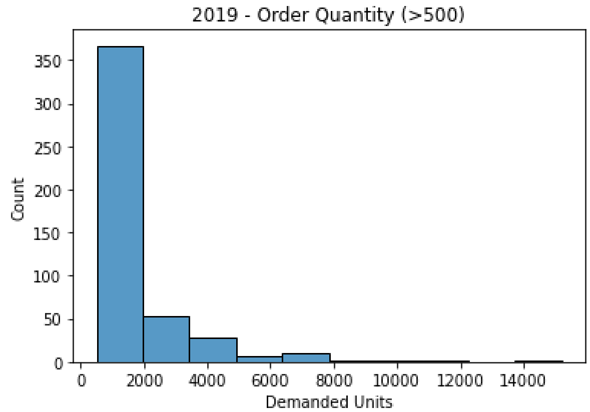


Figure 1.3: Large Order Frequency

The dataset was preprocessed prior to initiating the analysis in order to add state, day of the week, and week of the year data to each order line item. Refer to Appendix 1, 1. Orders - Metadata.csv for the processed dataset and 3.1 Data Pre-Processing.html for the Python code used to accomplish the pre-processing.

<u>3.1.1.a Demand Share Analysis (Location - Product)</u>

The first set of domains assessed were product and location. Annual demand was evaluated across each state and ZIP code, both globally and by product category.

<u>*Global Demand Share Analysis:*</u>

Addressing the global demand first, Figure 1.4 depicts a heatmap of the United States by state scaled by annual demanded units and Table 1.1 outlines the demand share and population percentage per State. Perhaps unsurprisingly, the states with the largest SwiftHelper global demand share are also the states with the largest population: California, Texas, New York, Florida, and Pennsylvania. However, state population is not necessarily a direct correlation between demand share. Colorado is only the 22nd most populous state but is 15th in SwiftHelper demand share. The District of Columbia (D.C.) is the 50th most populous state and 43rd in demand share. Meanwhile, Hawaii is ranked 48th in demand share but 41st in population. While a strong indicator, population is not the only factor in each state's global demand.

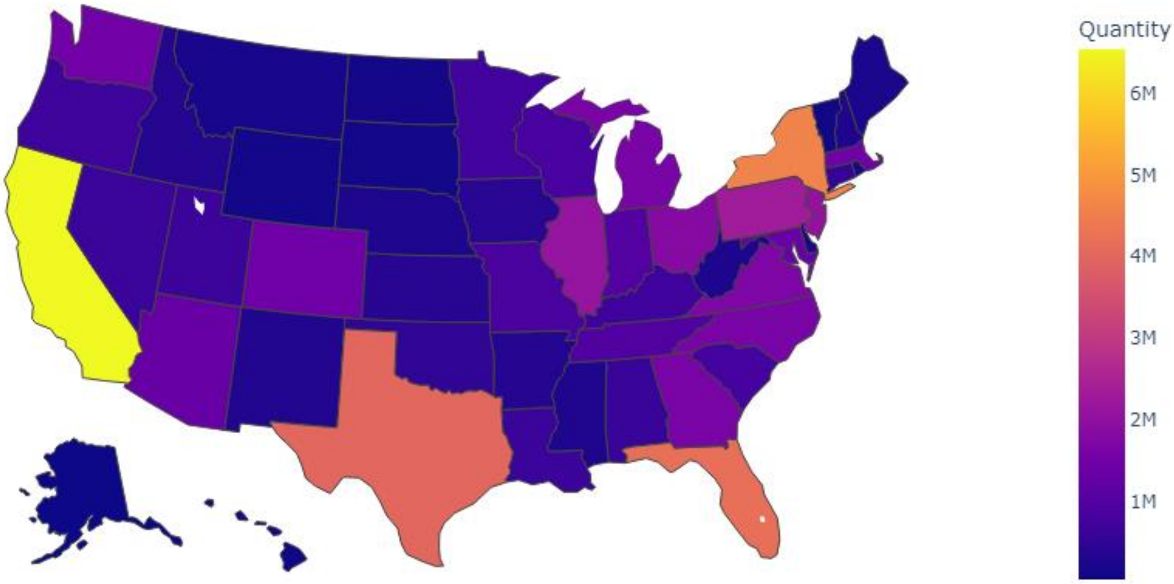


Figure 1.4: Global – State Heatmap

	CA	NY	FL	TX	PA	IL	NJ	OH	VA	NC
Demand	11.64	8.14	7.46	7.12	4.15	3.74	3.66	3.27	3.02	2.90
Population	11.80	6.03	6.43	8.69	3.88	3.82	2.77	3.52	2.58	3.12
	MI	GA	WA	MA	CO	MD	AZ	IN	TN	MO
Demand	2.90	2.89	2.66	2.63	2.61	2.41	2.35	1.82	1.77	1.51
Population	3.01	3.19	2.30	2.09	1.72	1.84	2.13	2.03	2.06	1.84
	WI	SC	MN	KY	OR	UT	NV	LA	AL	CT
Demand	1.47	1.39	1.31	1.25	1.20	1.18	1.13	1.13	1.05	1.04
Population	1.76	1.53	1.70	1.34	1.27	0.98	0.93	1.39	1.49	1.08
	OK	IA	KS	ID	AR	NM	MS	NH	WV	NE
Demand	0.91	0.73	0.69	0.62	0.61	0.58	0.53	0.52	0.49	0.48
Population	1.18	0.95	0.88	0.55	0.89	0.63	0.88	0.41	0.54	0.59
	ME	DE	DC	MT	RI	ND	WY	SD	HI	VT
Demand	0.41	0.39	0.38	0.34	0.33	0.28	0.22	0.21	0.19	0.19
Population	0.41	0.29	0.21	0.32	0.33	0.23	0.17	0.27	0.43	0.19
	AK									
Demand	0.09									
Population	0.21									

Table 1.1: Global – State Demand Share Percentages

Further analyzing the global demand by ZIP code, Figure 1.5 depicts a heatmap of the United States by ZIP code, scaled by annual demanded units and the top-10 ZIP codes and their demand share percentages are reported in Table 1.2. Given the volume of ZIP codes evaluated, a full table of their respective demand share percentages is not included in the body of this report. The ZIP codes that command the largest demand shares are centered around large, populated cities such as New York City, Chicago, Dallas, San Franciso, and Miami. Interestingly, many of the most populous cities in America are absent from SwiftHelper's top-10 ZIP codes, including Los Angeles, Houston, and Philadelphia. For reference, Table 1.3 includes the ten most populated cities, as determined from the 2021 U.S. census. Like the global-state analysis, SwiftHelper products do not appeal proportionately to the US population. An area of future analysis could include information on specific products and the qualities that make them more appealing to east coast cities.

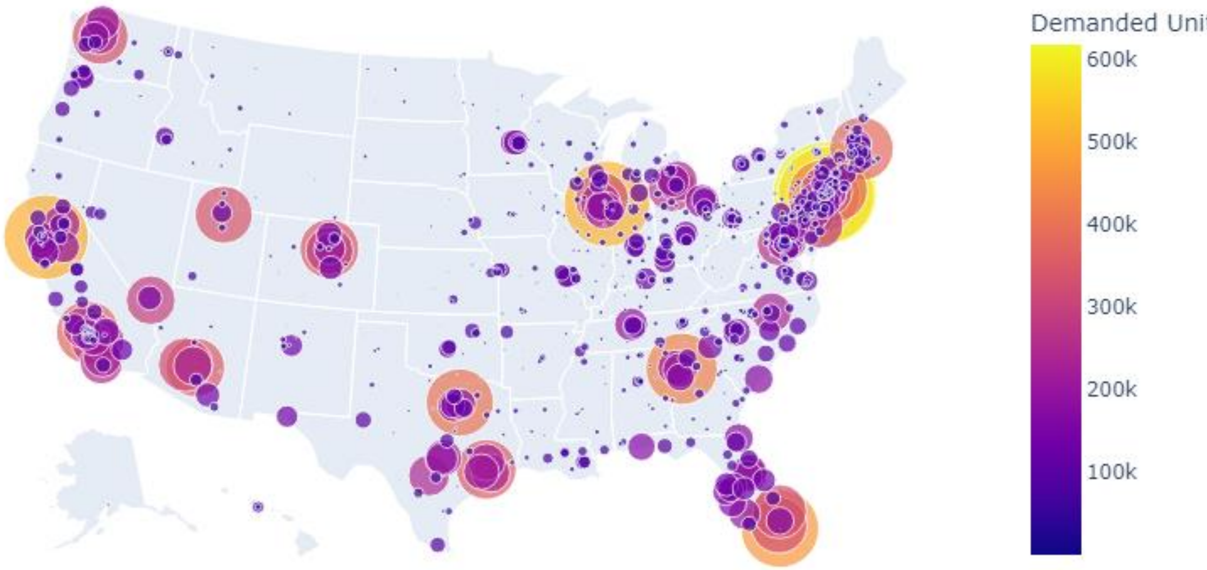


Figure 1.5: Global – ZIP Code Heatmap

ZIP Code	City, State	Demand Share
100	NYC, NY (Manhattan)	1.10
112	NYC, NY (Brooklyn)	1.02
606	Chicago, IL	0.91
945	San Francisco, CA	0.90
331	Miami, FL	0.83
300	Atlanta, GA	0.76
070	Jersey City, NJ	0.76
750	Dallas, TX	0.72
021	Boston, MA	0.68
117	NYC, NY (Long Island)	0.67

Table 1.2: Global Top-10 ZIP Code Demand Share

2021 Rank	City, State
1	New York City, NY
2	Los Angeles, CA
3	Chicago, IL
4	Houston, TX
5	Phoenix, AZ
6	Philadelphia, PA
7	San Antonio, TX
8	San Diego, CA
9	Dallas, TX
10	San Jose, CA

Table 1.3: US City Ranking

Categorical Demand Share Analysis:

Breaking down the product domain further, the demand share was calculated for each of the 25 product categories. Table 1.4 provides the results of the demand share by category. Examining the relationship between demand share and number of products within each category, there is evidence of a positive correlation (see Figure 1.6). The categories with the largest demand share also have the greatest number of products. However, there are exceptions: the top earning category has only a third the number of products as the next highest earning category. The number of products within a category matters but only up to a point. Without specific information on the products and their categories, at most it can be concluded that a positive relationship does exist between category and number of products.

Category	# of Products	Demand Share	Category	# of Products	Demand Share
H	56	16.57	C	17	0.94
D	159	15.69	B	5	0.59
L	103	15.24	F	2	0.20
R	91	12.57	J	6	0.18
U	77	10.38	V	11	0.16
Q	24	7.57	X	4	0.14
A	54	5.87	O	6	0.07
S	62	5.72	W	8	0.06
K	29	2.01	M	3	0.05
Y	39	1.99	E	10	0.05
I	8	1.65	P	5	0.03
N	9	1.25	G	1	0.004
T	7	0.96			

Table 1.4: Category Demand Share

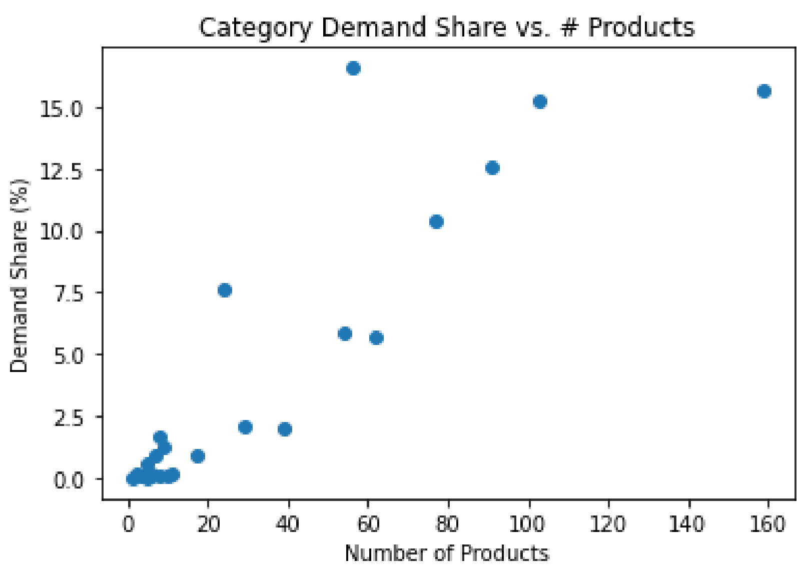


Figure 1.6: Category Demand Share - Number of Products Scatter Plot

The demand of each product category was evaluated by state. The results are shown in the form of a heatmap in Figure 1.7. Consistent from the results found in Table 1.1 and 1.2, product Categories D, H, and L are high performers across every state and feature most prominently in California, New York, and Texas. Interestingly though, the most demanded product varies from state to state. In California, Category D is the most demanded whereas New York prefers Category L and in Texas, Category H holds the top position. Additional information on the specifics of each product category might explain the difference in demand between states.

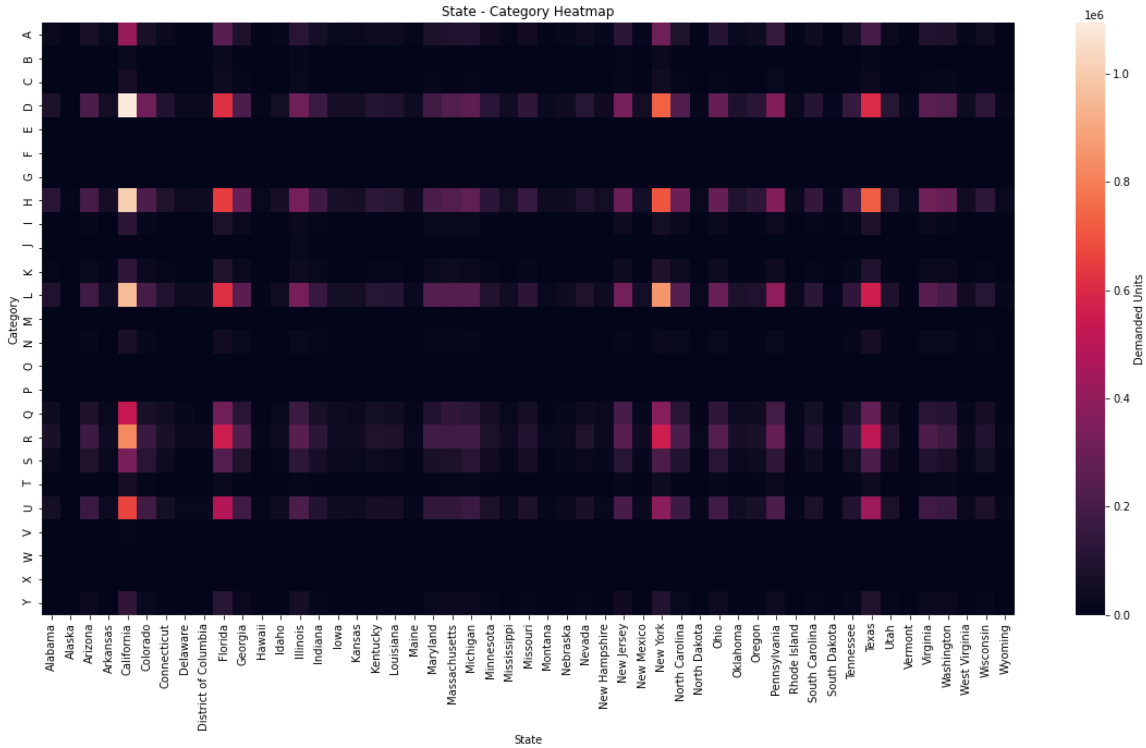


Figure 1.7: State – Category Heatmap

An analysis of product category demand across each ZIP code yielded a similar result as with the states and is shown in Figure 1.8. ZIP codes with the highest demand share are in top-performing states with NYC, NY being the primary driver in the state of New York’s demand for product Category L.

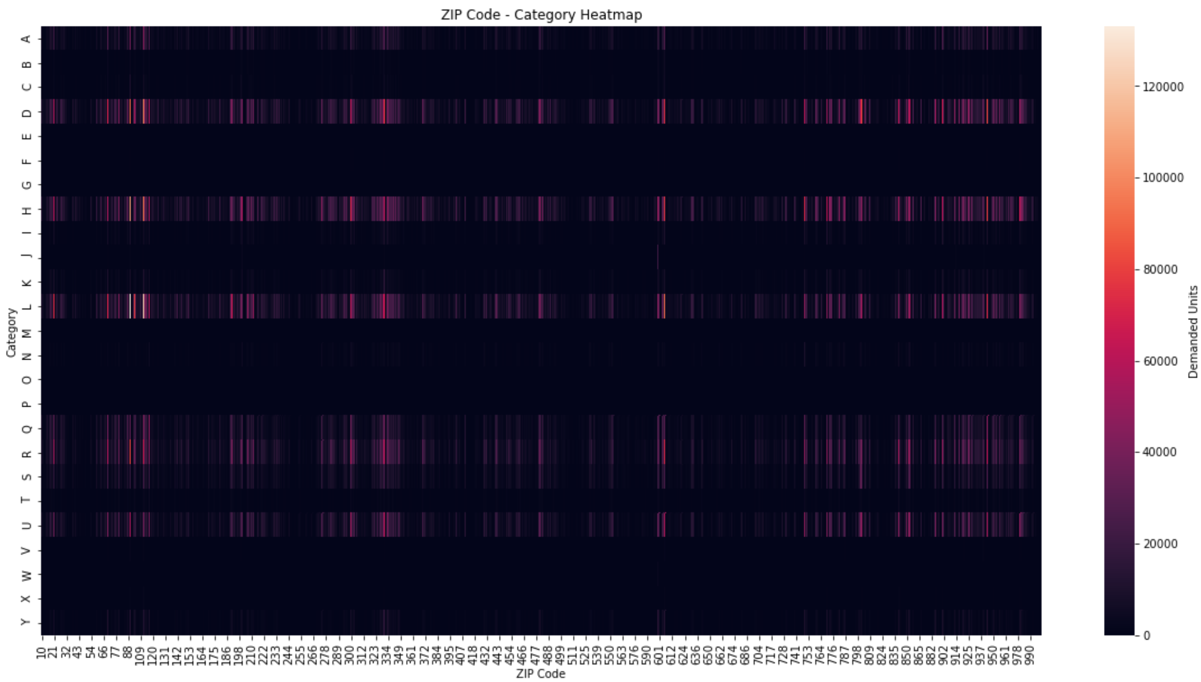


Figure 1.8: ZIP Code – Category Heatmap

Tables for ZIP code categorical demand share percentages as well as state categorical demand share percentages are not included in the body of the report due to the volume of combinations assessed. Refer to Appendix 1, 1.a Demand Share.xlsx for the complete listing of demand share percentages for each state and zip code, globally and by product category.

<u>3.1.1.b Demand Share Analysis (Time - Location)</u>

The second set of domains assessed were time and location. Global demand was evaluated on a weekly and daily basis, across each state and ZIP code.

<u>Weekly Demand Share Analysis:</u>

First, annual demand of all products across all locations was aggregated by week and depicted in Figure 1.9. Additionally, Table 1.5 provides the top 5 weeks in the year with respect to demand share along with their associated calendar dates. Potential explanations for these demand spikes are Spring Break (week 9, 10), Mardi Gras (week 10), Black Friday and Cyber Monday (week 48, 49), New Year’s (week 1). Additional datasets from previous years would assist in identifying if these demand peaks are due to recurring holidays or rather the result of unique current events (eg., a world-wide pandemic). A full table of the demand share per week of the year is not included in the body of this report.

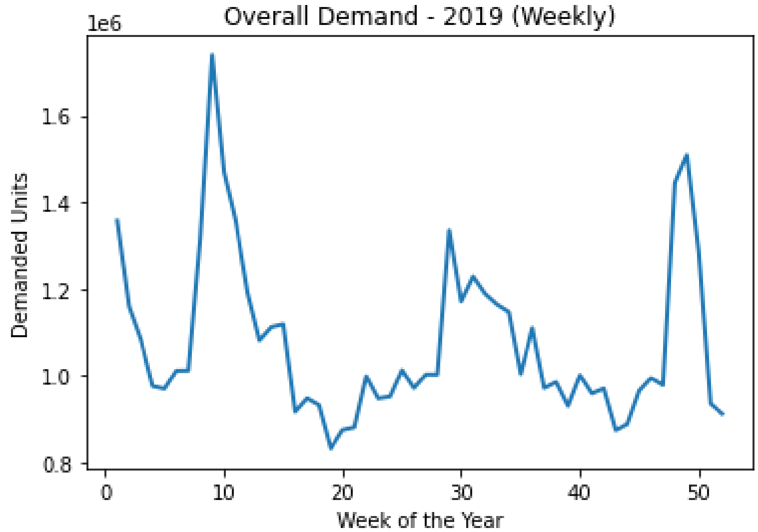


Figure 1.9: 2019 Overall Demand (by Week)

Week of the Year	Dates	Demand Share
9	25 Feb - 03 Mar	3.09
49	02 Dec – 08 Dec	2.69
10	04 Mar – 10 Mar	2.62
48	25 Nov – 01 Dec	2.57
1	01 Jan – 06 Jan	2.46

Table 1.5: Top 5 Weekly Demand Share

Weekly demand was further evaluated by state and ZIP code in order to identify any unique trend by location. Figure 1.10 depicts a heatmap of weekly demand by state to assist in identifying said trends. From a visual inspection, the demand in Illinois, Colorado, Arizona, and Massachusetts stood out as deviating from the average demand distribution.

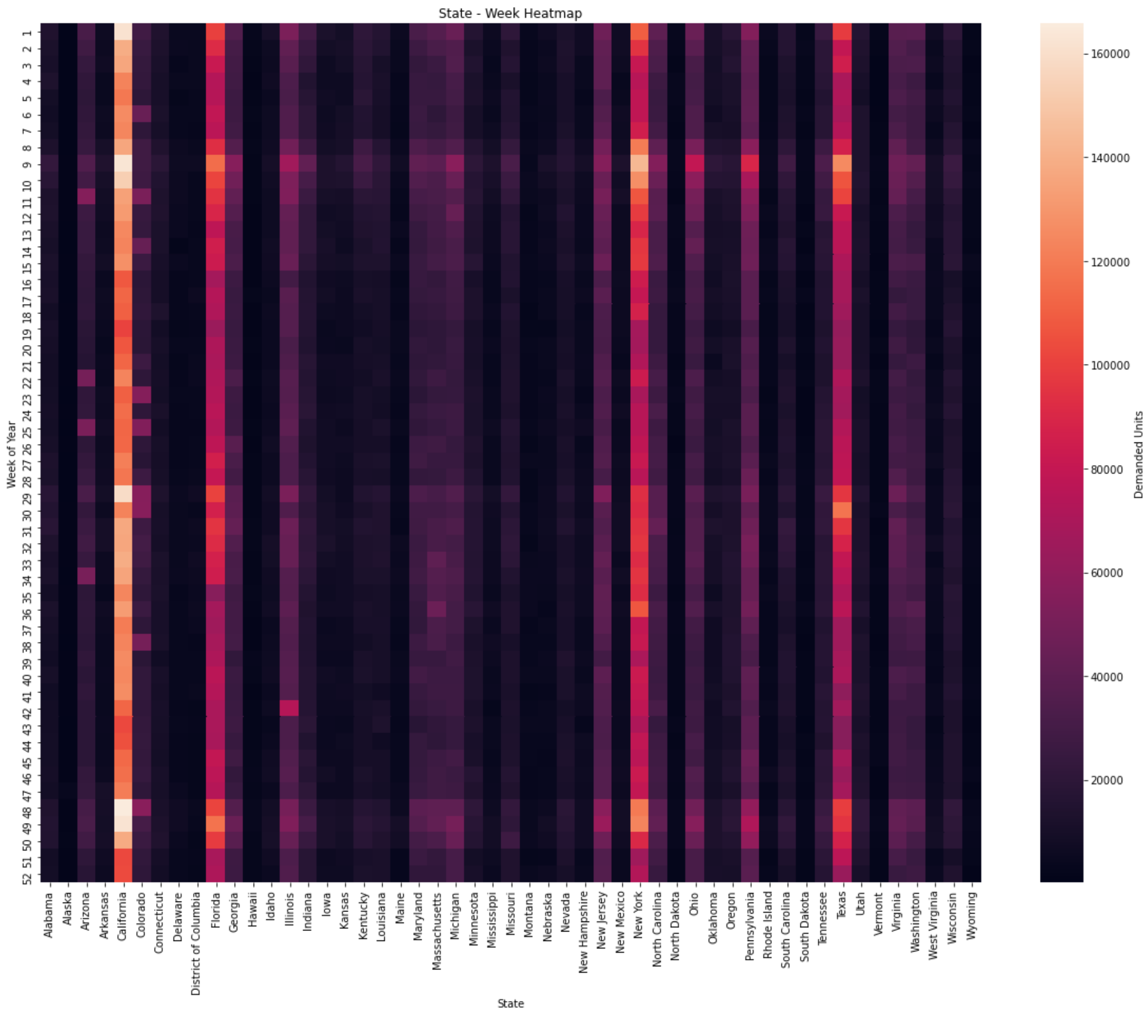


Figure 1.10: Week – State Heatmap

Figures 1.11 through 1.14 depict the SwiftHelper demand in Massachusetts, Illinois, Arizona, and Colorado. Massachusetts and Illinois both follow the average demand distribution until the latter half of the year. Week 36 in Massachusetts and Week 42 in Illinois saw a massive spike in demand while the average demand across the country was decreasing. In Arizona and Colorado, demand was much more volatile with multiple peaks that deviated from the average and were generally seen during the summer weeks.

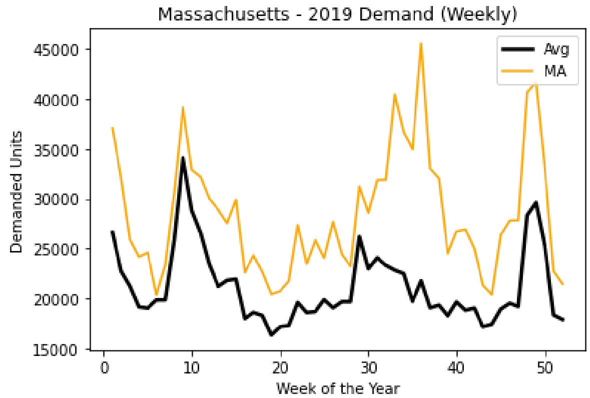


Figure 1.11: Massachusetts Weekly Demand

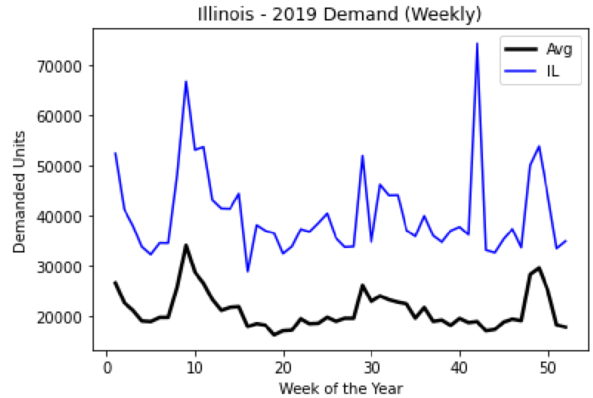


Figure 1.11: Illinois Weekly Demand

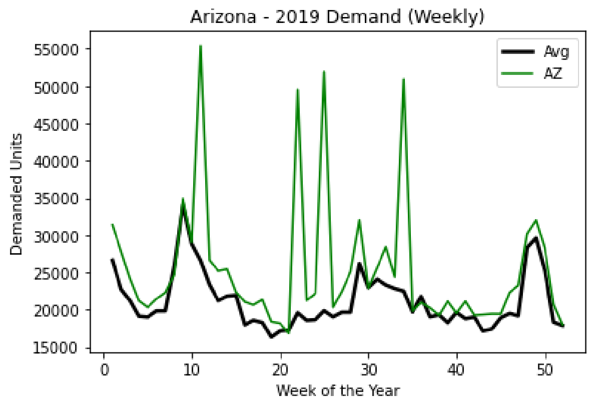


Figure 1.11: Arizona Weekly Demand

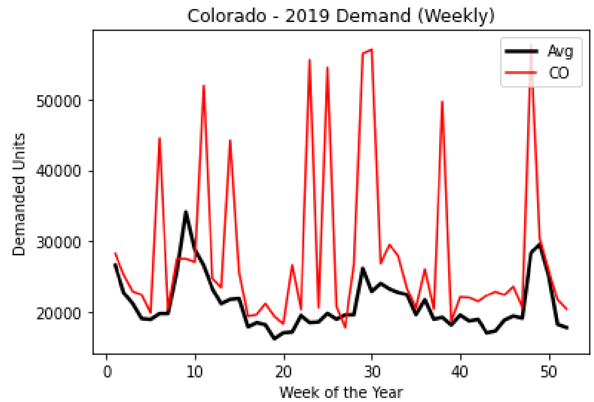


Figure 1.14: Colorado Weekly Demand

A similar analysis of weekly demand was done by ZIP code. Figure 1.15 depicts the heatmap used to identify deviations from the average demand distribution throughout the year. The following six ZIP codes stood out as deviating from the average demand distribution: 021, 600, 801, 802, 852, and 853.

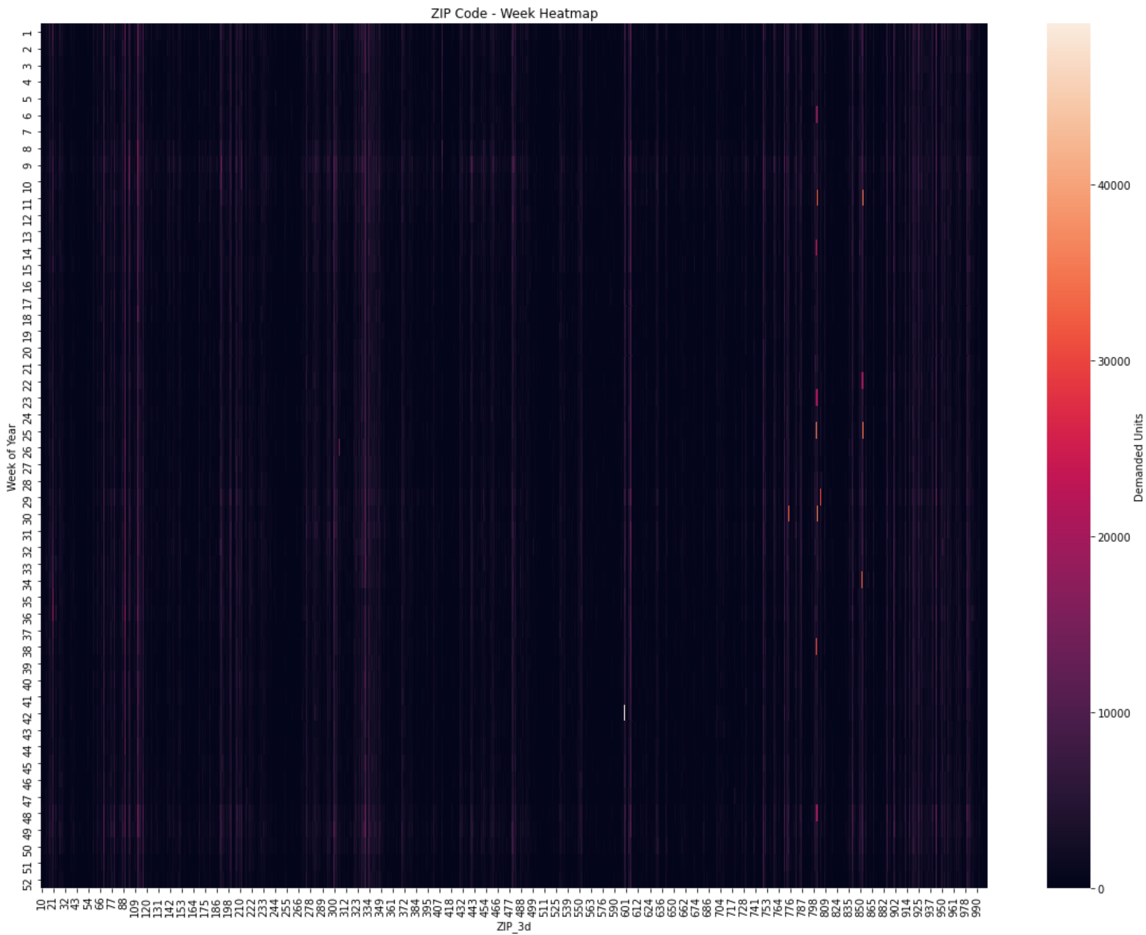


Figure 1.15: Week – ZIP Code Heatmap

Figures 1.16 through 1.19 depict the demand of SwiftHelper products in the specified ZIP code, along with the average demand distribution and the weekly demand of the ZIP code's respective state. From each plot, it is evident that these ZIP codes are the primary drivers behind the state's deviation from the average. Areas of additional analysis could include evaluating the specific products or category of products demanded in these time periods and in these specific ZIP codes. With supplemental information on the products themselves, the weekly increases could better be explained and understood.

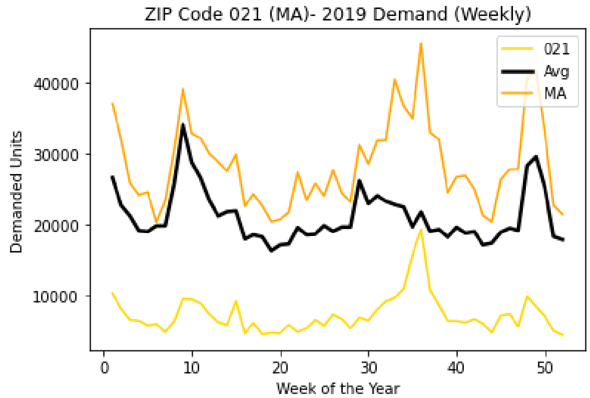


Figure 1.16: MA ZIP – Weekly Demand

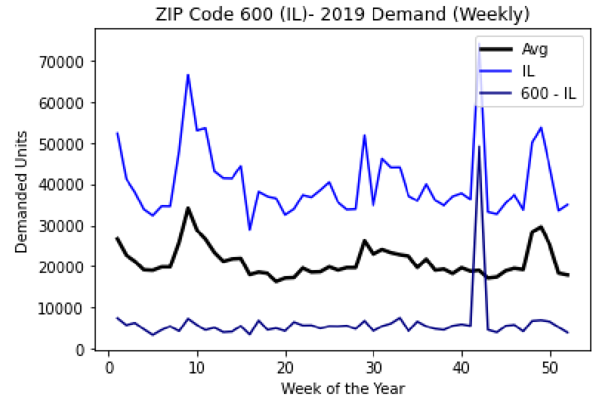


Figure 1.17: IL ZIP – Weekly Demand

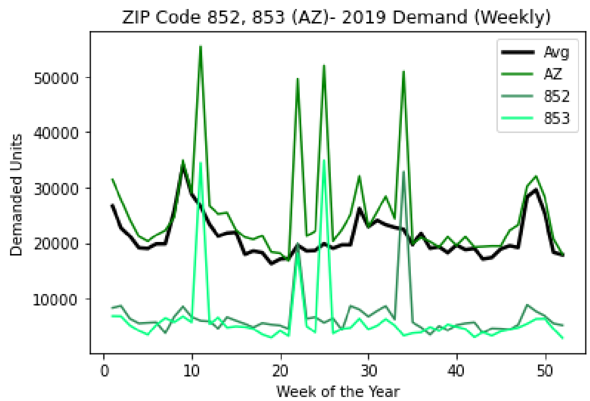


Figure 1.18: AZ ZIP – Weekly Demand

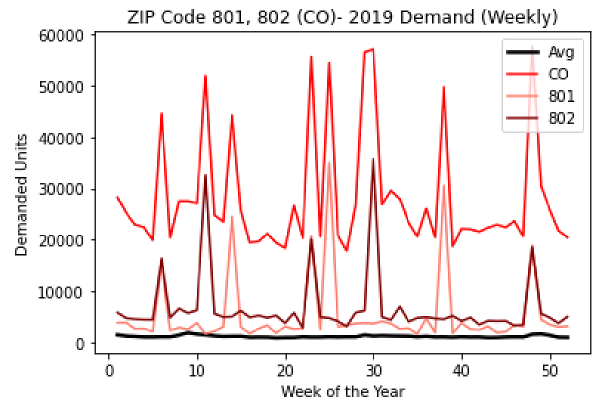


Figure 1.19: CO ZIP – Weekly Demand

__Daily Demand Share Analysis:__

In addition to weekly, demand was also assessed by day of the week. From Figure 1.20, the demand share of each day of the week is relatively evenly distributed. Monday commands the highest demand share with 16.3% and meanwhile, Saturday holds the lowest at 12.5%. Figure 1.21 depicts how the demand changes throughout the week, peaking on Sunday to Monday then steadily decreasing throughout the week with a small recovery on Friday.

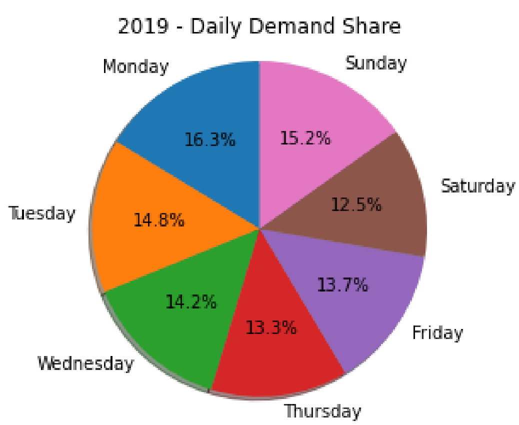


Figure 1.20: Daily Demand Share (Pie Chart)

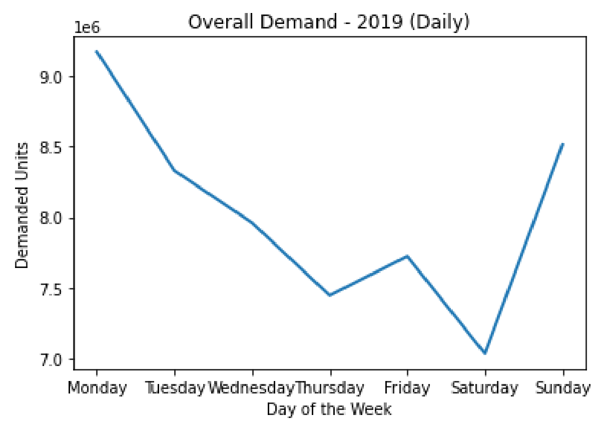


Figure 1.21: Daily Demand (Line Plot)

Daily demand was evaluated across all states and ZIP codes to identify any unique trends within the country. The heatmap in Figure 1.22 was used to visually identify any deviations from the average daily demand distribution. Illinois, Arizona, Colorado, and Maryland were identified for further inspection.

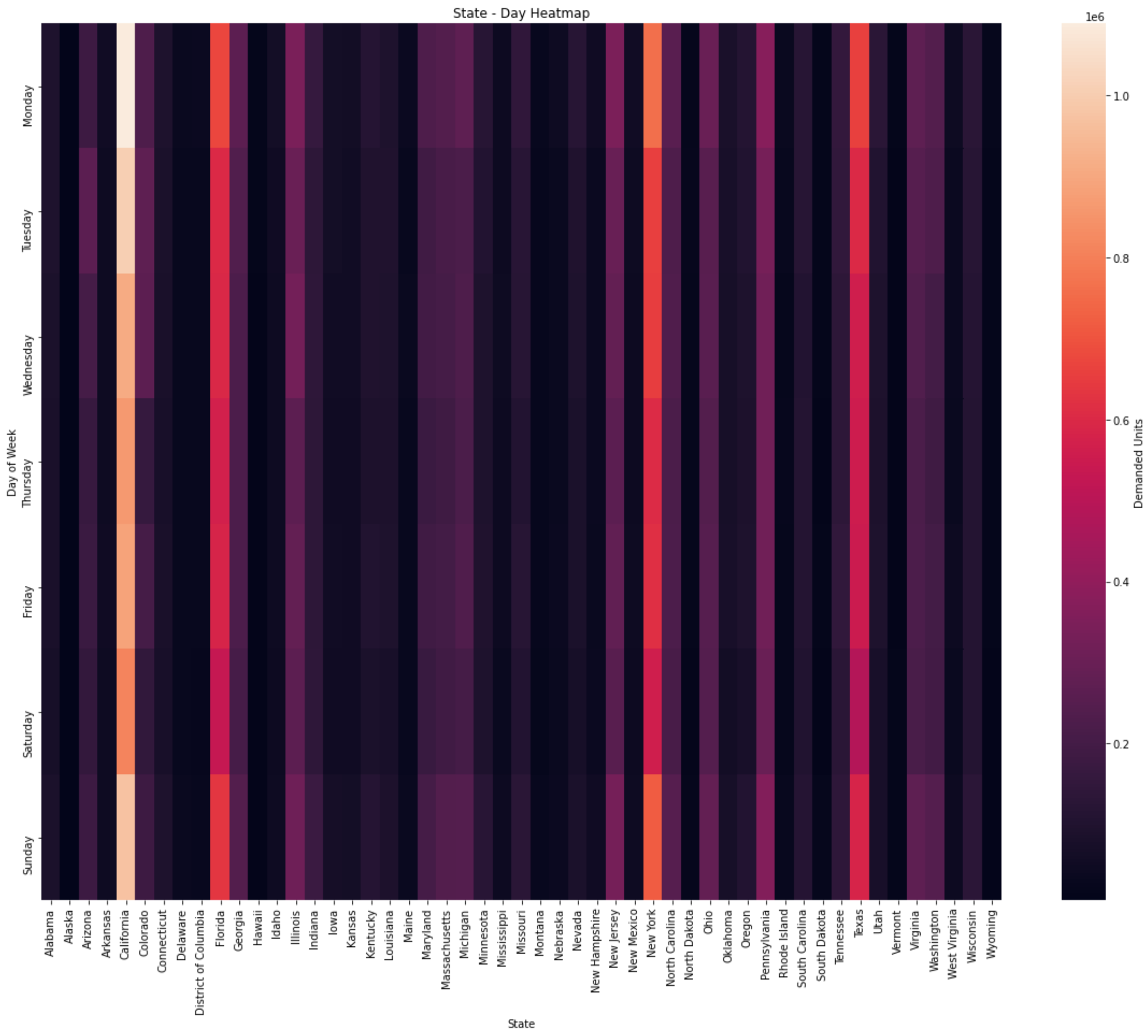


Figure 1.22: State – Day Heatmap

Figure 1.23 through 1.26 depict the daily demand distributions for Illinois, Maryland, Colorado, and Arizona, respectively. Illinois and Maryland both show a greater preference for Wednesday purchases than the rest of the country, while Arizona appears to have elected to shop entirely on Tuesdays. Colorado is a combination of the previous three, with demand at its maximum from Tuesday to Wednesday as opposed to Sunday to Monday.

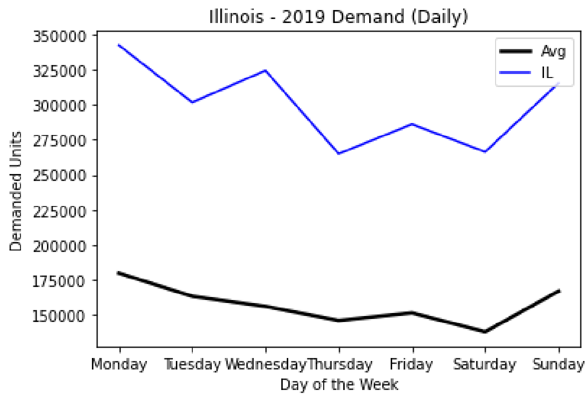


Figure 1.23: Illinois Daily Demand

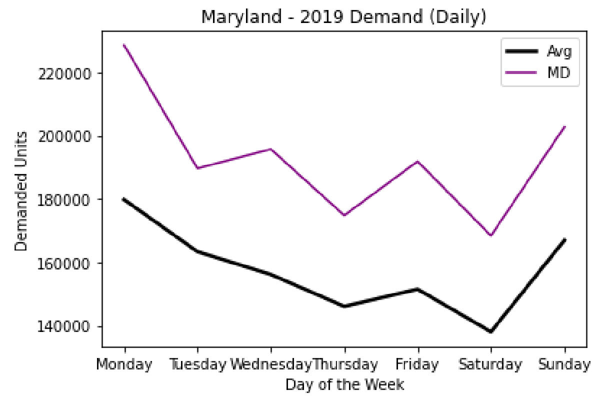


Figure 1.24: Maryland Daily Demand

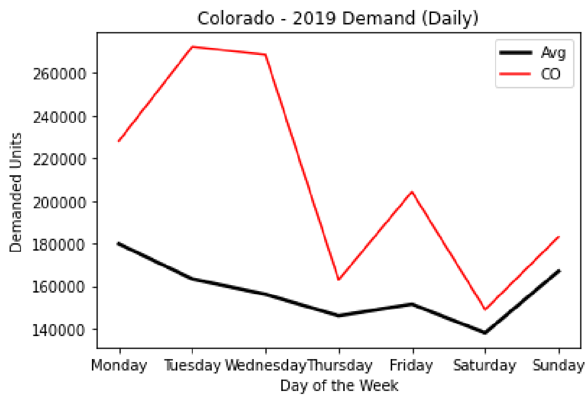


Figure 1.25: Colorado Daily Demand

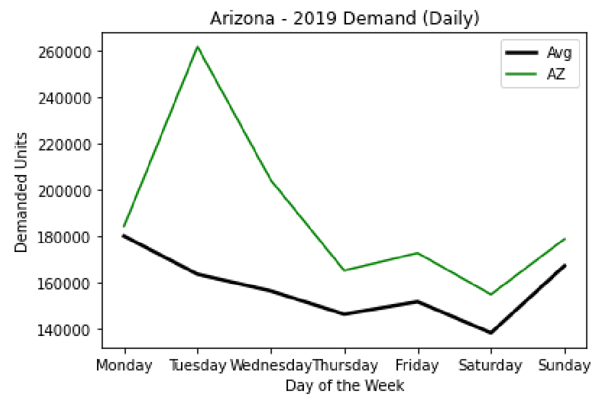


Figure 1.26: Arizona Daily Demand

To better understand which areas of the state were contributing to these deviations, the same daily demand analysis was done by ZIP code with the results shown in Figure 1.26. Using a visual inspection and the knowledge of each state's overall trend, the following ZIP codes were identified for further analysis: 210, 600, 801, 802, 852, and 853.

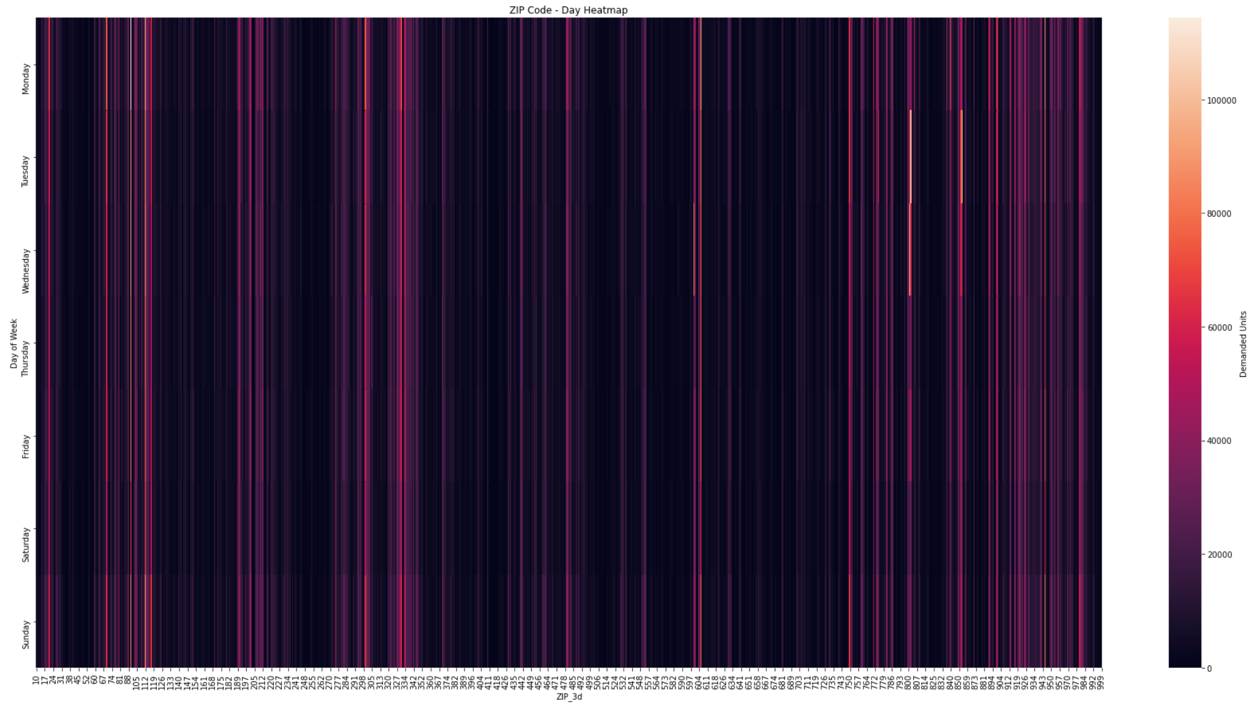


Figure 1.27: ZIP Code – Day Heatmap

Figures 1.28 through 1.31 provide a visualization of the daily demand of SwiftHelper products in the specified ZIP code as well as the average demand and state demand distributions. As with the weekly plots, it can clearly be shown that these ZIP codes are responsible for each state's deviation from the daily demand average.

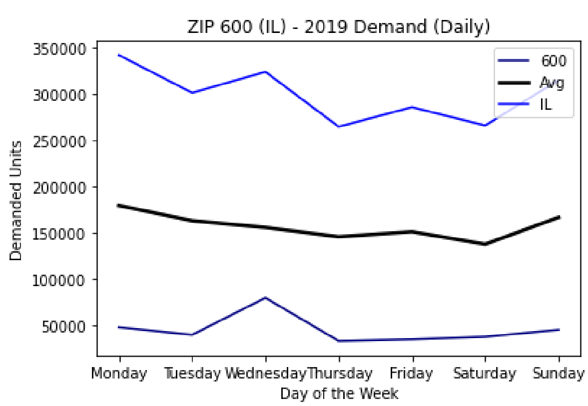


Figure 1.28: IL ZIP – Weekly Demand

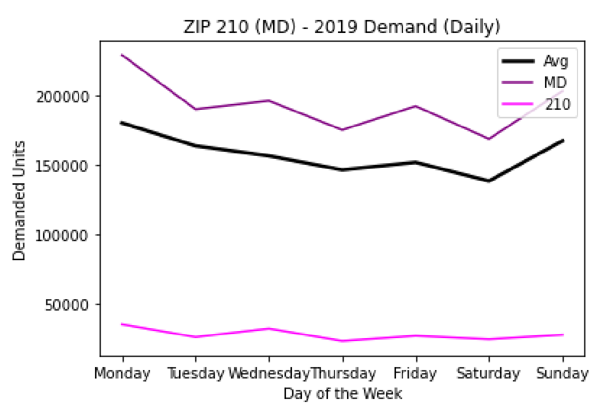


Figure 1.29: MD ZIP – Weekly Demand

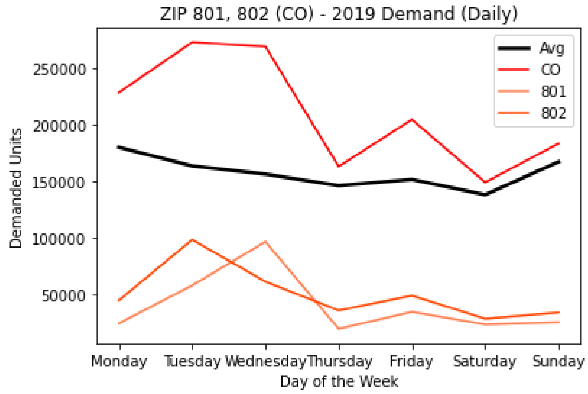


Figure 1.30: CO ZIP – Weekly Demand

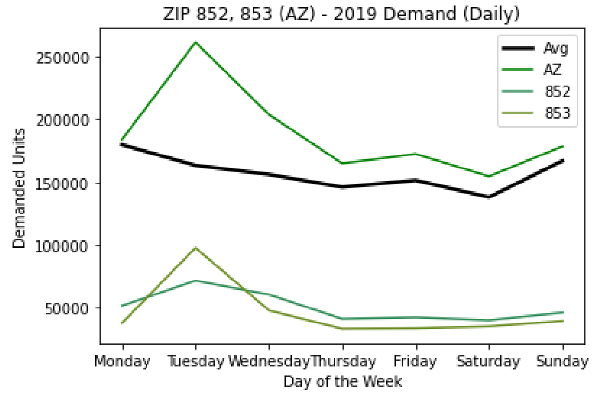


Figure 1.31: AZ ZIP – Weekly Demand

When considered in totality, 6 of the 8 assessed ZIP codes exhibit unique behavior on a weekly and daily basis that deviates significantly from the national average. An area of future analysis could be determining what qualities in these areas contribute to this purchasing behavior or the predominant products purchased that are driving these distributions.

Refer to Appendix 1, 1.b Demand Share.xlsx for the complete listing of demand shares by state and zip code, week and day.

3.1.1.c Demand Share Analysis (Product - Location)

Finally, the location and product domains were reassessed but with a specific focus on the annual demand of individual products sold across the United States and within each ZIP code.

Overall Product Demand Share Analysis:

Analysis was conducted on the demand share of each of SwiftHelper's products with the results depicted in Figure 1.32 in the form of a pareto chart. The pareto chart is supplemented by Table 1.6 which provides the top ten performing products across the United States. The conclusion from this analysis is that demand is not evenly distributed across all products. Of SwiftHelper's 796 products, less than 2.3% of the portfolio (18 products) account for over 25% of the demand. Nationally, products 474, 249, and 250 are the three highest performing products, with a cumulative 4.4 million units sold.

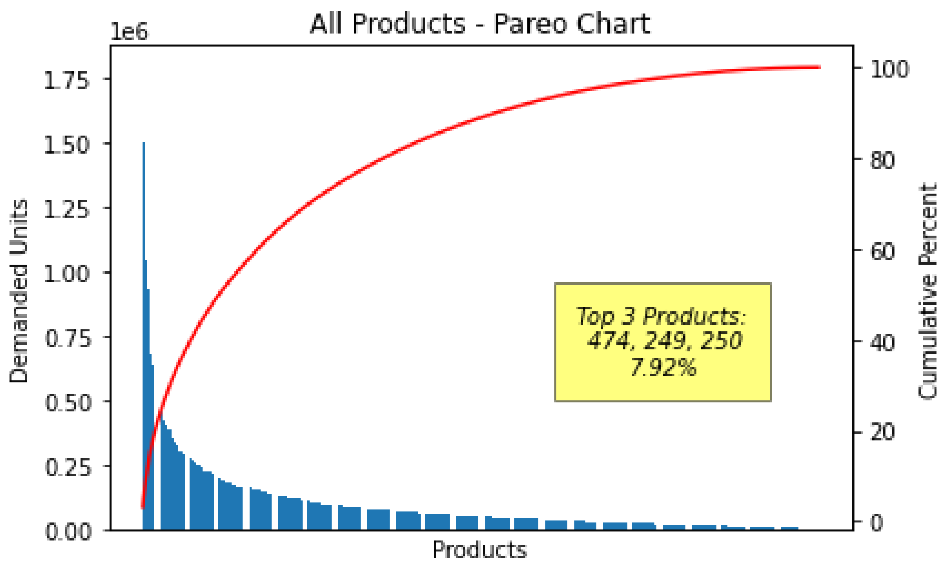


Figure 1.32: US – All Products Pareto Chart

Product	Category	Demand Share
474	Q	3.18
249	H	2.66
250	H	2.08
251	H	1.85
498	R	1.73
348	L	1.65
252	H	1.57
658	U	1.21
475	Q	1.20
349	L	1.13

Table 1.6: Top Performing Products

In addition to knowing the highly demanded products, it can be just as important to identify those under-performing. As stated in the initial review of the data source, 211 products have no demand history and thus are not captured in this analysis. Table 1.7 outlines the worst performing products in the portfolio, capturing a cumulative 0.003% of the demand share with each less than 2000 units demanded annually. It is interesting to note that despite the success of product categories D and L (the second and third highest categories with respect to demand share), that success does not extend to every product as evidenced by the performance of products 450 and 224.

Product	Category	Demand Share
450	L	0.00025
752	W	0.00072
224	D	0.00094
648	S	0.00095
757	X	0.00126

312	I	0.00167
726	U	0.00214
744	V	0.00258
239	E	0.00269
311	I	0.00332

Table 1.7: Worst Performing Products

Additional information on the specifics of each product or the nature of each product category might yield more salient conclusions on the demand patterns of each product.

<u>*Product Demand Share Analysis by ZIP Code:*</u>

Using ZIP code demand shares found in 3.1.1.a, the demand of each product within the top ten ZIP codes was calculated. Table 1.8 and Figure 1.32 illustrate the ZIP codes evaluated.

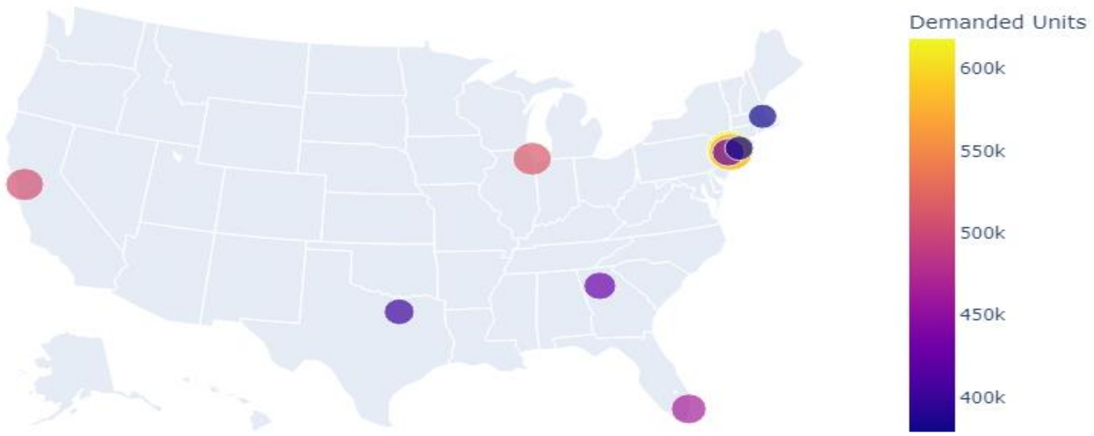


Figure 1.33: Map of Top Ten ZIP Codes

ZIP Code	City, State
100	NYC, NY (Manhattan)
112	NYC, NY (Brooklyn)
606	Chicago, IL
945	San Francisco, CA
331	Miami, FL
300	Atlanta, GA
070	Jersey City, NJ
750	Dallas, TX
021	Boston, MA
117	NYC, NY (Long Island)

Table 1.8: Top Ten ZIP Codes

Figures 1.34 through 1.43 depict the pareto charts for each of the ZIP codes listed in Table 1.8 and a text box with the top three products and their cumulative demand share.

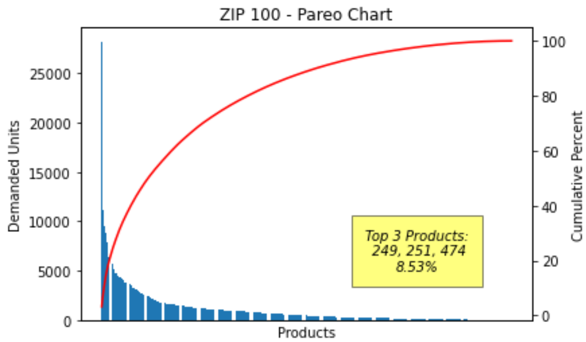


Figure 1.34: ZIP 100 Pareto Chart

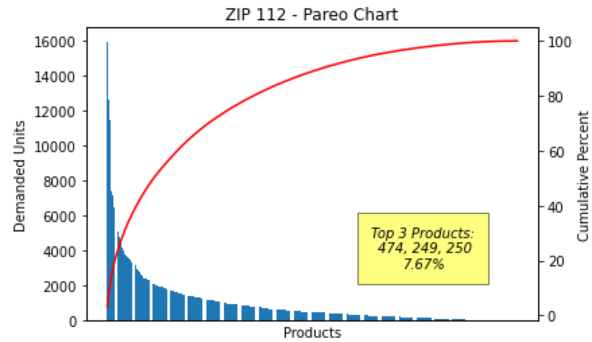


Figure 1.35: ZIP 112 Pareto Chart

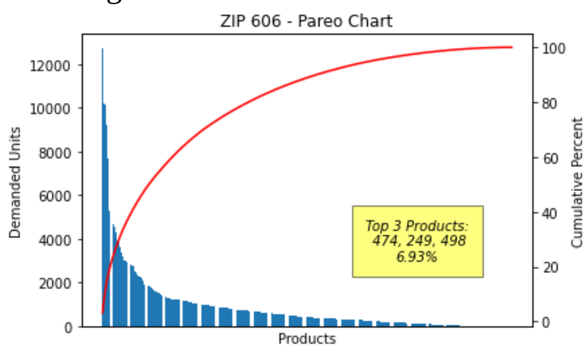


Figure 1.36: ZIP 606 Pareto Chart

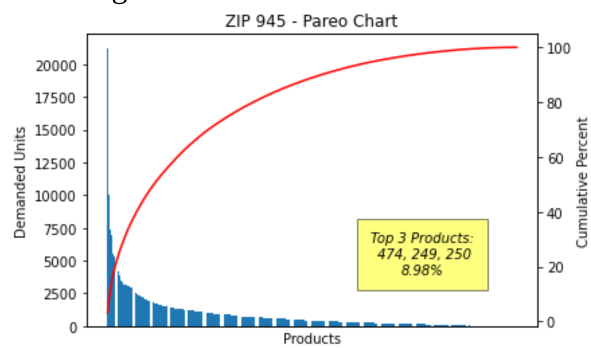


Figure 1.37: ZIP 945 Pareto Chart

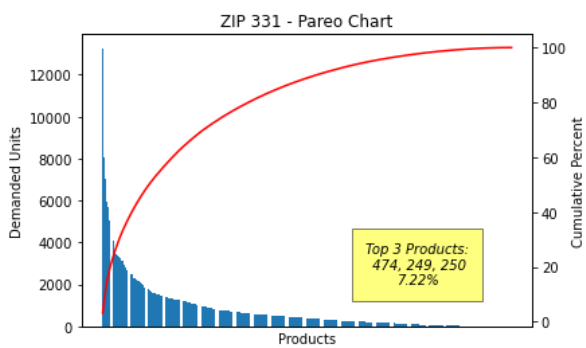


Figure 1.38: ZIP 331 Pareto Chart

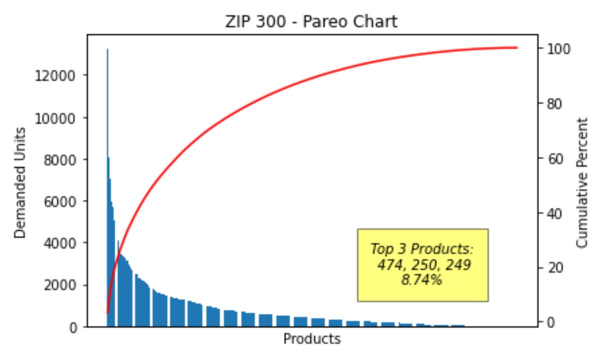


Figure 1.39: ZIP 300 Pareto Chart

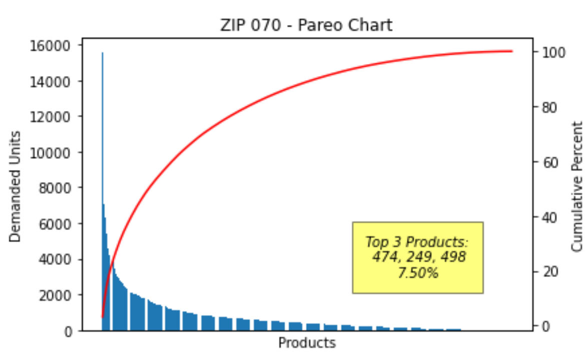


Figure 1.40: ZIP 070 Pareto Chart

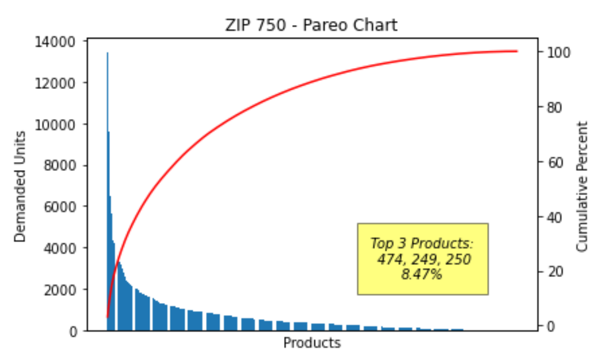


Figure 1.41: ZIP 750 Pareto Chart

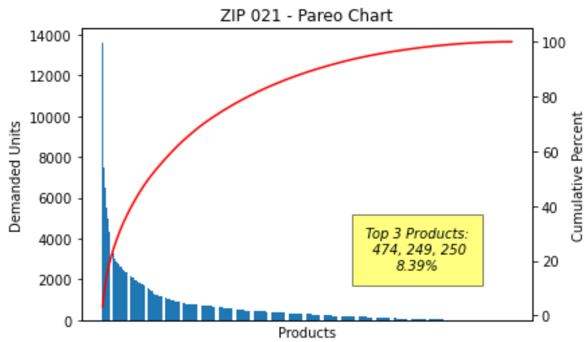


Figure 1.42: ZIP 021 Pareto Chart

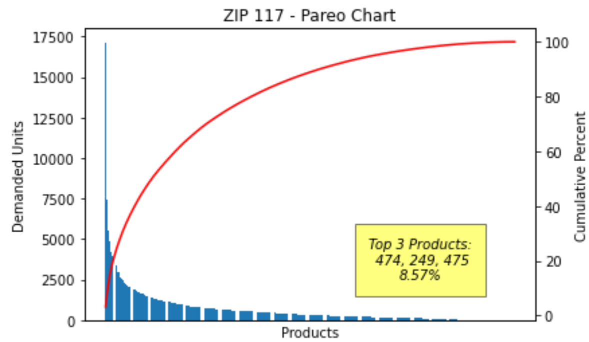


Figure 1.43: ZIP 117 Pareto Chart

As expected, the top performing products across the United States also appear in the top three for each ZIP code. Products 474 and 249 are in the top three of every ZIP code and the third position is shared amongst only four other products. Figure 1.44 displays a bar chart of the top three product counts.

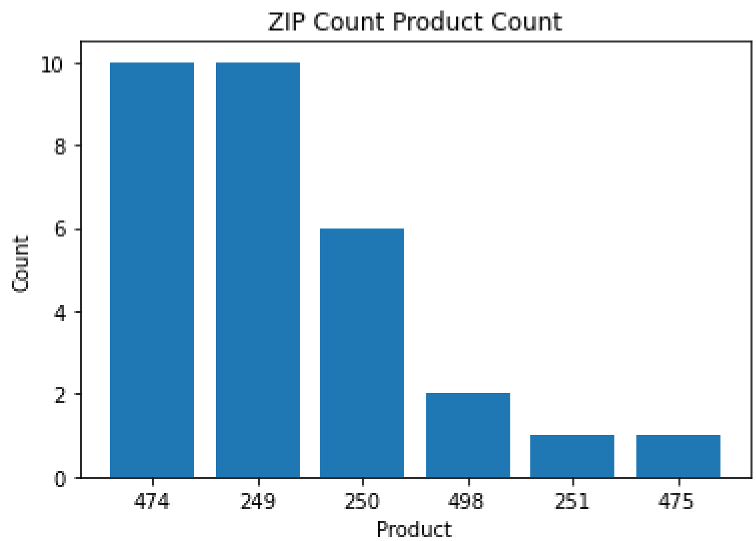


Figure 1.44: Product Count Bar Chart

Refer to Appendix 1, 1c Demand Share.xlsx for the complete table of demand share percentages by product, nationally and by ZIP code. Additionally, 3.1.1a-c Demand Analysis.html is the Python code used to assess each of the aggregation threads in Tasks a through c and generate plots, charts, and graphs.

Task 3.1.2 - Demand Forecast and Generation over the Planning Horizon

3.1.2.a Demand Forecast 2023 - 2028

Using the demand share analysis completed in Task 3.1.1, demand forecasts were generated for SwiftHelper products from 2023 to 2028 by combination of product, ZIP code, and week of the year.

Methodology

Given the assumption that 2019's order data will be representative of 2023's future demand, the total demanded units in 2019 (56,181,922 units) was used to estimate 2023's total demand. SwiftHelper's sales targets for 2024 (150%), 2025 (200%), and 2028 (300%) were used as the annual growth rate, with the growth rate for non-specified years calculated using interpolation. Figure 2.1 illustrates the forecasted growth and Table 2.1 specifies the calculated total demand per year.

Year	Annual Demand (Units)
2023	56,181,922
2024	84,272,883
2025	112,363,844
2026	131,091,151
2027	149,818,459
2028	165,545,766

Table 2.1: Annual Demand

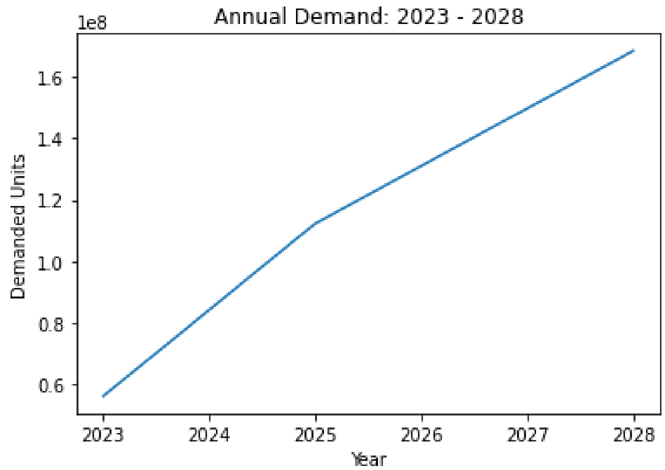


Figure 2.1: Annual Demand 2023-2028

Using the demand shares calculated in Task 3.1.1, the aggregation threads assessed were week of the year (52 weeks), product (797 products), and ZIP code (890 ZIP codes). There were a total of 36,885,160 combinations evaluated per year using the following formula:

$$Forecaste\ Demand_{ijkl} = Annual\ Demand_i \cdot week_j \cdot product_k \cdot ZIP_l$$

where $Forecaste\ Demand_{ijkl}$ is the forecasted demand of product ***k*** sold in ZIP code ***l*** on week ***j*** in year ***i***. The variables $week_j$, $product_k$, and ZIP_l are the demand shares for each of the three parameters and $Annual\ Demand_i$ is the number of units demanded that year.

The values calculated using the forecasted demand formula are distributed in accordance with the respective demand share percentages but without accounting for the minimum order quantity. Imposed by SwiftHelper, there is a minimum order quantity is 50 units in place and is in effect from 2023 until 2025. Starting in 2026, the minimum order quantity is then reduced to 25 units.

To account for this, an algorithm was written which aggregated the demand for product k in ZIP code l until it reached the minimum order quantity at which point an order was registered.

This process was repeated for each year to generate the forecasted demand from 2023 to 2028. For the purpose of the forecast, all parameters were treated as deterministic.

Results:

From the forecasted demand, several relevant metrics can be extrapolated. First, the number of orders changes over time as the minimum order quantity is reduced by half. Figure 2.2 and Table 2.2 provide the number of orders placed per year.

Year	Number of Orders
2023	865925
2024	1,278,144
2025	1,663,082
2026	3,390,132
2027	3,760,022
2028	4,110,534

Table 2.2: Number of Orders

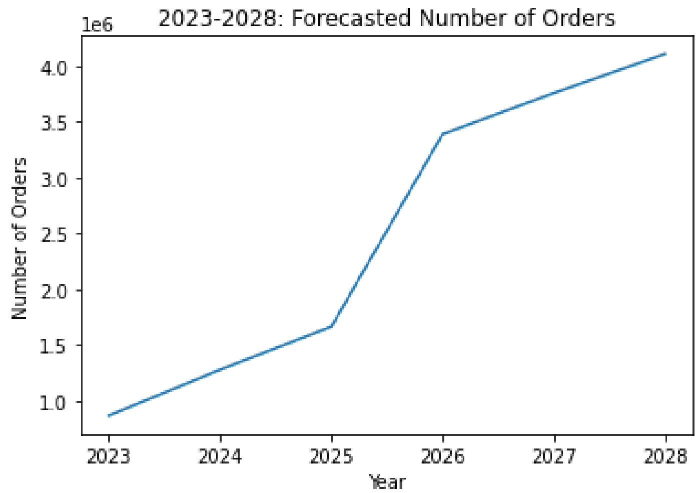


Figure 2.2: Number of Orders 2023-2028

In a similar vein, the frequency of the order quantity changes over time as a result of the minimum order quantity change. Prior to 2026, order quantities were predominantly centered on a quantity of 50. However, from 2026 to 2028, the overwhelming majority of orders are for a quantity of 25 units. Figure 2.3 depicts the order quantity frequency as a histogram.

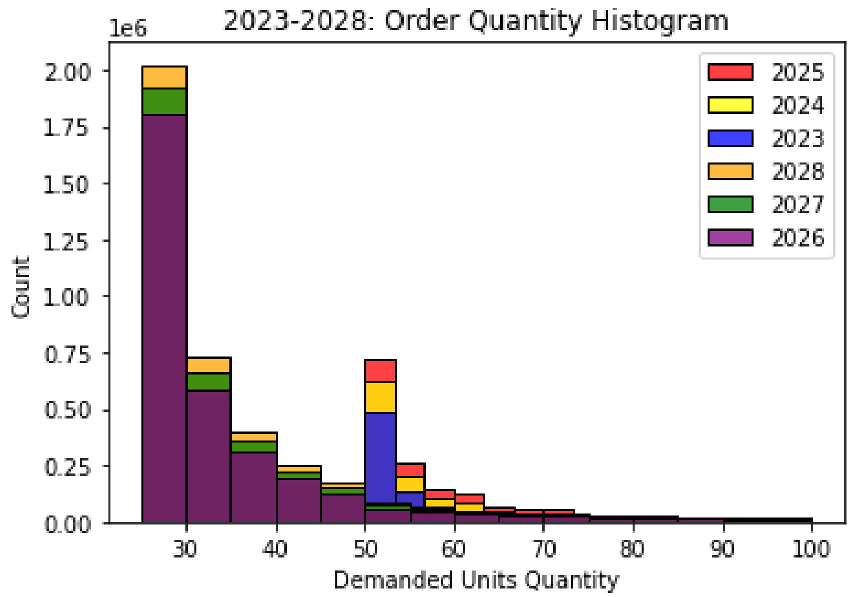


Figure 2.3: Order Quantity Histogram

One limitation of the forecasted demand model is that it does not account for those outlier orders found in the 2019 historical data. Recall that there were 4 orders with a quantity greater than 10,000 units and 22 orders greater than 5000. Given that it uses the demand share percentages to calculate the forecasted demand, order quantities are significantly smoothed as they are distributed across multiple weeks, products, or ZIP codes thereby reducing their impact. Evaluating the maximum order quantity, that effect is evident in that the order quantity increases proportionately with the annual growth rate. Figure 2.4 and Table 2.3 depict the maximum order quantities from 2023 to 2028.

Year	Maximum Order (Units)
2023	608
2024	912
2025	1216
2026	1419
2027	1622
2028	1824

Table 2.3: Maximum Order Quantity

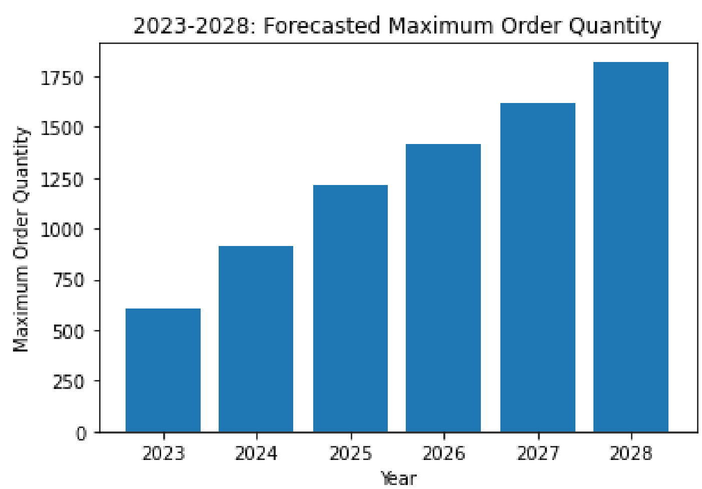


Figure 2.4: Maximum Order Quantity 2023-2028

Finally, because the forecast is based on the demand share data calculated in Task 3.1.1, the top performing products, product categories, states, ZIP codes, and weeks of the year are unchanged from the results explained in the previous task.

Refer to Appendix 2, 2a Forecasted Demand Folder for the generated forecast data from 2023 to 2028 and 3.1.2a - Forecasted Demand.html for the Python code file used for all calculations.

3.1.2.b Customer Order Scenario Generator 2023 - 2028

A simulator was constructed using Python to stochastically generate customer order data for ten unique scenarios.

Methodology:

The basic process of calculating the customer orders for each scenario is no different from the underlying methodology explained in Task 3.1.2a: determine the annual growth rate and initial demand, calculate the forecasted demand for each aggregation thread, and aggregate orders as needed to account for the minimum order quantity. The major difference introduced with Task 3.1.2b is stochasticity.

Previously deterministic, the following variables were assumed to follow a probability distribution: annual growth rate, 2023 initial demand, and daily, weekly, product, and ZIP code demand share percentages. The distributions are outlined in Table 2.4.

Variable	Distribution	Parameters
Annual Growth Rate	Triangular	$a = min; b = mode; c = \max$
Initial 2023 Demand	Normal	$\mu = 56{,}181{,}922;\ \sigma = 16.2$
Daily Demand Share	Normal	$\mu = day_j;\ \sigma = CV \cdot \mu$
Weekly Demand Share	Normal	$\mu = week_i;\ \sigma = CV \cdot \mu$
Product Demand Share	Normal	$\mu = product_k;\ \sigma = CV \cdot \mu$
ZIP Code Demand Share	Normal	$\mu = ZIP_l;\ \sigma = CV \cdot \mu$

Table 2.4: Variable Distribution

As part of the scenario generation, parameters for each variable are varied from scenario to scenario. Scenarios 1 through 5 model SwiftHelper's annual growth as generally in line with their targeted growth rate with moderate variability from the target. Comparatively, Scenarios 6 through 10 introduce significant volatility in the annual growth rate with the company pessimistically falling short of its target.

For the demand shares of each variable (day, week, product, and ZIP code), Scenarios 1 and 6 simulate little variation in the calculated demand share percentages; Scenarios 2 and 7 double the variation. In Scenario 3 and 8, the time-based variables have significant volatility while product and ZIP code experience minimal variation. For Scenarios 4 and 9, those roles are reversed. Finally, Scenarios 5 and 10 most closely follow the expected variation if additional datasets were made available. Table 2.5 and 2.6 specify the parameters used for each scenario.

Scenario	Growth Rate	Daily Demand	Weekly Demand	Product Demand	ZIP Code Demand
1	A	CV = 0.1	CV = 0.1	CV = 0.1	CV = 0.1
2	A	CV = 0.2	CV = 0.2	CV = 0.2	CV = 0.2

3	A	CV = 0.2	CV = 0.2	CV = 0.1	CV = 0.1
4	A	CV = 0.1	CV = 0.1	CV = 0.2	CV = 0.2
5	A	CV = 0.25	CV = 0.15	CV = 0.15	CV = 0.1
6	B	CV = 0.1	CV = 0.1	CV = 0.1	CV = 0.1
7	B	CV = 0.2	CV = 0.2	CV = 0.2	CV = 0.2
8	B	CV = 0.2	CV = 0.2	CV = 0.1	CV = 0.1
9	B	CV = 0.1	CV = 0.1	CV = 0.2	CV = 0.2
10	B	CV = 0.25	CV = 0.15	CV = 0.15	CV = 0.1

Table 2.5: Scenario Generation Parameters

Scenario A					
2024		2025		2028	
Min	135%	Min	180%	Min	270%
Mode	150%	Mode	200%	Mode	300%
Max	155%	Max	210%	Max	315%
Scenario B					
2024		2025		2028	
Min	100%	Min	130%	Min	200%
Mode	145%	Mode	205%	Mode	285%
Max	175%	Max	245%	Max	325%

Table 2.6: Annual Growth Distribution

Each variable’s distribution was sampled for every year in each scenario. To determine the daily demand share (i.e.., day of the year as opposed to day of the week), the weekly and day of the week demand share percentages were multiplied together. As a result, the simulation generates data for only 364 days, presenting a limitation of the model.

Additionally, the algorithm that accounts for the minimum order quantity is limited in that it does not loop into the next year, continuing to aggregate demand. Each year was evaluated individually and as such, if the algorithm reaches day 364 of a given year without reaching the order minimum, that demand never materializes. While each order quantity is small (less than 50 or 25 in later years), the result is compounded across each product and ZIP code per year. Creating a single array with all demand data for the six years was computationally expensive and required significant time and RAM to process. As such, this is an area of improvement for future analysis.

Results:

Using the data generated from the simulator, several relevant metrics were extrapolated to compare results from each scenario. First, Figure 2.5 illustrates the variability in the annual growth rate for SwiftHelper. In Scenario 10, there was a very slow start where the company clearly did not meet its sales target, but it was able to recover by 2025. Scenario 8 depicts an even slower start-up, requiring an investment of two years before the anticipated growth is realized.

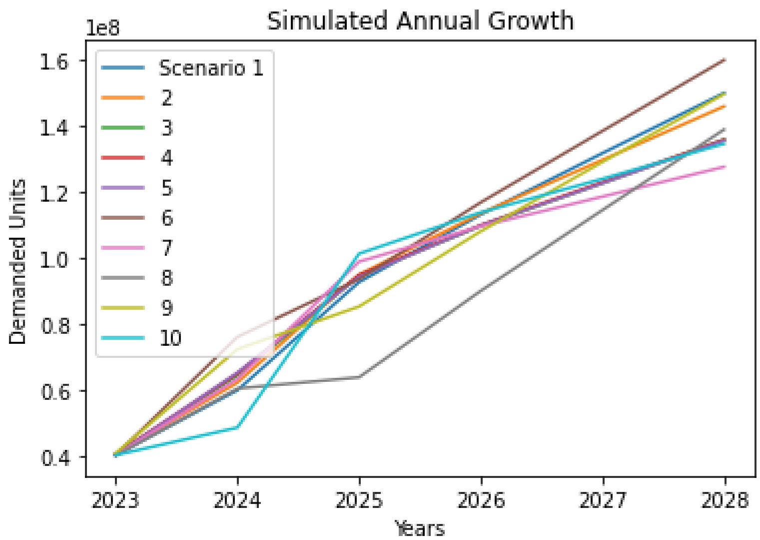


Figure 2.5: Simulated Annual Demand

From each scenario, the top ten ZIP codes were recorded for comparison. Figures 2.6 and 2.7 depict the count data for each ZIP code as a bar chart and map for visualization of the locations. The ZIP code leaders found in Task 3.1.1.a consistently appear in the top ten throughout nearly every scenario. Miami (331) and New York City (112) never failed to appear. In those scenarios where the ZIP code demand share was subject to greater variability, ZIP codes associated with Houston, Los Angeles, and Phoenix entered the mix when not previously seen before.

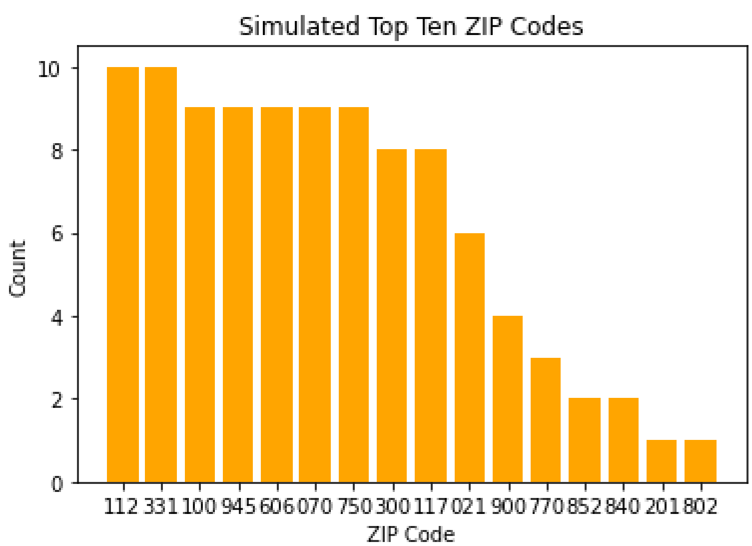


Figure 2.6: Top Ten ZIP Code Count

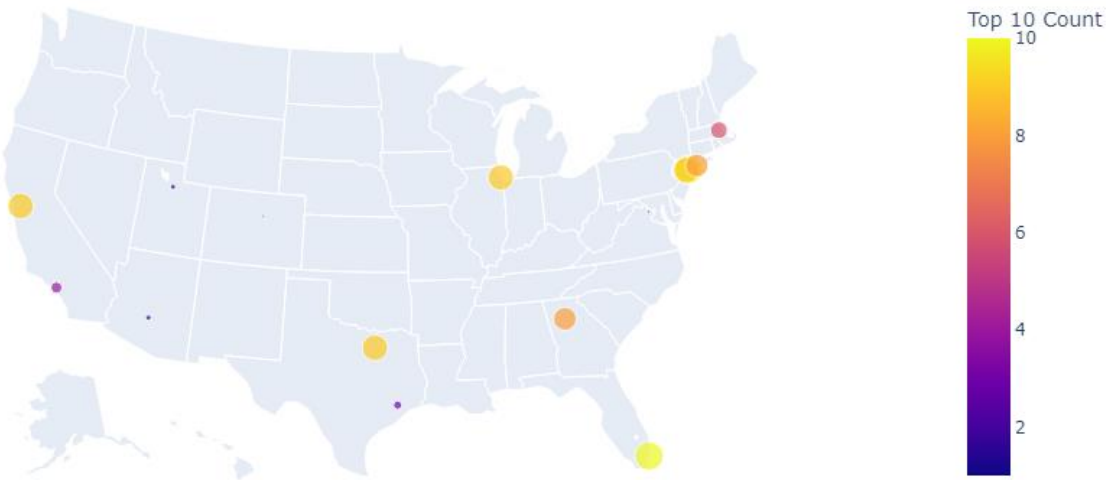


Figure 2.7: Top Ten ZIP Code Count Locations

The top ten products were also recorded with each scenario. Figure 2.8 illustrates the number of times the product number appeared in the top ten across all ten scenarios.

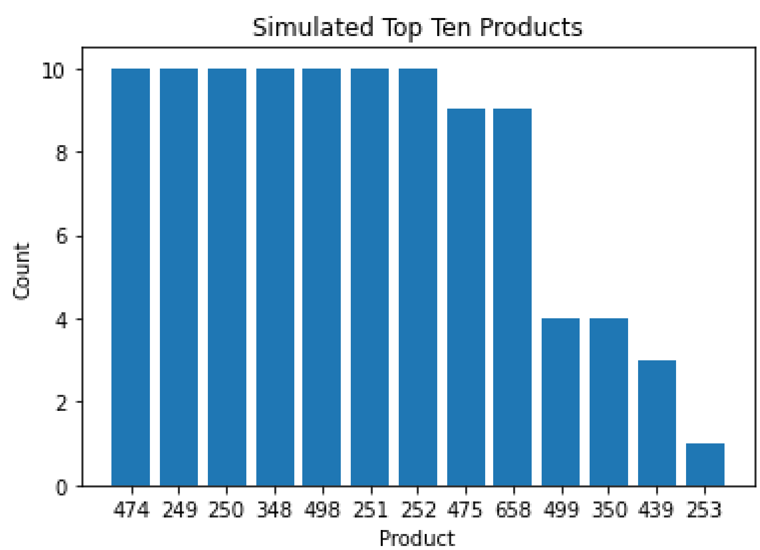


Figure 2.8: Top Ten Product Count

Once again, in those scenarios where product demand share had a higher standard deviation, the top ten experienced greater fluctuation. Products 474, 249, 250, 348, 498, 251, and 252 never failed to appear outside the top ten. Products 253 and 349 were introduced in Scenarios 3, 7 and 8.

Refer to Appendix 3, Scenarios 1 through 10, Orders for the complete listing of customer orders across all ten scenarios from 2023 to 2028. Additionally, 3.1.2b thru 4d – Simulator.html contains the Python code used to generate the simulation.

Task 3.1.3 Fulfillment Center Throughput and Storage Requirements

3.1.3.a Fulfillment Center Assignment

The customer's home 3-digit ZIP codes were assigned to the most appropriate fulfillment center among the twenty such centers considering the distance as the deciding factor; each customer's home 3-digit ZIP code was assigned to the closest fulfillment center. The distance was calculated using the Spherical Law of Cosines. The formula considered was the following:

$$Distance(miles) =$$

$$\frac{6371}{1.609} * [ACOS(COS(RADIANS(90 - Latitude_{CUSTOMER})) * COS(RADIANS(90 - Latitude_{FC}))$$

$$+ SIN(RADIANS(90 - Latitude_{CUSTOMER})) * SIN(RADIANS(90 - Latitude_{FC}))$$

$$* COS(RADIANS(Longitude_{CUSTOMER} - Longitude_{FC}))]$$

The result obtained is depicted in Figures 3.1 and 3.2.

Figure 3.1: ZIP code assignment to most appropriate FC

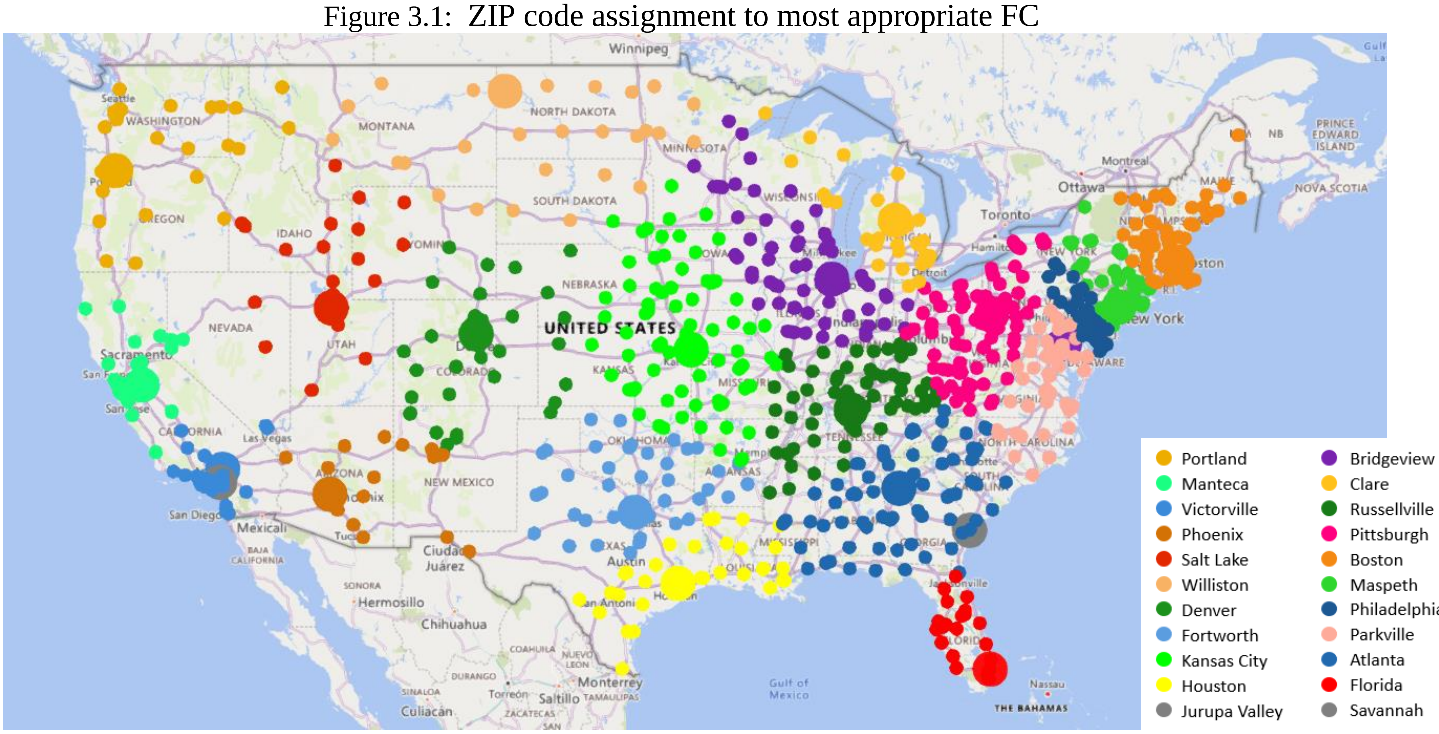


Figure 3.2: Alaska's ZIPcode assignment to most appropriate fulfillment center

The number of 3-digit ZIP codes that each fulfillment center must serve is detailed in the table 3.1 presented below.

FC ZIP code	FC City	FC State	# of ZIP codes served
30336	Atlanta	GA	36
42276	Russellville	KY	60
76164	Fort Worth	TX	44
77078	Houston	TX	36
92395	Victorville	CA	34
95336	Manteca	CA	30
97230	Portland	OR	33
58801	Williston	ND	27
80204	Denver	CO	35
66115	Kansas City	KS	77
60455	Bridgeview	IL	71
48617	Clare	MI	26
15205	Pittsburgh	PA	79
19138	Philadelphia	PA	30
21234	Parkville	MD	60
11378	Maspeth	NY	113
2118	Boston	MA	39
33334	Fort Lauderdale	FL	21
84044	Salt Lake City	UT	21
85017	Phoenix	AZ	20

Table 3.1: Number of Customer's home 3-digit ZIP code served by each Fulfillment center

Refer to the Excel file Calculations_task 3(a)_working.xlsx for the complete calculations of fulfillment center assignment and distance calculations.

3.1.3.b Fulfillment Center Forecasted Demand

To calculate the throughput of each fulfillment center, the team required as inputs the data generated 3.1.2.(a) and 3.1.3.(a). The demand forecast was calculated at a product-week-ZIP code level, accounting for a 99% robust demand. The team decided to take a conservative approach and consider the same service level target for all product categories. The reasoning being that to achieve the growth goals defined by SwiftHelper, there is no room for non-compliances in terms of delivery time so to ensure excellent service throughout, 99% service level was used across all categories. Once the 99% robust demand by product-week-zip code was obtained, the demand was linked to each fulfillment center using the zip code assignment to most appropriate fulfillment center derived in 3.1.3.(a) to obtain the throughput of each fulfillment center throughout the planning horizon.

The throughput of each fulfillment center per year in units is shown in Figure 3.3.

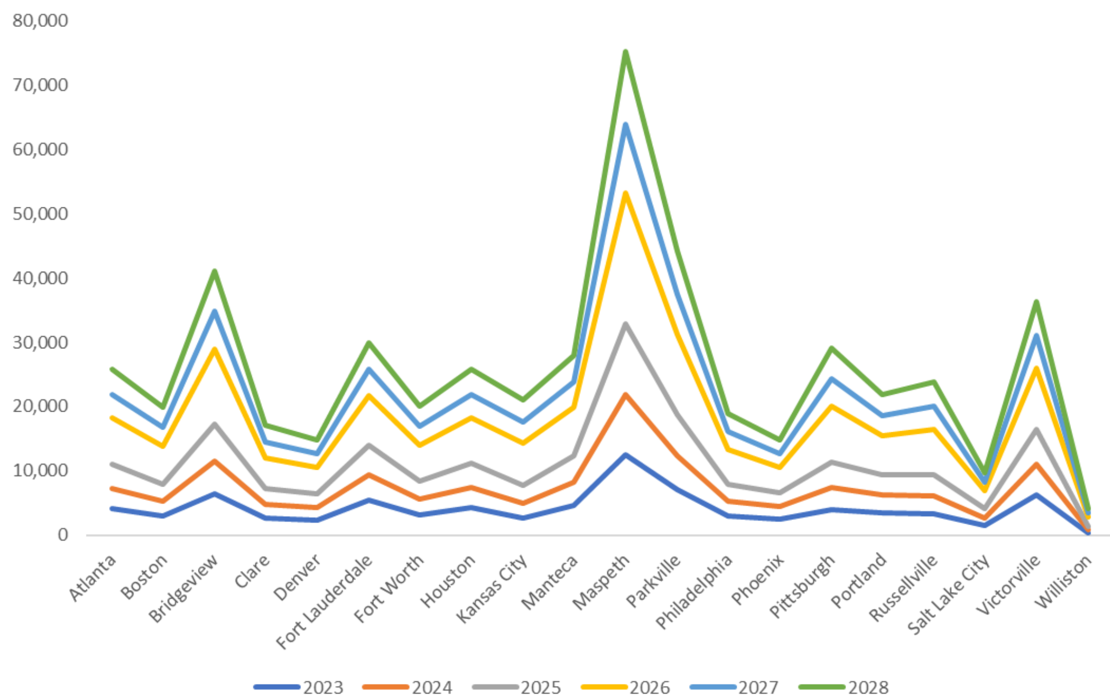


Figure 3.3: Throughput of each fulfillment throughout the planning horizon (in thousands).

As shown in Figure 3.3, the fulfillment center with the highest throughput in each of the years comprising the planning horizon is the fulfillment center located in Maspeth, NY. This was expected since Maspeth is the fulfillment center that serves the highest number of customer's home 3-digit ZIP codes (113).

Refer to the Excel file Calculations_3(b)_working.xslx for the throughput of each fulfillment center per product per week throughout the planning horizon.

3.1.3.c Fulfillment Center Order Simulations

The team proceeded to stochastically generate ten fulfillment center order scenarios over the 2023 - 2028 horizon. The scenarios generated stem from the simulation done in 3.1.2.(b) (see Task 3.1.2.(b) for simulation assumptions). For this task, the added variable was that each order zip-code was assigned to a fulfillment center leveraging the results obtained in task 3.1.3.(a) where each order ZIP code was assigned to the most appropriate fulfillment center. From that definition the order quantities by fulfillment center were simulated for the ten scenarios, results are shown in figures 3.4 to 3.13. The maximum throughput capacity required by each fulfillment center will be its maximum order quantity during the planning horizon across all the scenarios.

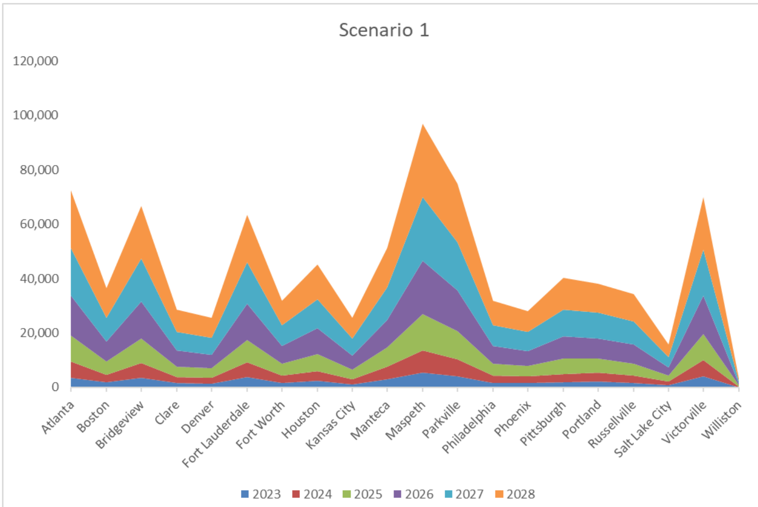


Figure 3.4: Fulfillment center outbound throughput capacity requirements per year in thousands of units scenario 1

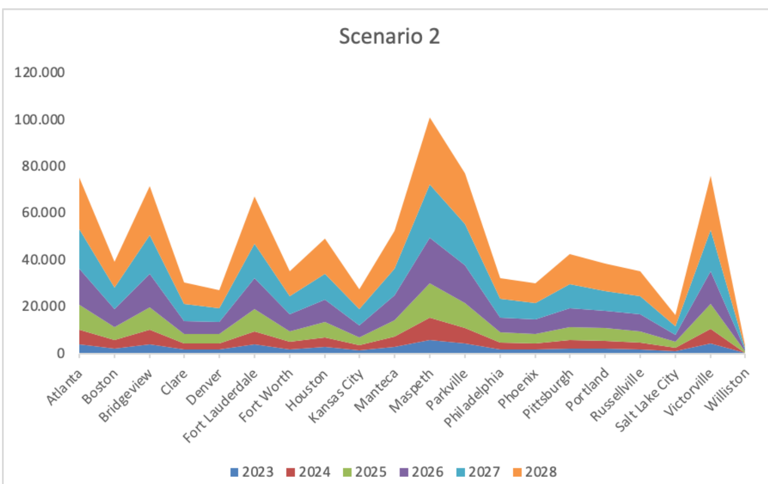


Figure 3.5: Fulfillment center outbound throughput capacity requirements per year in thousands of units scenario 2

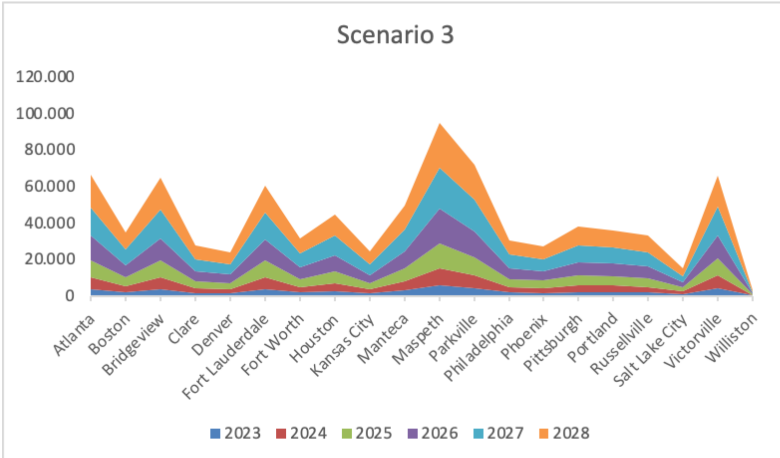


Figure 3.6: Fulfillment center outbound throughput capacity requirements per year in thousands of units scenario 3

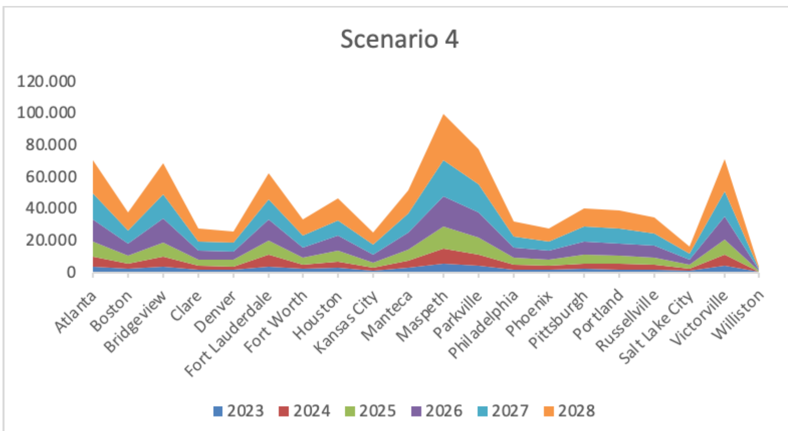


Figure 3.7: Fulfillment center outbound throughput capacity requirements per year in thousands of units scenario 4

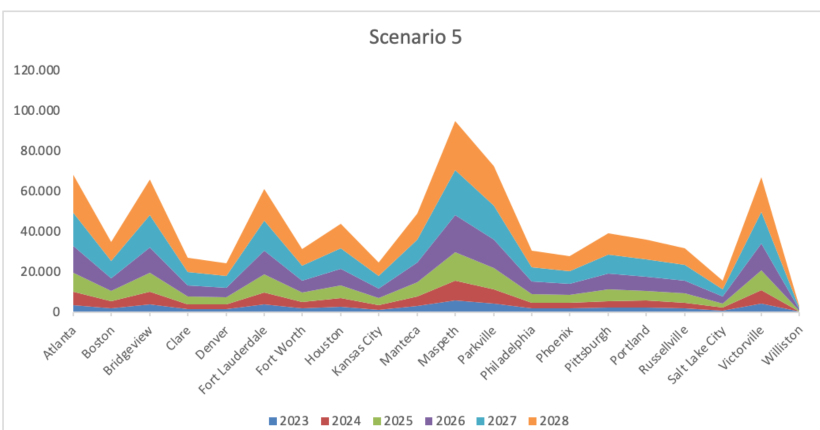


Figure 3.8: Fulfillment center outbound throughput capacity requirements per year in thousands of units scenario 5

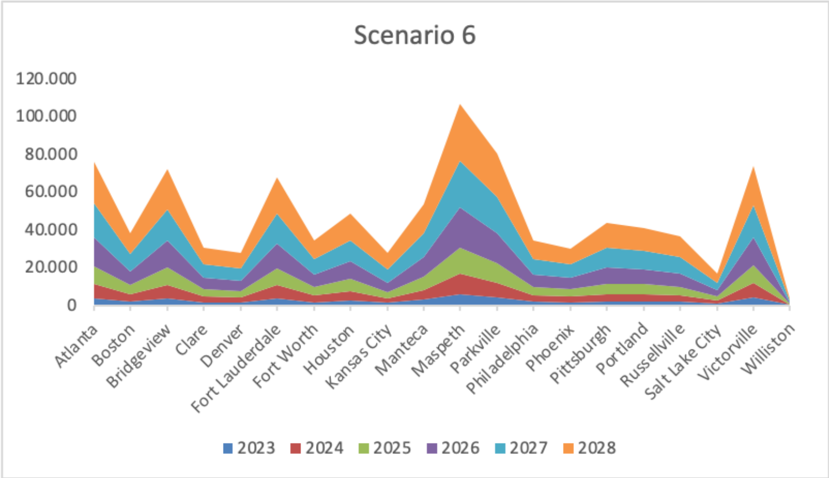


Figure 3.9: Fulfillment center outbound throughput capacity requirements per year in thousands of units scenario 6

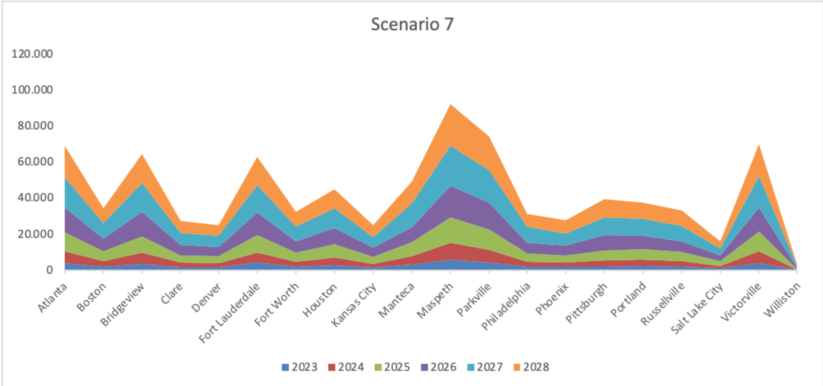


Figure 3.10: Fulfillment center outbound throughput capacity requirements per year in thousands of units scenario 7

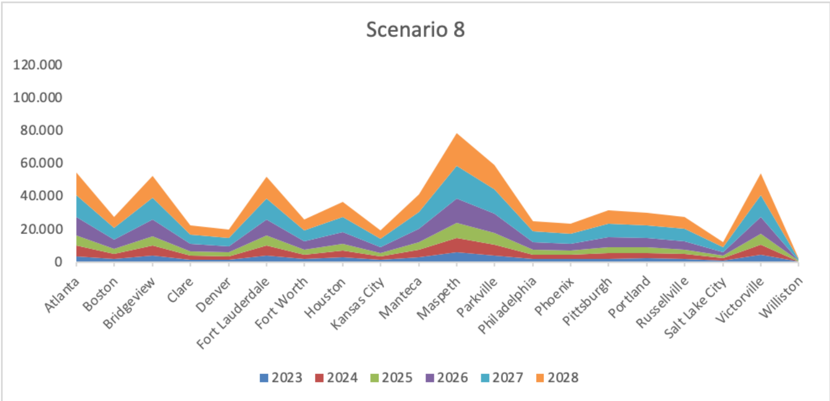


Figure 3.11: Fulfillment center outbound throughput capacity requirements per year in thousands of units scenario 8

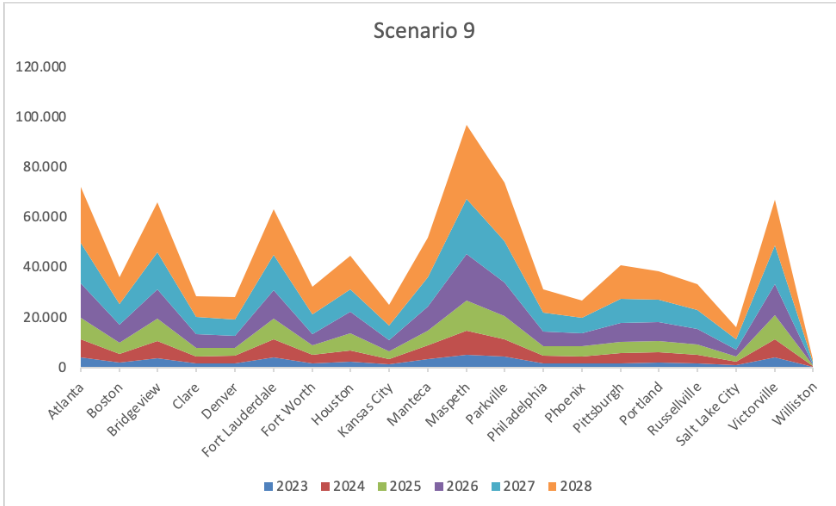


Figure 3.12: Fulfillment center outbound throughput capacity requirements per year in thousands of units scenario 9

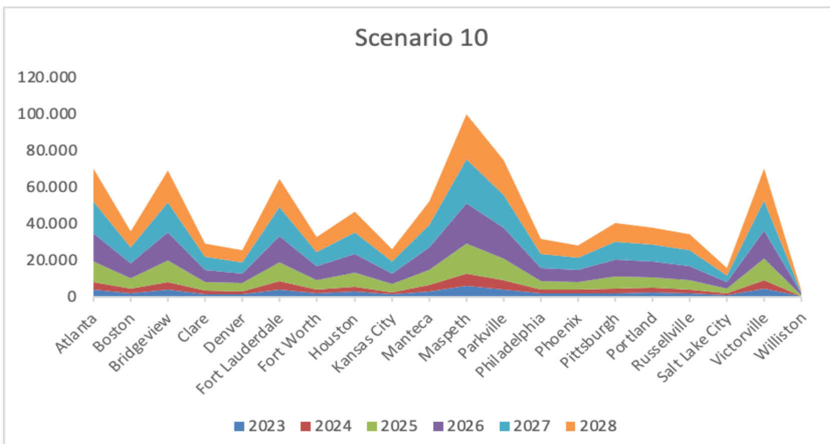


Figure 3.13: Fulfillment center outbound throughput capacity requirements per year in thousands of units scenario 10

The maximum daily outbound throughput capacity required in thousands of units during the planning horizon across all the stochastic scenarios for each fulfillment center is shown in Table 3.2.

Atlanta	**Boston**	**Bridgeview**	**Clare**	**Denver**	**Fort Lauderdale**	**Fort Worth**	**Houston**	**Kansas City**	**Manteca**
269	130	208	92	70	178	104	128	117	141
Maspeth	**Parkville**	**Philadelphia**	**Phoenix**	**Pittsburgh**	**Portland**	**Russellville**	**Salt Lake City**	**Victorville**	**Williston**
255	249	102	76	162	114	134	54	196	21

Table 3.2: Maximum daily outbound throughput capacity requirement in thousands of units during the planning horizon across all the scenarios for each fulfillment center

The team considers that SwiftHelper does not need to plan its fulfillment centers’ capacity to fulfill the maximum daily outbound required shown in Table 3.2. Two alternatives could be considered instead:

1. If there is a peak in demand in fulfillment center A, other fulfillment centers that have idle capacity in that specific time period could contribute to fulfilling the orders received in A.
2. DCs could ship directly to customers hiring 3PL whenever they have peaks to ease the demand in certain fulfillment center

Refer to Appendix 3, Scenarios 1 through 10, FC Orders for the complete listing of fulfillment center orders for each scenario from 2023 to 2028.

3.1.3.d Fulfillment Center Inventory Simulation

The team proceeded to stochastically generate ten replenishment scenarios of each appropriate combination of fulfillment center and product over the 2023-2028 horizon. The scenarios generated stem from the simulation done in 3.1.2.(b) and 3.1.2.(c) (see task 3.1.2.(b) for simulation assumptions).

It is known that fulfillment centers will be replenished on a weekly basis. Additionally, the fulfillment centers are to target a 99% robust autonomy always covering 20 days of demand with its on-hand stock. During task 3.1.3.(b) 99% robust demand was calculated on a daily, product and zip-code basis. Leveraging this information, the on-hand inventory used was calculated as follows:

$$X_i = demand\ on\ day\ i$$
$$I_i = inventory\ on - hand\ on\ day\ i$$
$$I_i = 7 * X_i + \sum_{i}^{i+19} X_i$$

The on-hand inventory was calculated for each of the ten stochastic scenarios, results per fulfillment center are shown in figures 3.14 to 3.23. Storage requirements for each fulfillment center can be obtained calculating the maximum on-hand inventory for each fulfillment center during the planning horizon across all the scenarios. It is important to note that each fulfillment center sources a different number of zip-codes, with different order quantities and that results in different storage requirements for each fulfillment center.

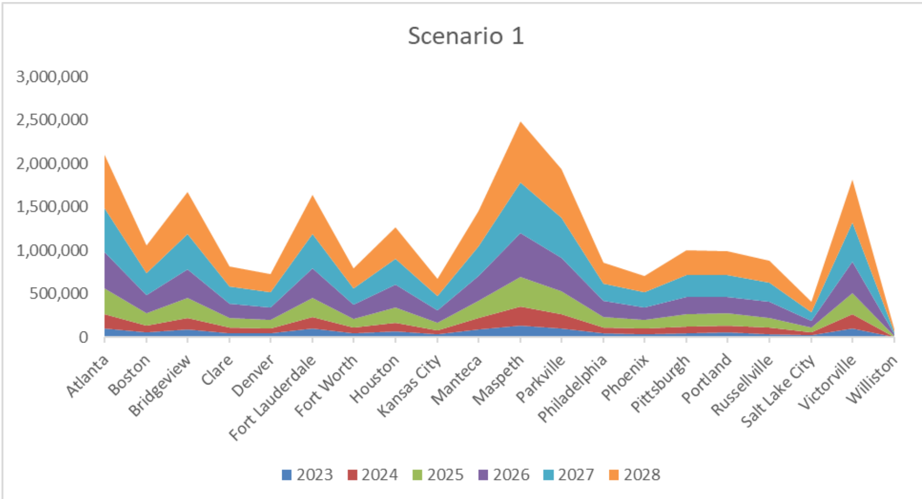


Figure 3.14: Fulfillment center storage capacity required per year in thousands of units scenario 1

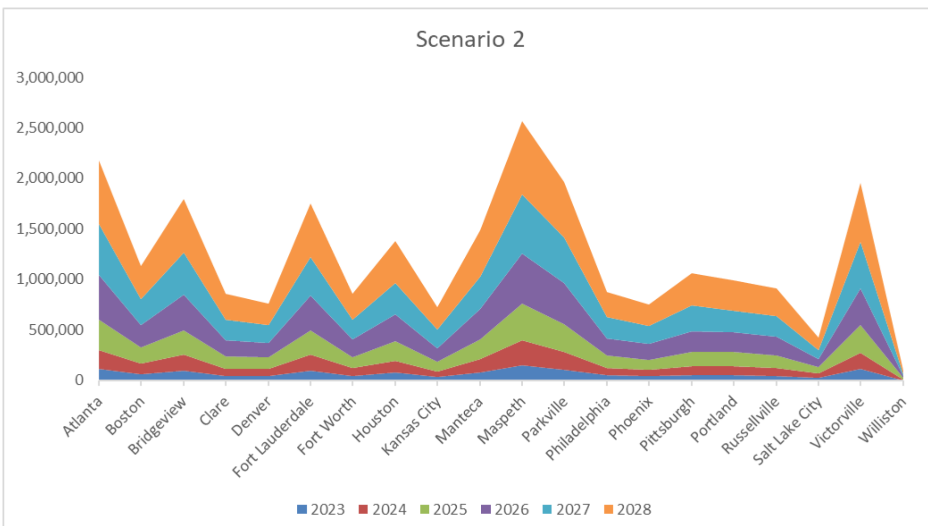


Figure 3.15: Fulfillment center storage capacity required per year in thousands of units scenario 2

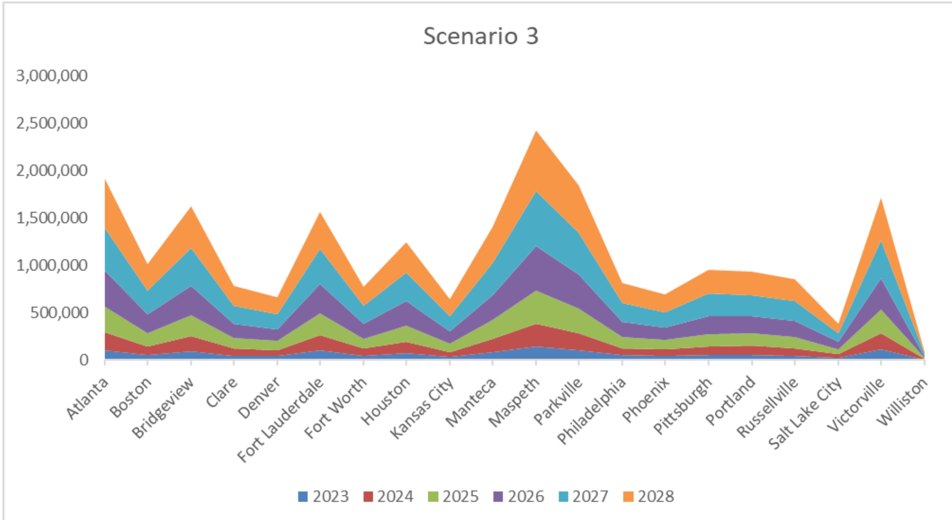


Figure 3.16: Fulfillment center storage capacity required per year in thousands of units scenario 3

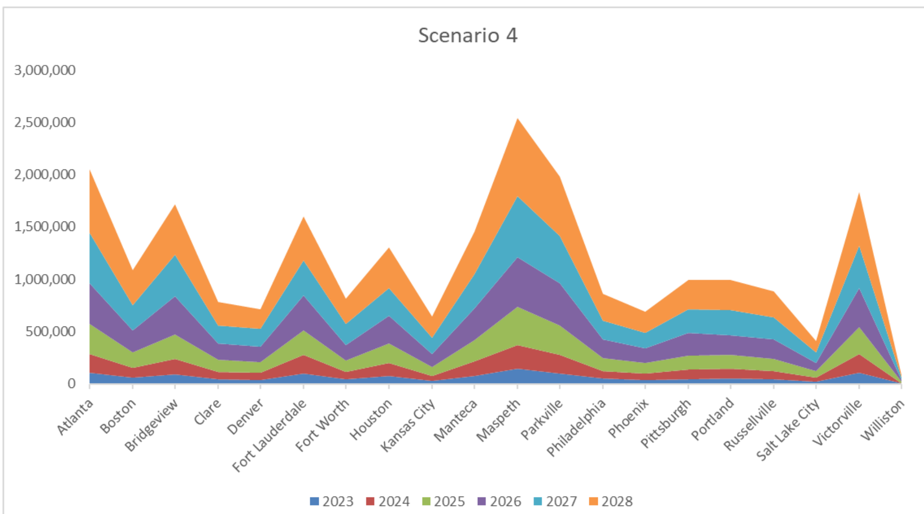


Figure 3.17: Fulfillment center storage capacity required per year in thousands of units scenario 4

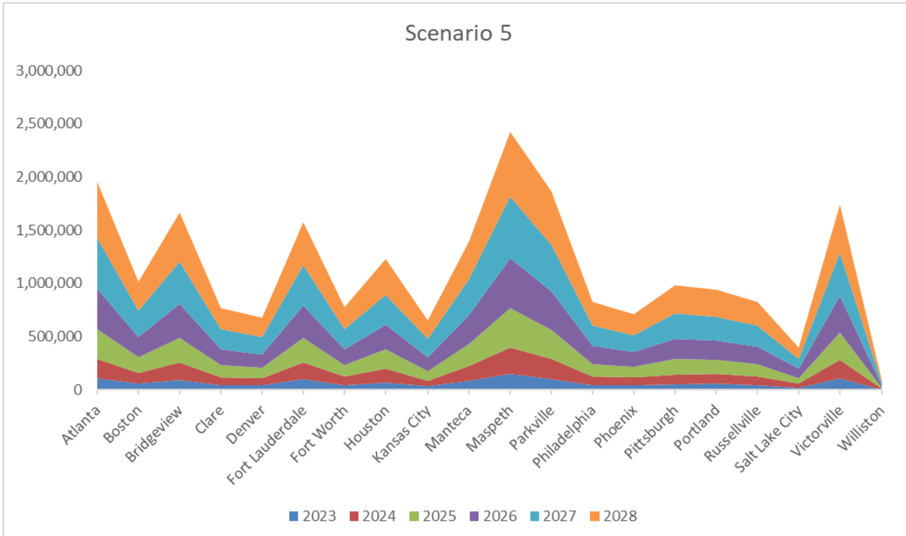


Figure 3.18: Fulfillment center storage capacity required per year in thousands of units scenario 5

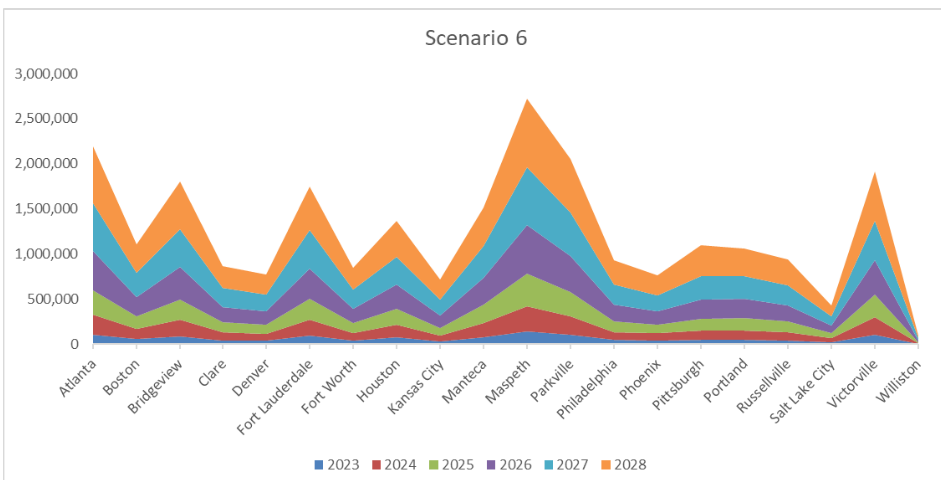


Figure 3.19: Fulfillment center storage capacity required per year in thousands of units scenario 6

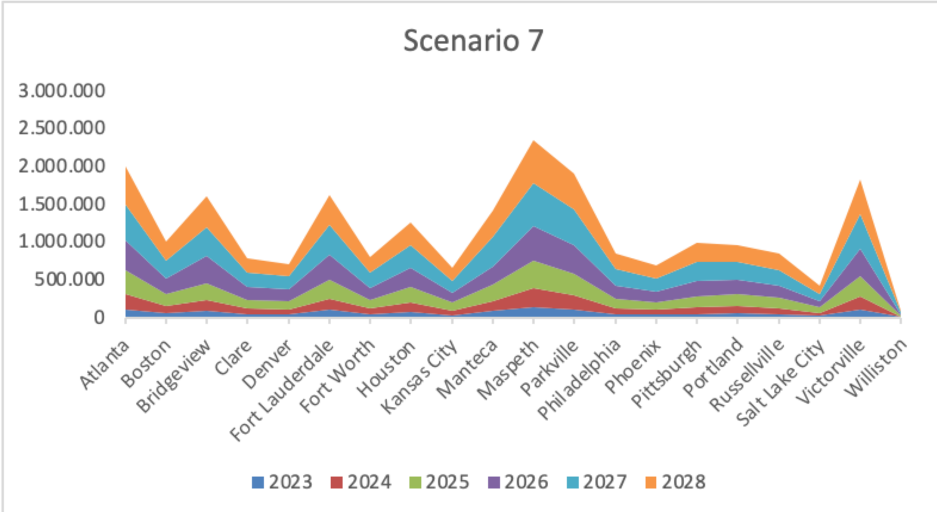


Figure 3.20: Fulfillment center storage capacity required per year in thousands of units scenario 7

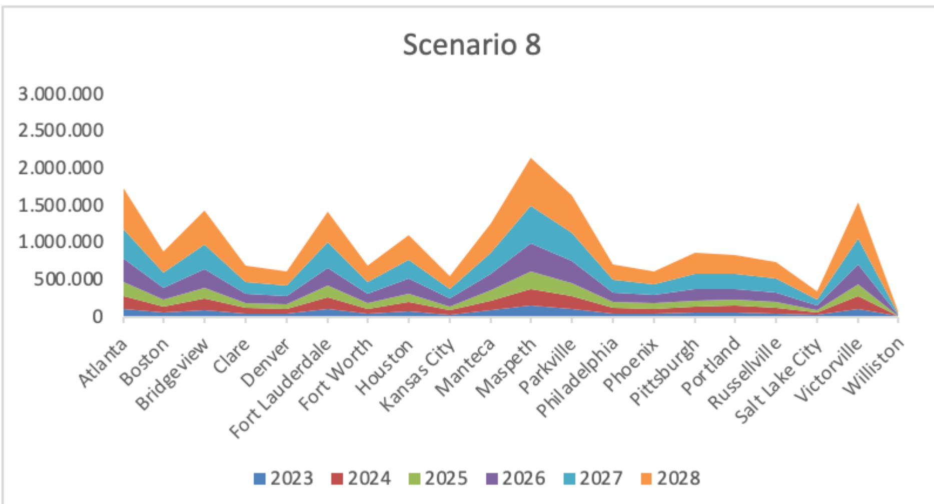


Figure 3.21: Fulfillment center storage capacity required per year in thousands of units scenario 8

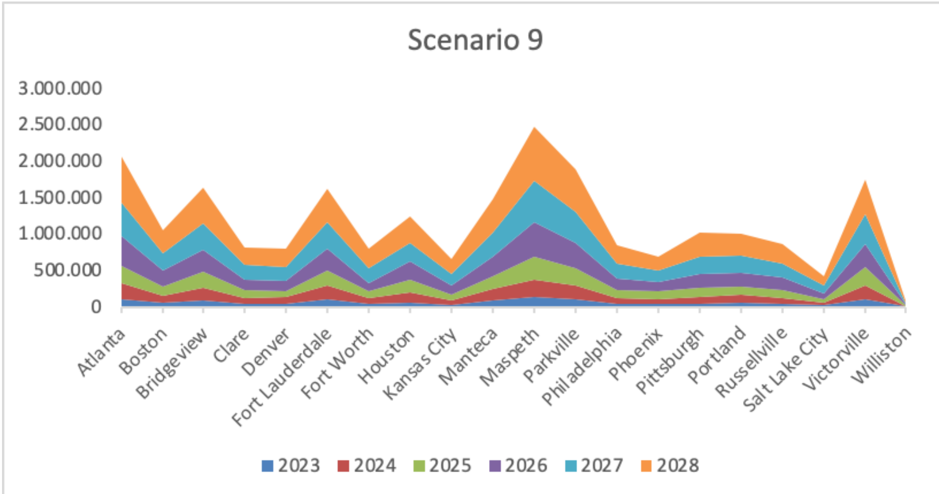


Figure 3.22: Fulfillment center storage capacity required per year in thousands of units scenario 9

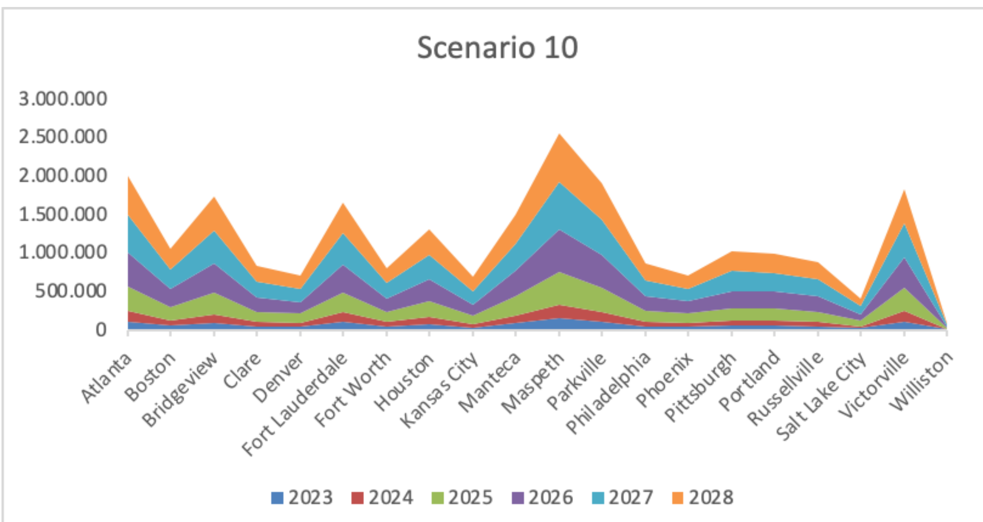


Figure 3.23: Fulfillment center storage capacity required per year in thousands of units scenario 10

The maximum daily storage capacity required in thousands of units during the planning horizon across all the stochastic scenarios for each fulfillment center is shown in Table 3.3.

Atlanta	Boston	Bridgeview	Clare	Denver	Fort Lauderdale	Fort Worth	Houston	Kansas City	Manteca
95	50	87	35	36	67	33	56	48	59

Maspeth	Parkville	Philadelphia	Phoenix	Pittsburgh	Portland	Russellville	Salt Lake City	Victorville	Williston
113	93	40	22	65	46	51	22	78	11

Table 3.3: Maximum daily storage capacity requirement in thousands of units during the planning horizon across all the scenarios for each fulfillment center

The team considers that SwiftHelper does not need to plan its fulfillment centers storage to fulfill the maximum storage capacity required shown in Table 3.3 since it would be better for the company in terms of costs to outsource storage capacity to cover punctual peaks.

Refer to Appendix 3, Scenarios 1 through 10, FC Inventory for the complete listing of fulfillment center inventory levels for each scenario from 2023 to 2028.

Task 3.1.4 Distribution Center Throughput and Storage Requirements

3.1.4.a Distribution Center Assignment

One of the two distribution centers was assigned to each fulfillment center be the preferred distribution center for replenishment. Again, the distance was considered as the deciding factor; each fulfillment center's ZIP code was assigned to the closest distribution centers. The distance was calculated using the Spherical Law of Cosines, the formula was shown in 3.1.3.(a).
The result obtained is depicted in Figure 4.1.

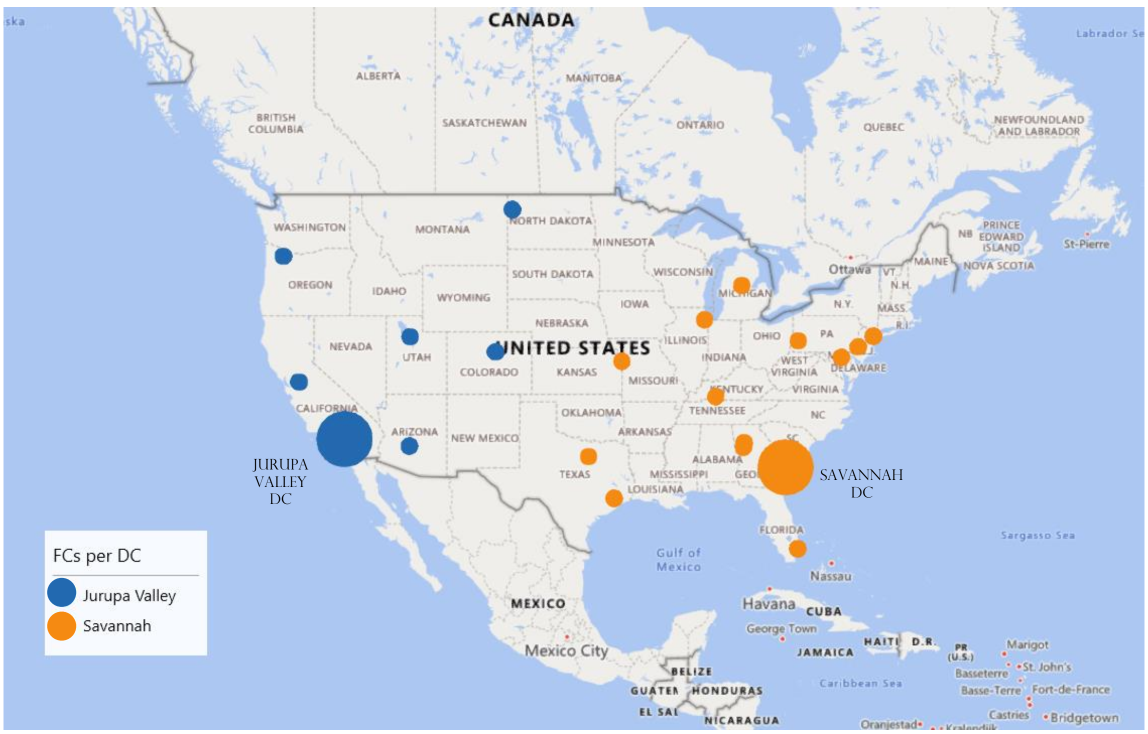


Figure 4.1: Fulfillment center assignment to most appropriate Distribution center

The distribution of fulfillment centers per distribution center is detailed in Table 4.1 presented below.

FC City	DC
Atlanta	Savannah
Russellville	Savannah
Fort Worth	Savannah
Houston	Savannah
Victorville	Jurupa Valley
Manteca	Jurupa Valley
Portland	Jurupa Valley
Williston	Jurupa Valley
Denver	Jurupa Valley
Kansas City	Savannah
Bridgeview	Savannah
Clare	Savannah
Pittsburgh	Savannah
Philadelphia	Savannah
Parkville	Savannah
Maspeth	Savannah
Boston	Savannah
Fort Lauderdale	Savannah
Salt Lake City	Jurupa Valley
Phoenix	Jurupa Valley

Table 4.1: Fulfillment center assignment to most appropriate Distribution center

Refer to Excel file calculations_task 4_working_xlsx for the complete calculations of distribution center assignment and distance calculations.

3.1.4.b Distribution Center Order Simulations

The team proceeded to stochastically generate ten distribution center order scenarios over the 2023-2028 horizon. The scenarios generated stem from the simulations done in 3.1.2.(b) and 3.1.3.(c) (see task 3.1.2.(b) for simulation assumptions). For this task, the added variable was that each fulfillment center was assigned to the most appropriate distribution center for replenishment leveraging the results obtained in task 3.1.4.(a). From that definition the order quantities by distribution center were simulated for the ten scenarios, results are shown in figures 4.2 to 4.11. The maximum throughput capacity required by each distribution center will be its maximum order quantity during the planning horizon across all the scenarios.

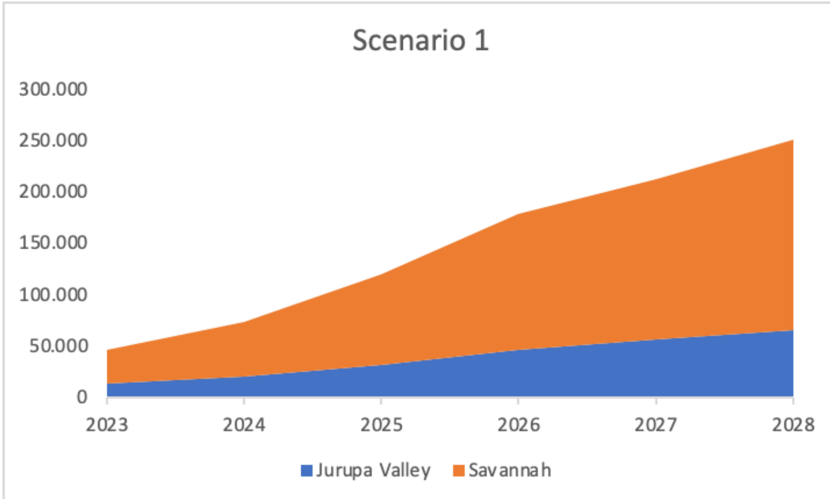


Figure 4.2: Distribution center annual order quantity in thousands of units scenario 1

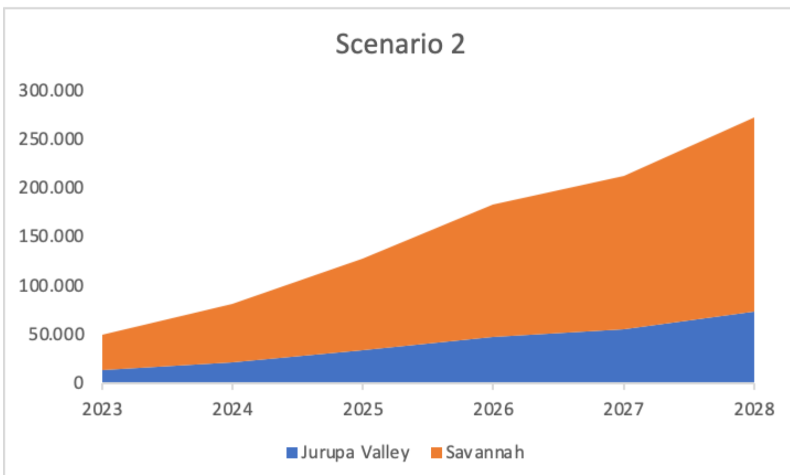


Figure 4.3: Distribution center annual order quantity in thousands of units scenario 2

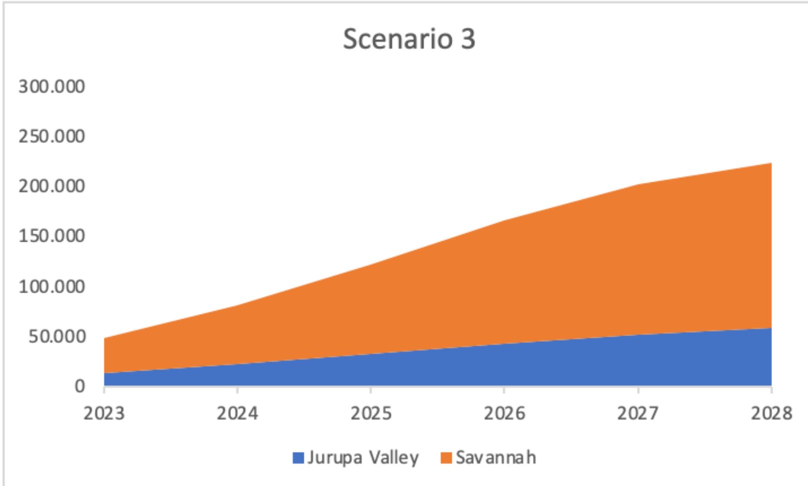


Figure 4.4: Distribution center annual order quantity in thousands of units scenario 3

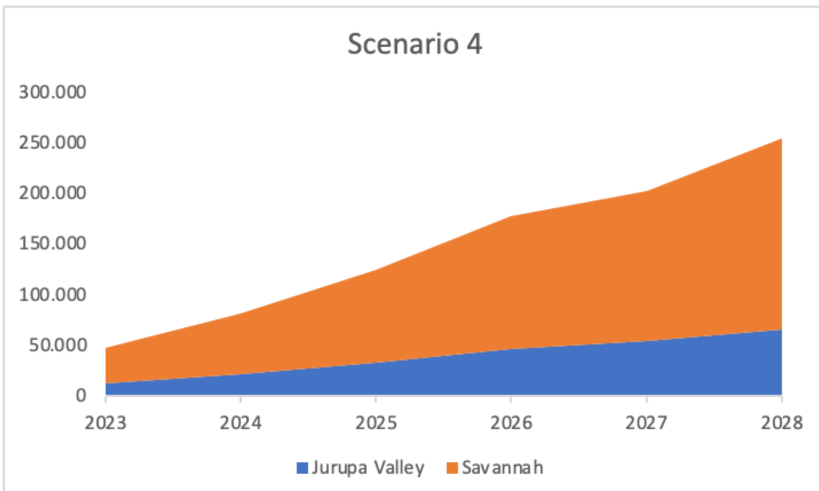


Figure 4.5: Distribution center annual order quantity in thousands of units scenario 4

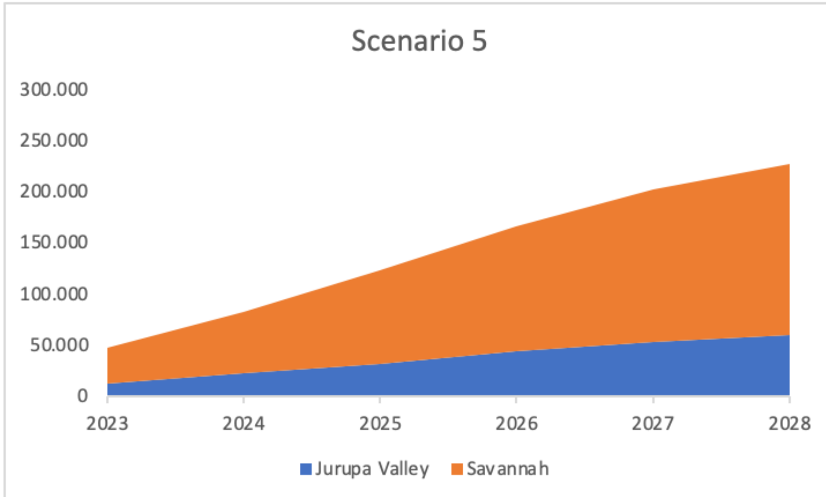


Figure 4.6: Distribution center annual order quantity in thousands of units scenario 5

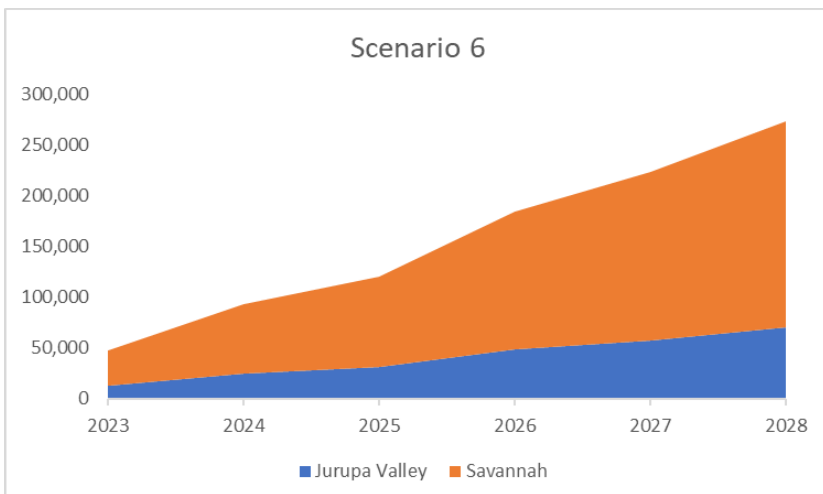


Figure 4.7: Distribution center annual order quantity in thousands of units scenario 6

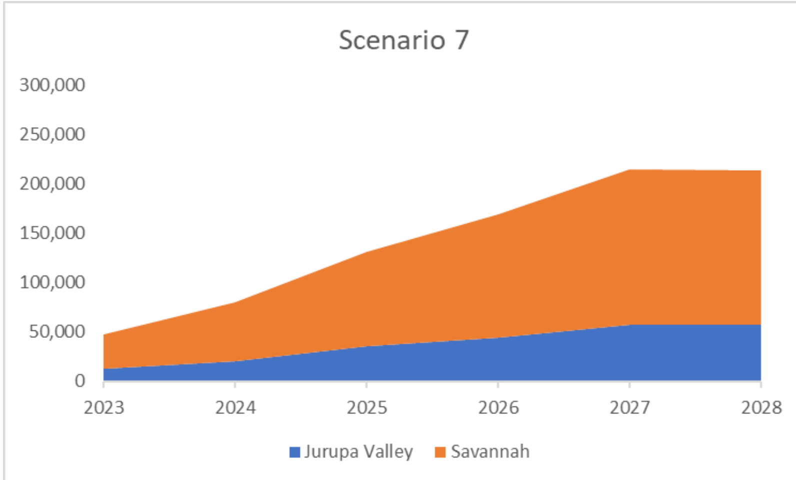


Figure 4.8: Distribution center annual order quantity in thousands of units scenario 7

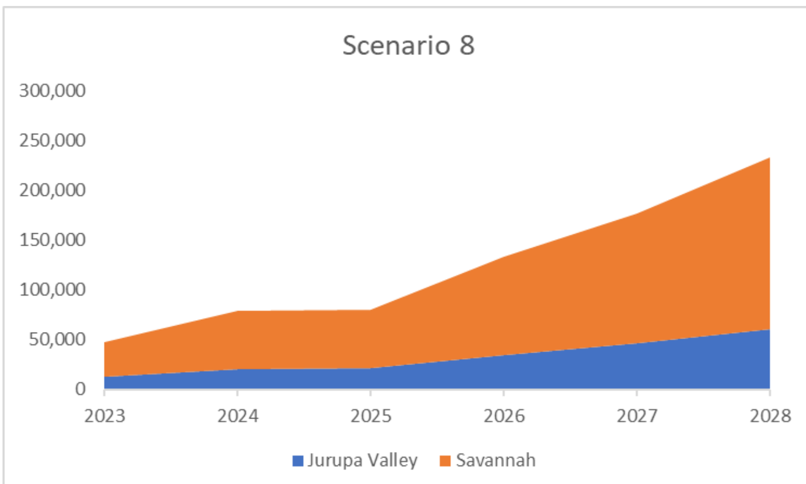


Figure 4.9: Distribution center annual order quantity in thousands of units scenario 8

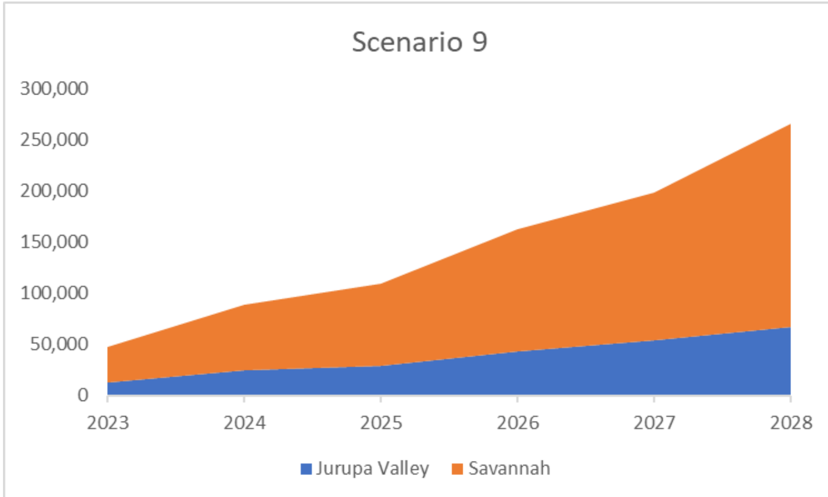


Figure 4.10: Distribution center annual order quantity in thousands of units scenario 9

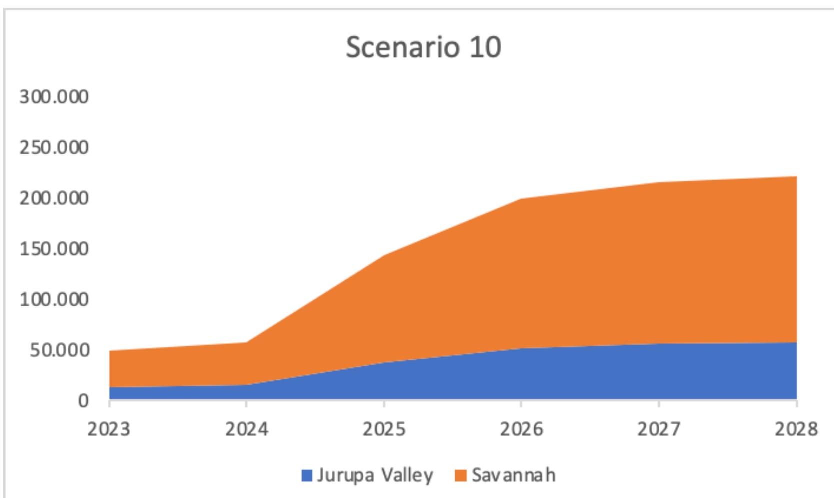


Figure 4.11: Distribution center annual order quantity in thousands of units scenario 10

The maximum daily outbound throughput capacity required in thousands of units during the planning horizon across all the stochastic scenarios for each distribution center is shown in Table 4.2.

DC	Maximum daily outbound throughput capacity required in thousands of units during the planning horizon across all the stochastic scenarios
Jurupa Valley	692
Savannah	2244

Table 4.2: Maximum daily outbound throughput capacity requirement in thousands of units during the planning horizon across all the scenarios for each distribution center

The team considers that SwiftHelper does need to plan its distribution centers' capacities to fulfill the maximum daily outbound required shown in Table 4.2.

Refer to Appendix 3, Scenarios 1 through 10, DC Orders for the complete listing of distribution center orders for each scenario from 2023 to 2028.

3.1.4.c Distribution Center Inventory Simulations

The team proceeded to stochastically generate ten replenishment scenarios of each appropriate combination of distribution center and product over the 2023-2028 horizon. The scenarios generated stem from the simulation done in 3.1.2.(b) and 3.1.2.(c) (see task 3.1.2.(b) for simulation assumptions). It is known that distribution centers must plan their operations considering the supplier lead times by product sub-category expressed in table 4.3.

Product Sub-category	Supplier Lead Time (days)			
	Targeted	99.9% Min	Mode	99.9% Max
f	28	21	26	60
m	56	40	52	85
s	112	72	100	182

Table 4.3: Supplier lead time

Compared to the previous task, in which the supplier lead time averaged one week for all products, the situation is different for the distribution centers since they are sourced by different manufacturers with different delivery lead times for each product sub-category.

To account for the stochasticity of the supplier lead times, random numbers where generated by sub-category to obtain the lead time in days. The random lead times where generated using a triangular distribution because SwiftHelper provided minimum, mode and maximum statistics by sub-category. Additionally, the fulfillment centers are to target a 99% robust autonomy always covering 20 days of demand with its on-hand stock. In task 3.1.3.(b) the 99% robust demand was calculated on a daily, product and zip-code basis. Combining all the above information, the on-hand inventory required in each DC used was calculated using the following expression for each product sub-category:

$$X_i = demand\ on\ day\ i$$

$$I_i = inventory\ on\ day\ i$$

$$I_{if} = np.random.triangular(21{,}26{,}60{,}1) * X_i + \sum_{i}^{i+19} X_i$$

$$I_{im} = np.random.triangular(40{,}52{,}85{,}1) * X_i + \sum_{i}^{i+19} X_i$$

$$I_{is} = np.random.triangular(72{,}100{,}182{,}1) * X_i + \sum_{i}^{i+19} X_i$$

The on-hand inventory per distribution center was calculated for each of the ten stochastic scenarios, results are shown in figures 4.12 to 4.21. Storage requirements for each distribution center can be obtained calculating the maximum on-hand inventory for each distribution center during the planning horizon across all the scenarios. It is important to note that each distribution center sources a different number of fulfillment center, and therefore a different number of zip-codes, with different order quantities and that results in different storage requirements.

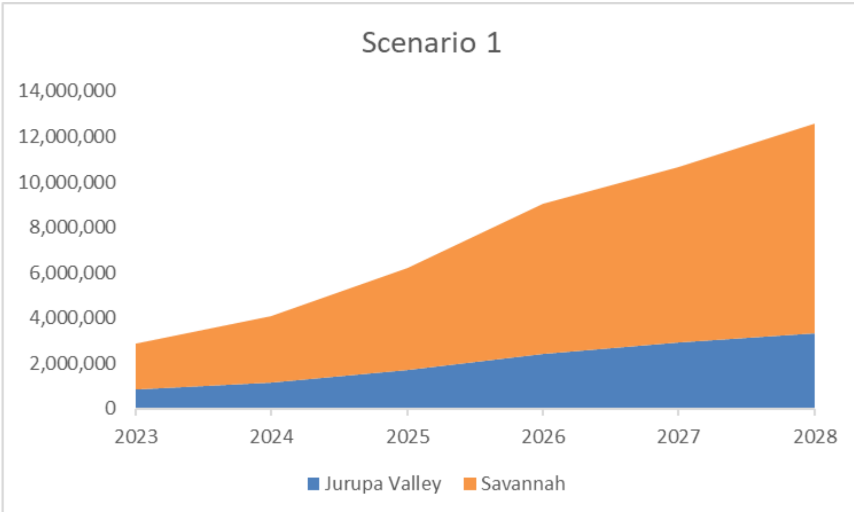


Figure 4.12: Distribution center storage capacity required per year in thousands of units scenario 1

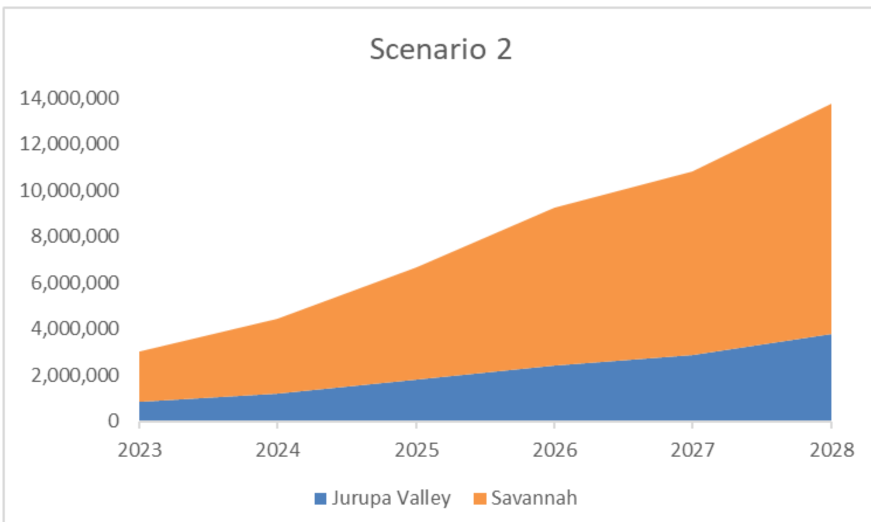


Figure 4.13: Distribution center storage capacity required per year in thousands of units scenario 2

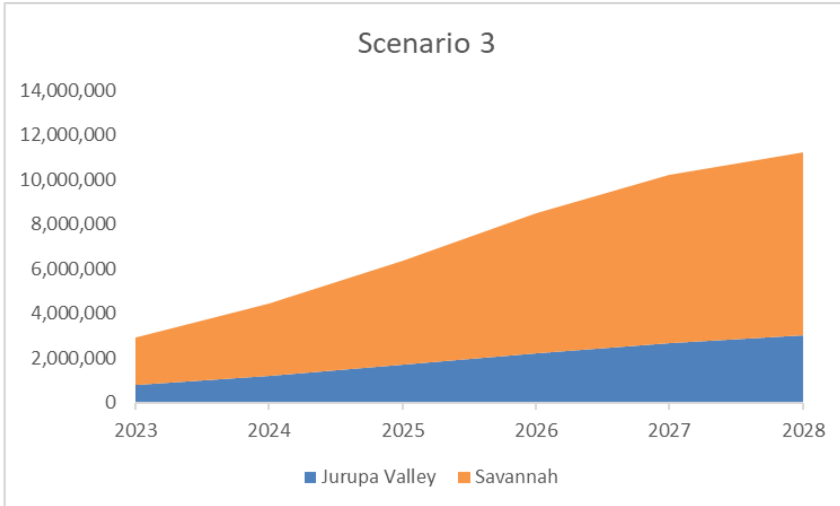


Figure 4.14: Distribution center storage capacity required per year in thousands of units scenario 3

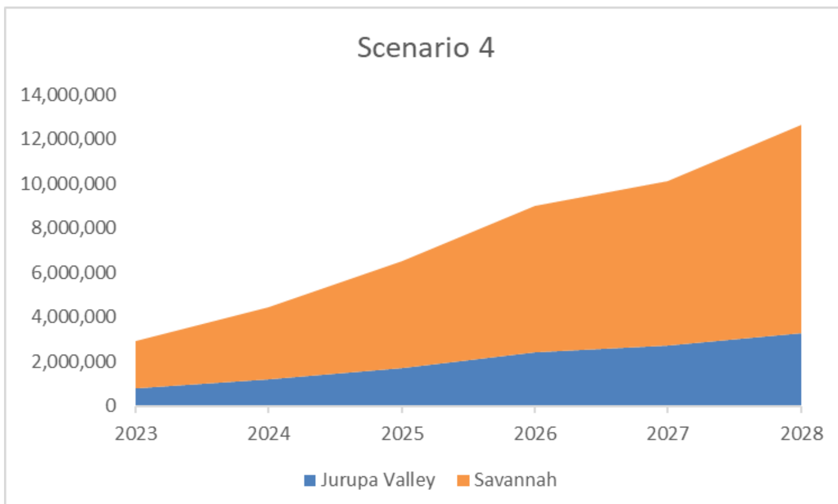


Figure 4.15: Distribution center storage capacity required per year in thousands of units scenario 4

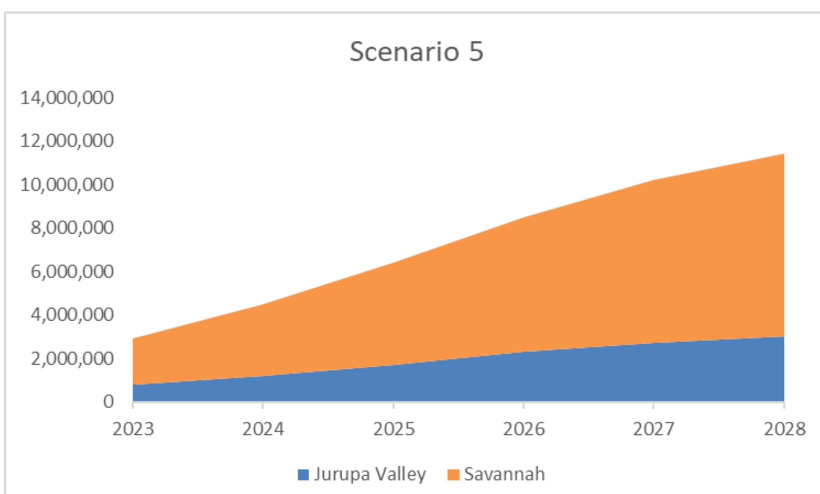


Figure 4.16: Distribution center storage capacity required per year in thousands of units scenario 5

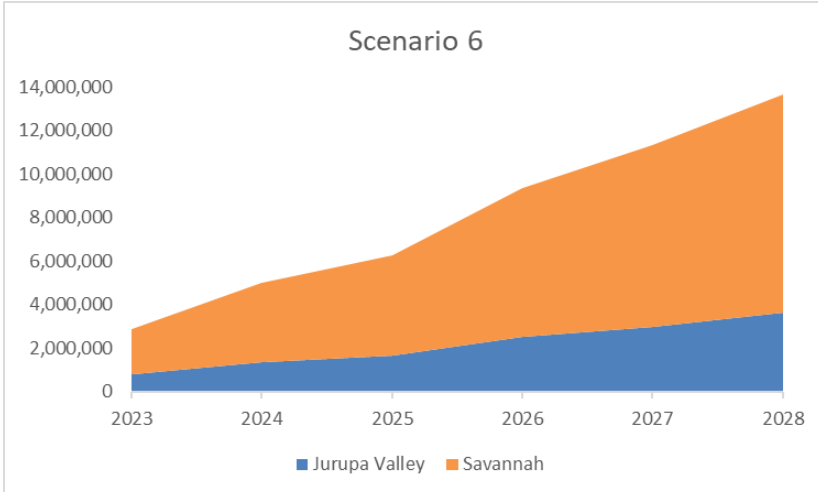


Figure 4.17: Distribution center storage capacity required per year in thousands of units scenario 6

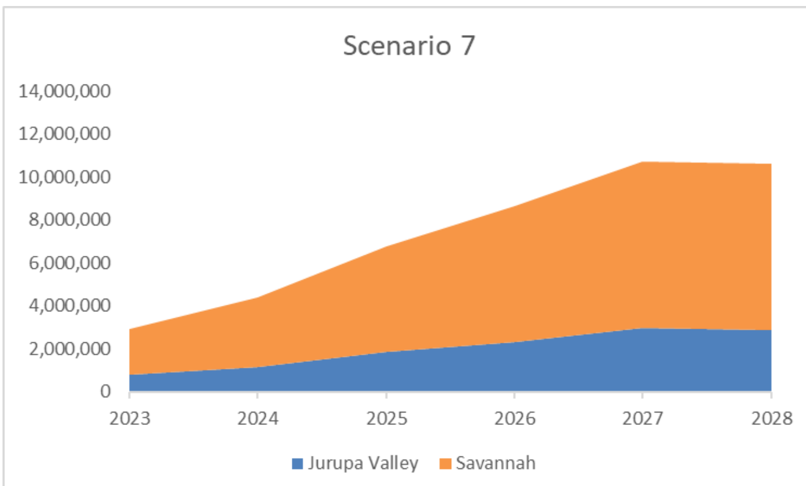


Figure 4.18: Distribution center storage capacity required per year in thousands of units scenario 7

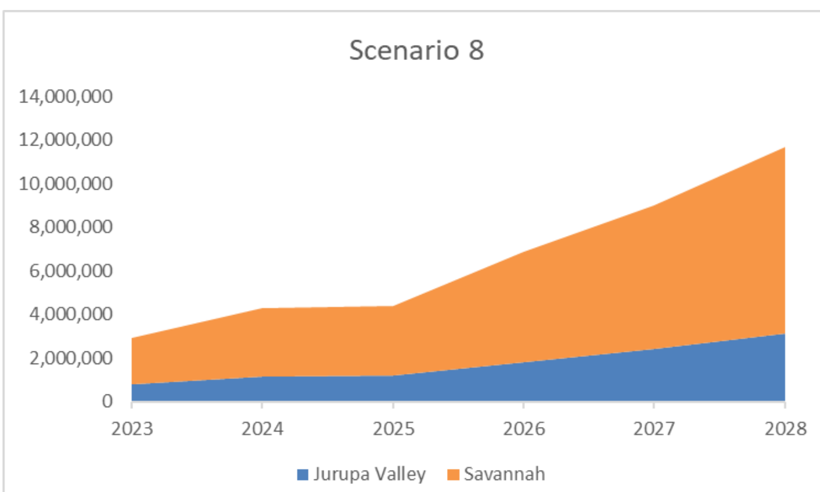


Figure 4.19: Distribution center storage capacity required per year in thousands of units scenario 8

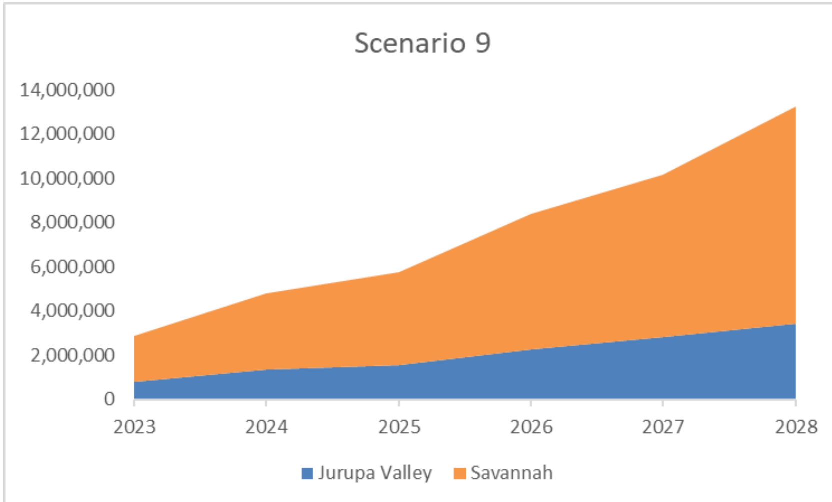


Figure 4.20: Distribution center storage capacity required per year in thousands of units scenario 9

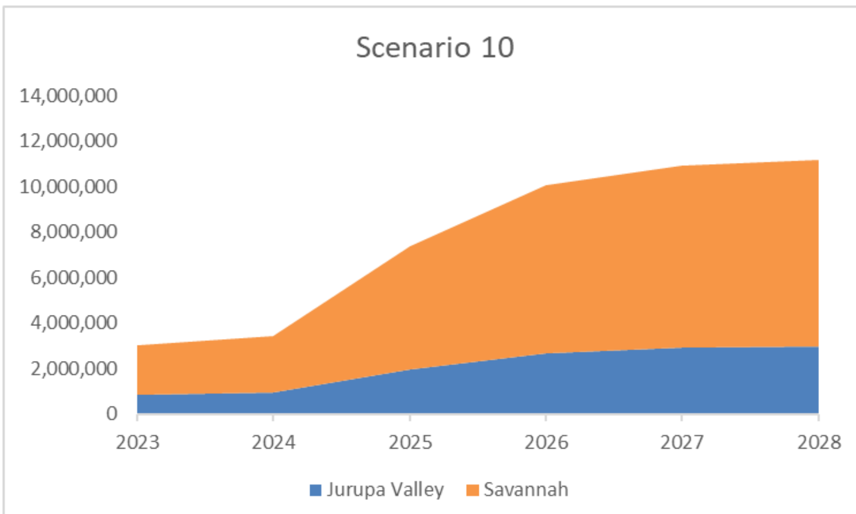


Figure 4.21: Distribution center storage capacity required per year in thousands of units scenario 10

The maximum daily storage capacity required in thousands of units during the planning horizon across all the stochastic scenarios for each distribution center is shown in Table 4.4.

DC	**Maximum daily storage capacity required in thousands of units during the planning horizon across all the stochastic scenarios**
Jurupa Valley	729
Savannah	2062

Table 4.4: Maximum daily storage capacity requirement in thousands of units during the planning horizon across all the scenarios for each distribution center

The team considers that SwiftHelper does not need to plan its distribution centers storage to fulfill the maximum storage capacity required shown in Table 4.4 since it would be more cost-efficient for the company to outsource storage capacity to cover punctual peaks.

Refer to Appendix 3, Scenarios 1 through 10, DC Inventory for the complete listing of distribution center daily inventory levels for each scenario from 2023 to 2028.

Task 3.1.5 Human-Centric Distribution Center Design

Task 3.1.5.(I)
The two designs assume that the distribution centers will receive pallets of different products. Each pallet is assumed to be single uniform SKU. The items will be sorted and consolidated according to each fulfilment center demand before being shipped out. For this task the team provided two designs of the distribution center with distinct characteristics described as follows.

For Design A – Receiving and shipping on the opposite sides, no cross aisles, and dedicated storage for both forward picking and bulk storage. The items are picked with the batch picking method.
For Design B – Receiving and shipping on the same side with cross aisles, dedicated storage in the forward pick area and shared storage for bulk storage. The items are picked with the cluster picking method.

Centers for design A

Receiving docks
The area outside the distribution center where the trucks will back up to the door and park. This area must account for the maximum number of trucks that the DC can experience at a single time.
Outbound docks
The area on the outside of the building itself, inside the facility where the trucks backup and park, and the sorted pallets are loaded onto. This center is outside the building and must be adjacent to the outbound loading area.
Unloading area
The unloading area takes the pallets out from truck into the building where they are prepared to be stored in the bulk storage area or fast pick area according to WMS determination.
Inspection area
A portion of the incoming pallets pass through this area to be checked by the inspectors. The criteria that inspectors check on will be based on weight, packaging guidelines, damages, label accuracy, and accurate quantities. If the pallets are verified, they are moved into bulk storage area. If they don’t pass the inspection criteria, they are moved to quarantine area.
Quarantine area
Any inspected items which don’t pass the inspection criteria will have to be placed in the quarantine area and then returned to the factory. The reason to separate is that to prevent QC failed items from being mixed into the system with QC pass products and for the inventory to be accurately monitored. Any items which are found later to be damaged are also placed here.

Bulk Storage
This is where most of the inbound would go to. It is a storage for incoming pallets with dedicated storage between all the SKUs. It has a convenient location to forward pick area. Size of this center is dependent on 99% robust inventory level of 2 months. It takes over 50% of the space of the facility. Picking from the bulk storage will only be for full pallet quantities.
Forward picking area
The fast-moving SKUs will be allocated here to reduce the cost of picking compared to picking from the storage. Pickers will pick from forward pick area less than pallet quantities (cases).
Sorting station
In this first design, the items picked will be done in a batch picking manner where the items need to be sorted later. In other words, each picker will be assigned to pick items for multiple orders, and they will then go to this station to sort each order independently.
Packing station
The sorted items are then moved to the packing station where the pallets are wrapped up with shrink and ensure they meet the packaging guidelines.
Outbound loading area
This is the area next to the packing station in which full orders are placed awaiting for the truck to back-up and load the order onto the trucks. This is also where the outbound team can also ensure correctness of the orders, time permitting.
Bathroom
According to Occupational Safety and Health Standards (OSHA). The number of water closets are given in the following table. The size of the bathroom must be scaled according to the number of workers needed to handle the demand.

Number of employees	Minimum number of water closets
1 to 15	1
16 to 35	2
36 to 55	3
56 to 80	4
81 to 110	5
111 to 150	6
over 150	1 for every 40 employees

Table 5.1 Bathroom requirements by OSHA

Office
The office space is the work area of the distribution center administration team as well as all white-collar workers that manage the people and resources of the DC. It is also used for hosting meetings, conducting trainings and storing documents. No material flow will be passing into offices.

Design A
The team prepared a flowchart for design A as a starting point in order to determine the movement of pallets inside the distribution center and the interactions between the different centers as shown in figure 3.5.1 below. The team then created abbreviations for each center and ranked the importance of having each center next to the other on a scale of A, E, I, O, U, X as

shown in table 3.5.4 below. For example, it is “absolutely necessary” to have the forward picking area next to the bulk storage in order to minimize the cost of restocking and to increase the number of movements an operator can do in a unit time. Absolutely necessary corresponds to 16 points, therefore since the block diagram had both centers next to each other, the design got 16 points for this factor. The team then added all the possible points for design A based on the block diagram in figure 3.5.2 below. The design obtained a score of 151/196 (77%) possible points.

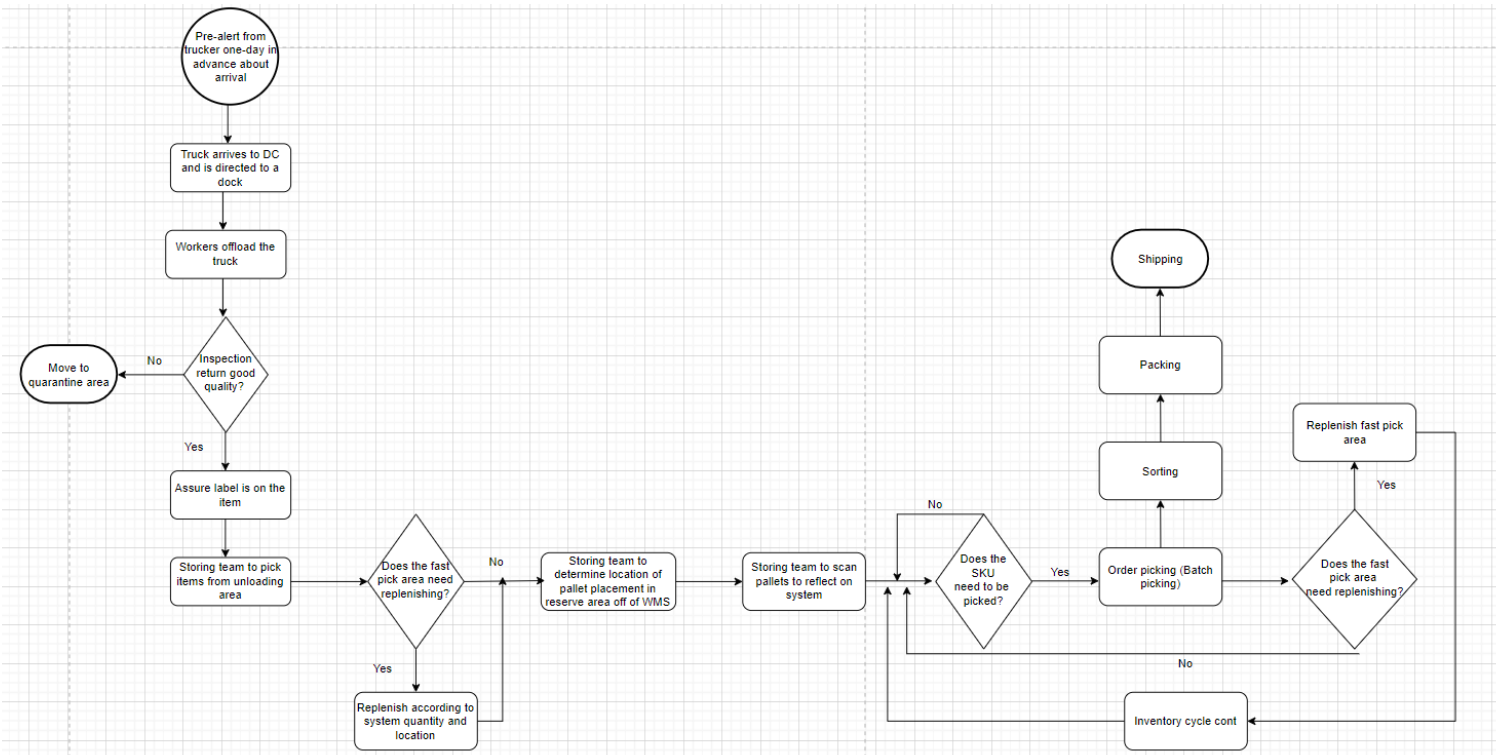


Figure 5.1 – Flowchart of the movements of SKUs in Design A

Station name	Letter abbreviation
Unloading area	A
Inspection area	B
Quarantine area	C
Outbound loading area	D
Bulk Storage	E
Forward picking area	F
Sorting station	G
Packing station	H
Bathroom	I
Office	J

Table 5.2 – Station names and letter correspondence

	A	B	C	D	E	F	G	H	I	J
A		A	E	U	I	U	U	U	I	O
B			A	U	E	U	U	U	I	I
C				U	I	I	U	U	I	I
D					O	I	E	A	I	O
E						A	E	O	I	O
F							E	E	I	O
G								A	I	O
H									I	O
I										I
J										

Table 5.3 – Muther's Relationship Chart for Design A

	A	B	C	D	E	F	G	H	I	J
A		16	0	0	4	0	0	0	0	1
B			16	0	8	0	0	0	0	0
C				0	4	0	0	0	0	0
D					1	4	8	16	0	1
E						16	8	1	4	1
F							8	8	4	1
G								16	0	0
H									0	1
I										4
J										

Table 5.4 – Muther's Relationship score for Design A

Abbreviation	Importance	Weight	Count	Max Score	Design Score	
A	Absolutely necessary	16	5	80	80	
E	especially important	8	6	48	40	
I	Important	4	15	60	24	
O	Ordinary	1	8	8	7	
U	Unimportant	0	11	0	0	
X	Undesirable	-80	0	0	0	
				196	151	**77%**

Table 3.5.5 – Design A grade based on qualitative relationships

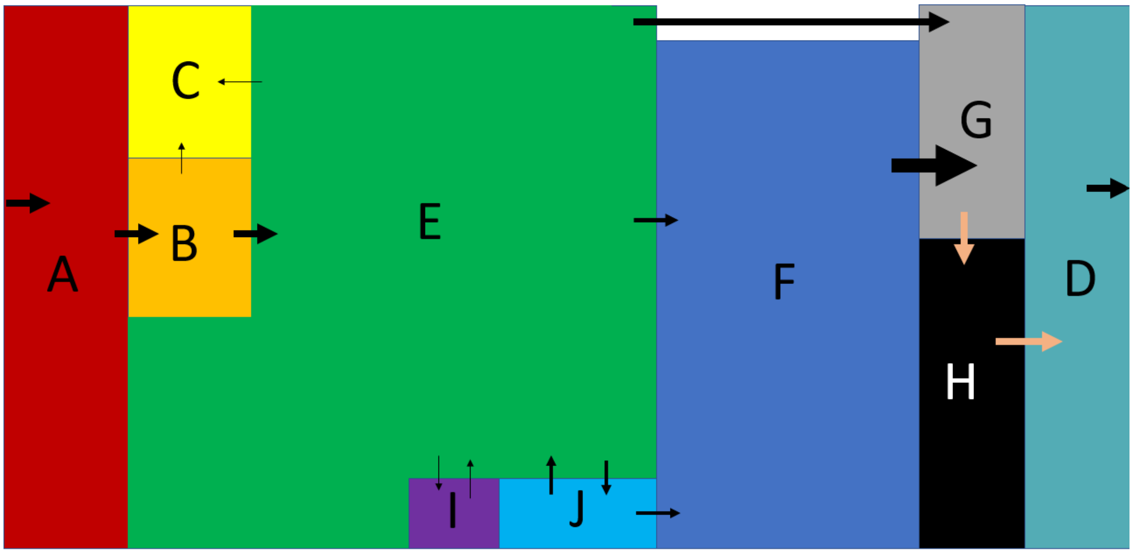


Figure 5.2 – Block diagram with flows for design A

Centers for design B

Unloading area
The unloading area is the place in which when the pallets are removed from truck are stored in the facility. A portion of them is then prepared to be taken into the inspection area or prepared to be stored in the bulk storage area or fast pick area according to WMS determination.

Inspection area
A portion of the incoming pallets pass through this area to be checked by the inspectors. The criteria that inspectors check on will be based on weight, packaging guidelines, damages, label accuracy, and accurate quantities. If the pallets are verified, they are moved into bulk storage area or forward pick area. If they don't pass the inspection criteria, they are moved to quarantine area.

Quarantine area
Any inspected items which don't pass the inspection criteria will have to be placed in the quarantine area and then returned to the factory. The reason to separate is that to prevent QC failed items from being mixed into the system with QC pass products and for the inventory to be accurately monitored. Any items which are found later to be damaged are also placed here.

Bulk Storage
This is where most of the inbound would go to. It is a storage for incoming pallets with shared storage between all the SKUs. It has a convenient location to forward pick area. The size of this center is dependent on 99% robust inventory level of 2 months and itt takes over 50% of the space of the facility. Picking from the bulk storage will only be for full pallet quantities.

Forward picking area
The fast-moving SKUs will be allocated here to reduce the cost of picking compared to picking from the storage. Pickers will pick from forward pick area less than pallet quantities (cases).

Packing station
After each order is picked individually, cluster picking method from the bulk/forward pick area, the pallets are then moved to the packing station where the pallets are wrapped up with shrink and ensure they meet the packaging guidelines.

Outbound loading area
This is the area next to the packing station in which full orders are placed awaiting for the truck to back-up and load the order onto the trucks. This is also where the outbound team can also ensure correctness of the orders, time permitting.

Bathroom
The number of water closets will be determined following the Occupational Safety and Health Standards (OSHA). The size of the bathroom must be scaled according to the number of workers needed to handle the demand.

Office
The office space is the work area of the distribution center administration team as well as all white-collar workers that manage the people and resources of the DC. It is also used for hosting meetings, conducting trainings and storing documents. No material flow will be passing into offices.

Equipment storage area
This is the place in the facility which all equipment are stored at the end of each shift. It will include the storage of all weighing scales, forklifts, pallets, motorized pallet jacks, excess racks, and any other equipment.

Design B
The team prepared a flowchart for design B as a starting point in order to determine the movement of pallets inside the distribution center and the interactions between the different centers as shown in figure 3.5.3 below. The team then created abbreviations for each center and ranked the importance of having each center next to the other on a scale of A, E, I, O, U, X as shown in table 3.5.6 below. For example, it is “absolutely necessary” to have the forward picking area next to the bulk storage in order to minimize the cost of restocking and to increase the number of movements an operator can do in a unit time. Absolutely necessary corresponds to 16 points, therefore since the block diagram had both centers next to each other, the design got 16 points for this factor. The team then added all the possible points for design B based on the block diagram in figure 3.5.4 below. The design obtained a score of 153/182 (84%) possible points. Therefore, design B is proven to be significantly better than design A in terms of closeness of centers and flow of pallets.

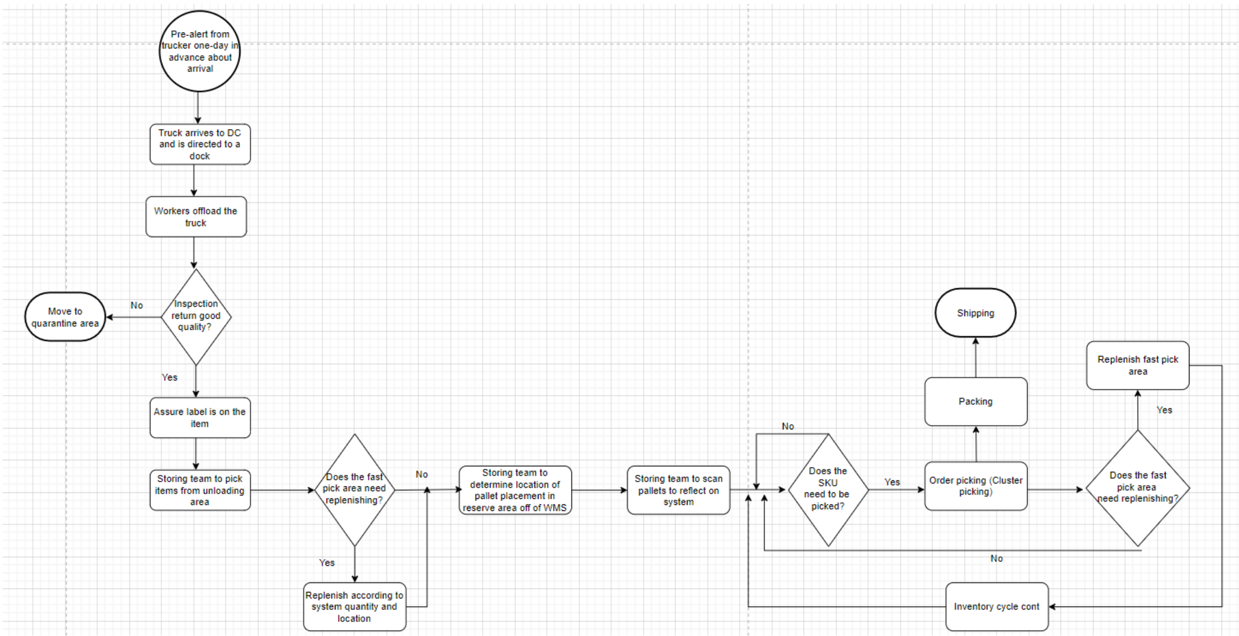


Figure 5.3 – Flowchart of the movements of SKUs in Design B

Station name	Letter abbreviation
Unloading area	A
Inspection area	B
Quarantine area	C
Outbound loading area	D
Bulk Storage	E
Forward picking area	F
Equipment storage area	G
Packing station	H
Bathroom	I
Office	J

Table 5.6 – Station names and letter correspondence

	A	B	C	D	E	F	G	H	I	J
A		A	E	A	I	U	O	U	I	O
B			E	U	E	U	U	U	I	I
C				U	I	I	U	U	I	I
D					O	I	O	A	I	O
E						A	I	O	I	O
F							I	A	I	O
G								U	I	O
H									I	O
I										I
J										

Table 5.7 – Muther's Relationship Chart for Design B

	A	B	C	D	E	F	G	H	I	J
A		16	8	16	4	0	0	0	0	0
B			8	0	8	0	0	0	0	0
C				0	4	4	0	0	0	0
D					1	4	0	16	0	0
E						16	4	0	4	1
F							4	16	4	1
G								0	4	1
H									4	1
I										4
J										

Table 5.8 – Muther's Relationship Score for Design B

Abbreviation	Importance	Weight	Count	Max Score	Design Score	
A	Absolutely necessary	16	5	80	80	
E	especially important	8	3	24	24	
I	Important	4	17	68	44	
O	Ordinary	1	10	10	5	
U	Unimportant	0	10	0	0	
X	Undesirable	-80	0	0	0	
				182	153	**84%**

Table 3.5.9 – Design B grade based on qualitative relationships

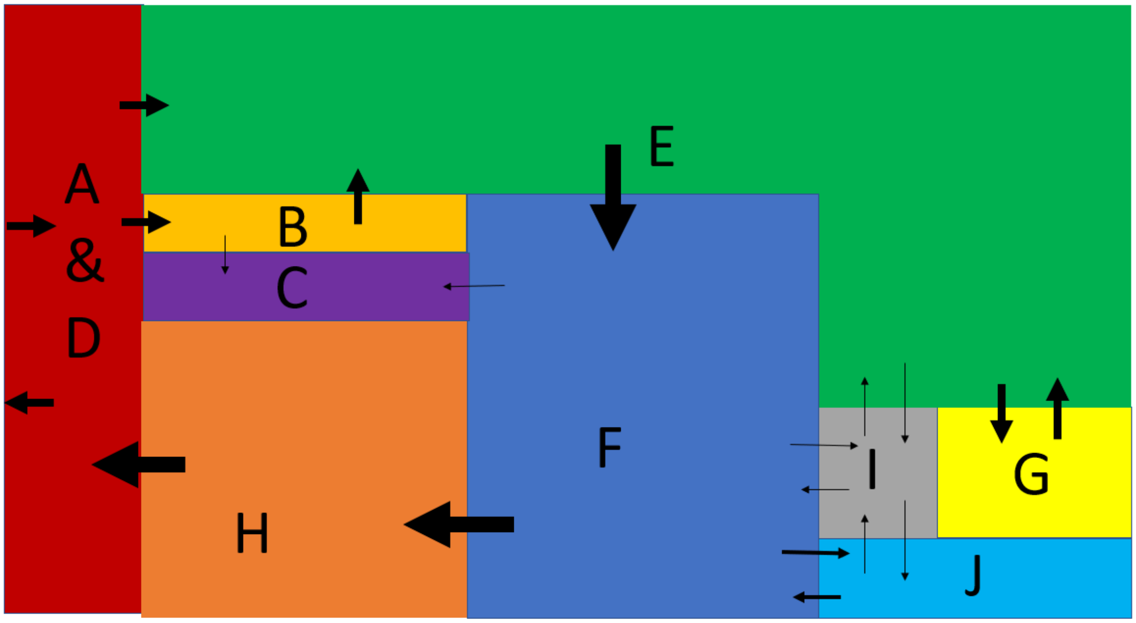


Figure 5.4 – Block diagram with flows for design B

Task 3.1.5.(II)

The team decided that in order to measure performance of the distribution center, the team needed to measure the performance of each internal team inside the DC and measure their contributions to the overall goal of the DC, shipping the right items, in the right quantities to the right place at the right time. The team broke up the DC team into three teams; First Mile – the team in charge of receiving the items, offloading from truck and inspections. The Put-away team – the team in charge of storing all the items and picking for dispatch. The last mile team in charge of on loading the pallets to the truck and pallet positioning inside the truck as well as routing to the FCs.

1. The key performance indicators for the First Mile Team are Receiving AHT, workers utilization, and QC accuracy.

2. The key performance indicators for put-away team are space utilization, worker utilization, AHT for moving item from receiving to storing, AHT for moving item from sorting to dispatch, IRA (Inventory Record Accuracy), and damage rate.

3. The key performance indicators for the Last Mile team includes SLA compliance (per each type of mover), success rate, damage rate, and rejection rate.

Task 3.1.5.(III)

Design A consists of receiving and shipping on opposite sides of each other. The distribution center will operate with no cross aisles and there will only be dedicated storage for all the SKUs.

The design will have a fast pick area where the SKUs of less than pallet ordered quantity will be picked and a bulk/reserve storage in which full pallets quantity are stored and picked from. Both the fast pick area and the bulk storage will be dedicated space. The team will perform a bang-for-buck calculation to compute the top products that have the biggest benefit from being stored in the forward pick area. Dual-cycle command will not be performed in design A as there are no cross-aisles and time to travel will be high as well as empty travel. The orders will be batch picked and a sorting station will be in place to sort all the orders picked into their respective orders.

Design B consists of receiving and shipping on the same side of the distribution center. The distribution center will also be different in the layout, in which cross aisles will be in place to ease and minimize time for dual command cycles. The bulk storage area will be dedicated storage for all the SKUs and the fast pick area will be shared storage for the SKUs that have a high enough bang-for-buck to be stored in the fast pick area. The orders in Design B will be picked using the cluster picking method in order to maintain order integrity and try to minimize the lead time for picking.

Product Placement

The team will use the same product placement strategy for both design A and B. The determination of which products to store in the fast-pick area will be determined by the bang-for-buck equation, meaning the products that return the most benefit from being given the convenient fast-pick area. The equation is given below:

$$\frac{sp_i - c_r d_i}{l_i}$$

where $p_i$is the number of picks for less-than-pallet quantities, $d_i$the number of pallets moved by such picks, $l_i$is the minimum number of locations required by SKU i in the fast-pick area, it saves s minutes when a pick is made from the forward area rather than from bulk-storage; and that each restock of the forward area (that is, each move of a pallet from reserve to the forward area) requires $c_r$minutes. The team will rank the SKUs from highest to smallest bang-for-buck and place them in the fast-pick area until pallet locations in the fast pick area are complete. The team will assume the number of savings and restocking minutes to be 2 and 4 respectively.

The SKUs that will be placed in the fast pick area will be given convenient locations in the reserve storage closer to the fast pick area to minimize the restocking minutes to the fast pick area. Then, products with high demand will be placed closer to the packing station.

Quantity Placement

The team will use the same quantity placement strategy for both design A and B. The quantity placement is for products that have already been determined to be placed in the fast pick area. The determination on the number of pallets to place in the forward area is done by estimating the minimum and maximum number of pallet locations for each product. If the bang-for-buck is larger for the minimum, then the minimum is placed, if it is larger for the maximum then the maximum is placed as shown in the equation below:

$$\frac{sp_i - c_r d_i}{l_i} > \frac{sD_i + c_r d_i}{u_i}$$

Where Di the number of pallets moved by full-pallet picks, ui be the maximum number of forward locations. The team estimated the minimum number of pallets for each SKU with respect to demand and the amount to account for safety sock. The maximum number of pallets to be stored was determined by the maximum the DC can receive per SKU.

Task 3.1.5.(IV)

Procedure

1. **First Mile**
    i. The manufacturing facility sends a notification alert to the DC one day in advance stating the items they will deliver to the DC as well as the time window of which the DC should receive the items.
    ii. The shift leader is required to acquire the data of all items that will be delivered next day from the manufacturers and allocate resources accordingly.
    iii. The First mile (FM) team is required to direct the driver to the dock station (receiving dock) when he arrives.
    iv. If the driver does not adhere by the time window and there are other drivers waiting to deliver their items; the driver is required to wait until all other drivers are done.
    v. Two members from the FM team are required to offload all pallets of the truck using a forklift.
    vi. A FM specialist is required to check if the item follows the specified packaging guidelines, meaning pallets are sealed with shrink wrap and cases are closed.
    vii. If the item follows the specified guidelines, FM specialist is required to check the packaging box on the hand-held device. A QC check is made on 10% of the shipment, if it is of good quality, the FM specialist is supposed to place the labels on the items which includes: Pallet ID, Order ID, FC Destination, and Vendor and scan them in order to reflect on the system as **DC - Received**.
    viii. If the item follows the specified guidelines, FM specialist is required to check the packaging box on the hand-held device. A QC check is made on 10% of the shipment, if it is of poor quality, the FM specialist is supposed to document the reason for rejection in the receiving document, load the item back on the truck if the driver is returning to origin or place in the quarantine area and reflect as **DC - Rejected**.
    ix. If the item does not follow the specified packaging guidelines, FM specialist is required to label the item as “packaging required” for the packaging team to fully package the pallet.
    x. If the item has a status of **DC – Rejected** the system is supposed to automatically open a ticket to manufacturer with the rejection reason

mentioned.

xi. The key performance indicators for the First Mile Team are Receiving AHT, workers utilization, and QC accuracy.

2. Put away & Picking

xii. If the item reflects on the system as **DC – Received**, system notifies and alerts the Put away & Picking team supervisor for picking from the dock station.

xiii. Put away member is required to check the system which showcases the dock station number pallets are in, item ID, package needed or not, and location of placement in the DC.

xiv. If the item is labeled "packaging needed", packaging team to obtain item from the dock station perform packaging and document on the system for billing to the manufacturer and then move to the storage area.

xv. If the item is not labeled as "packaging needed", DC team to obtain item from the dock move to the storage area through forklifts.

xvi. Put away team member to check the system for determination of item placement in the DC.

xvii. Facility supervisor to have the location clean and ready for when items arrive for storing.

xviii. Put away team member to store the items in the specified location according to system determination. Put away Supervisor to overlook placement of items according to system determination.

xix. Put away specialist to scan the items for it to reflect on the system as **DC – Allocated**.

xx. Once the status is reflected to the DC as **DC – Scheduled** when an order is made, and LM planner hands over the delivery run to SC - through the system; picking team to determine the location of the items, pick the pallets on the delivery run one night in advance, and place the items on the dispatch area number mentioned on the system.

xxi. The key performance indicators for Put away team are space utilization, worker utilization, AHT for moving item from receiving to sorting, AHT for moving item from sorting to dispatch, IRA (Inventory Record Accuracy), and damage rate.

3. Last Mile

xxii. Once the FC confirms the delivery, the LM team changes the status of the item on the system to **DC – Scheduled**. The LM planner then prepares a plan off an LMS with items in delivery run based on CBM, material fragility, region, and volume and include in the form delivery run number (this indicates truck).

xxiii. LMS to then inform the trucking agency of the delivery run to ensure they received the information and assign the drivers.

xxiv. Once the picking team places the items in the specified dispatch area number, the LM team then scans the items and onloads the items in the truck. The truck must enter the DC from the LM area which is closest to the dispatch area. Once scanned, the system will reflect the item status as

DC – In Transit.

xxv. The LM supervisor then ensures that the driver has on the system the pallets with Pallet ID, delivery location, VR, and POD.

xxvi. **Customer Confirms** – The driver then updates the system which reflects to the LM supervisor of delivered pallets.

xxvii. The key performance indicators for the LM team includes SLA compliance, Success Rate, damage rate, and rejection rate.

<u>Task 3.1.5.(V)</u>

For the distribution center to operate efficiently, capture key performance indicators, and apply changes to enhance operations; some systems need to be put in place. These systems will help management drive changes and provide full visibility for how the floor is operating.

Technology	Usage and benefit	Price of installation
WMS	A warehouse management system is needed in order to determine accurate arrival and departure of all pallets in the system. This is also where the logic for product placement and quantity for the forward pick area is placed. It helps manage inventory inside the DC and move products inside in order to maximize efficiency and increase throughput. Some key performance indicators that can be captured from a WMS is receiving AHT, average time in system, AHT for moving items from receiving to sorting and sorting to dispatch, and average picks per hour.	$25,000
LMS (Logistics Management System)	A logistics management system is used mainly for the dispatch of orders to the fulfillment centers. A LMS will provide the vehicle routing that minimizes costs, connects and informs 3PLs of their deliveries. An LMS gives the team a clear and live view of all trucks on the road, the system also has all proofs of delivers and all delivered orders.	$15,000
ERP	The enterprise resource planning software will receive the notifications when orders are being sent to the DC and receive orders from the FC. ERP system will help forecast demand,	$50,000

	improve inventory planning, vendor relationship management, and procurement management. It will be the focal system between the DC, manufacturer and FCs.	
LMS (Labor Management System)	A labor management system is used in order to record attendances of all the workers inside the distribution center. It helps set shifts for all the workers and report real-time performance visibility.	$10,000

Table 5.10 - Technology requirements

All three systems must be integrated, and information must sync from one system to another. When incoming orders are processed in the ERP and after resource planning is achieved, the orders will sync into the WMS. The WMS will be the start point for on-ground operations and this is where orders will be scanned as received and used for inventory management throughout. When orders from the FCs are received in the ERP, a trigger is sent to the WMS to sync the order into the LMS in which planning is performed to get the orders ready for picking and dispatch.

<u>Task 3.1.5.(VI)</u>

Storage capacity

It is assumed that the DC has to handle all the incoming shipments and no third-party vendor will be used to help with the excess demand. The overall storage capacity requirement for each year is calculated from the maximum inventory level of each year.

Year	Maximum Inventory level (units)
2023	561278
2024	743953
2025	1089891
2026	1020586
2027	1178004
2028	1476404

Table 5.11 - maximum inventory of each year for scenario 1 of 3.1.4

Inside the distribution center, the items are stored in pallet quantities instead of the unit quantities. Thus, the number of pallet positions required needs to be estimated. The number of units inside one pallet is calculated by taking the standard size of the pallet (L*W*H) = (48’’ * 40’’ * 48’’) and fit as many cases as possible inside this dimension. The number of cases per pallet of each product category is given below.

Category	L (in)	W (in)	H (in)	Cases/pallet
A	24	16	12	24

B	12	12	8	72
C	24	16	8	36
D	12	12	12	48
E	4	4	4	1440
F	8	8	4	360
G	12	12	12	48
H	4	4	4	1440
I	12	12	4	144
J	4	4	4	1440
K	20	12	12	24
L	24	12	12	24
M	24	16	8	36
N	16	16	8	54
O	16	16	16	27
P	20	12	12	24
Q	24	16	8	36
R	4	4	4	1440
S	16	16	16	27
T	20	16	16	18
U	24	12	12	24
V	16	16	4	108
W	8	8	4	360
X	20	12	12	24
Y	12	8	8	120

Table 5.12 - number of items per pallet for each product category

Our team found that the average items per pallets for any scenario is approximately 43 items per pallets. Thus, this number will be used to convert the quantities in units to quantities in pallets. The maximum inventory level in pallet quantities is given in the table below.

Year	Maximum inventory level in pallet quantity									
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
2023	13511	13495	12855	12276	11850	13947	12749	14204	17641	15464
2024	14398	23372	22306	16817	22656	17704	24631	22761	16351	15479
2025	22820	27355	24570	31952	25083	22689	24514	20479	21619	47948
2026	24992	29182	23109	27263	22281	29268	28760	21115	22228	44149
2027	30123	40949	31565	31558	33392	33798	40911	22775	21233	41746
2028	37164	47518	36867	41906	39897	32891	36360	39087	34361	37338

Table 5.13 - maximum inventory level for each scenario

Throughput and inventory is calculated from file Task 5 Inventory level for each scenario_working.xlsx

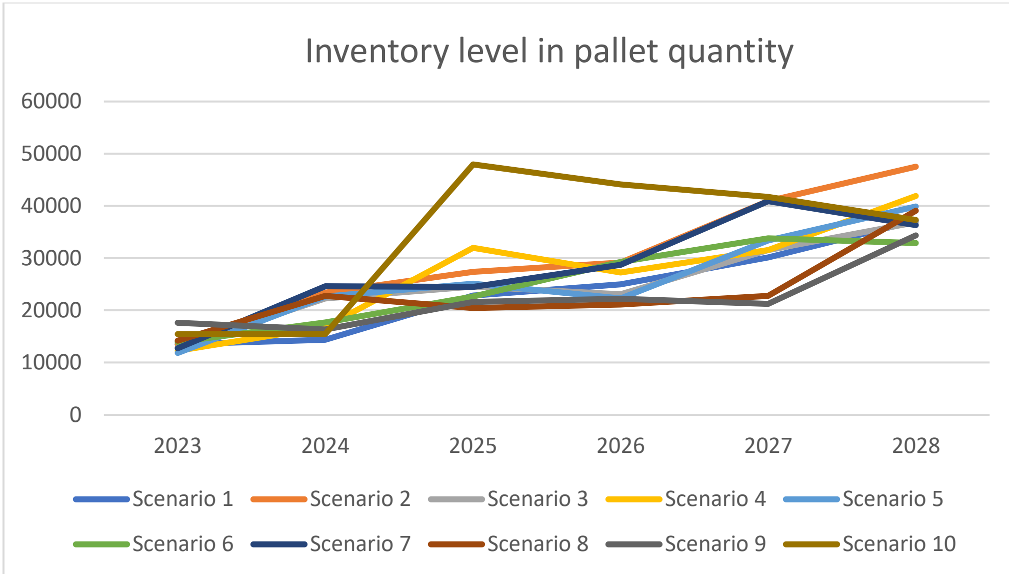


Figure 5.5 - Graph showing maximum inventory level

Throughput capacity

The number of pallets that the distribution center must handle in each day will be used to calculate the requirement of the equipment and personnel. In order to obtain this number, we take the average daily demand of the distribution in each year and each scenario. Since the fulfilment centers have the robust inventory level to achieve autonomy. It is assumed that the peak demand on the distribution center can be aggregated to be on average level. Thus, the team concluded to use the average daily demand in pallet quantity to measure the throughput capacity that the distribution center need to have. Given that the distribution center receives items in pallet quantity and ships out as pallets. The base unit to consider is the pallet unit.

Year	**Maximum throughput level in pallet quantity**									
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**	**Scenario 8**	**Scenario 9**	**Scenario 10**
2023	2068	2282	2235	2236	2201	2212	2241	2224	2183	2271
2024	3394	3841	3812	3781	3887	4430	3792	3716	4105	2709
2025	5567	5970	5715	5827	5822	5664	6114	3740	5159	6732
2026	8414	8649	7876	8342	7794	8691	8032	6299	7684	9437
2027	9885	10070	9553	9480	9551	10580	10036	8338	9280	10227
2028	11825	12724	10510	12057	10738	12935	10034	10974	12670	10451

Table 5.14 - average throughput level for each scenario

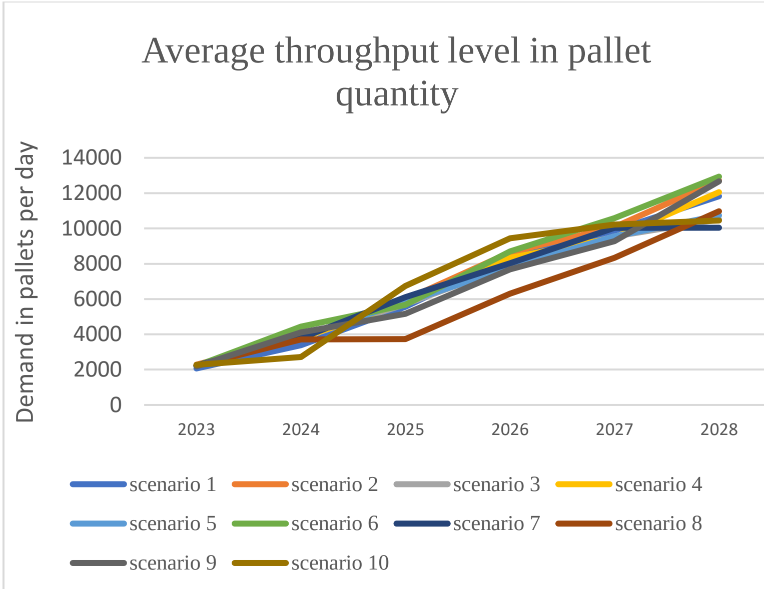


Figure 5.6 - Graph showing average throughput level

Task 3.1.5.(VII)

The main inputs for the resource model are the maximum inventory level and average throughput obtained from the previous task 3.1.5.vi. The model takes input from each scenario and calculate the number of required resources based on the estimated capacity of each resource. For this casework, the example calculation of scenario 1 during year 2023 is provided.

Equipment requirements

Model for equipment required is based on the estimation of the capacity of each equipment in term of pallet unit per hour. Some equipment capacity is limited by other equipment which it has to be used in combination with. For example, the scanner for the bulk storage area is used in combination with the motorized pallet jack to retrieve items from the shelves. The actual capacity of the scanner can be much higher than the 4 pallet per hour, but it is limited by the capacity of the motorized pallet jack.

The requirement for racks in bulk area and the flow racks in the forward area are calculated separately since they are calculated based on the maximum inventory level per year instead.

Workforce requirements

The workforce requirements consider the number of operators from the equipment requirement. Each equipment is assigned an operator if there’s a need for labor to operate it. With every 5 workers for the workstation, there needs to be one supervisor.

Center	Equipment	Type	Capacity (Pallets/hr)	Units required	Cost	Total cost	Operator	Required operators
Unloading area	Forklift	Equipment	52	3	30,000	90000	1	3
Unloading area	Dock doors	Equipment	52	3	1,500	4500	1	3
Unloading area	Scanners	Equipment	52	3	2,000	6000	1	3
Inspection area	Scale	Equipment	200	1	1,200	1200	1	1
Inspection area	Pallet jack	Equipment	200	1	400	400	1	1
Inspection area	Scanners		200	1	2,000	2000	1	1
Quarantine area	Pallet jack	Equipment	400	1	400	400	1	1
Outbound loading are	Forklift	Equipment	35	4	30,000	120000	1	4
Outbound loading are	Dock doors	Equipment	35	4	1,500	6000	1	4
Outbound loading are	Scanners	Equipment	35	4	2,000	8000	0	0
Bulk Storage	Racks	Storage	15	766	400	306400	0	0
Bulk Storage	Forklift	Equipment	26	5	30,000	150000	1	5
Bulk Storage	Motorized Pallet jack	Equipment	4	33	4500	148500	1	33
Bulk Storage	Tote cart	Equipment	4	33	1000	33000	0	0
Bulk Storage	Scanners	Equipment	4	33	2,000	66000	0	0
Forward picking area	Flow rack	Storage	9	226	1500	339000	0	0
Forward picking area	Motorized Pallet jack	Equipment	8	17	4500	76500	1	17
Forward picking area	Scanners	Equipment	8	17	2,000	34000	0	0
Sorting station	Manual put wall	Equipment	5.8	23	1500	34500	1	23
Sorting station	Sorting station	Equipment	5.8	23	500	11500	1	23
Packing station	Label printers	Equipment	5.8	23	1000	23000	0	0
Packing station	Forklift	Equipment	52	3	30,000	90000	1	3
							Total	125
Bathroom	Bathroom	Equipment				0		
Office	Computers	Equipment				0		
	Printers	Equipment				0		
	Desks	Equipment				0		
	Chairs	Equipment				0		
						1550900		125

Table 5.15 – Equipment requirements and number of workers

Center	Operator	Supervisor	Total salary
Bulk Storage	38	8	3959520
Forward picking area	17	4	1827920
Inspection area	3	1	467200
Outbound loading area	8	2	1062880
Packing station	3	1	362080
Quarantine area	1	1	210240
Sorting station	46	10	4835520
Unloading area	9	2	1162160
Total	125	29	13887520

Administration team& Maintenance team	24	80000	1920000
Security	4	113880	455520

Total labor cost per year	30150560

Table 5.16 – Team size for each center

To account for administration team, 15% for the total operators and supervisors are calculated to be the number of administration team while the there will be one security personnel for every 50 people inside the facility. In total, there are 193 SwiftHelper at the site.

Space requirements

The space requirement model is divided into two categories: the workstation and the inventory. The workstations are the centers where the items flow through without needing to be stored and the inventory are the centers where there need to be a storage capacity for keeping the stock. The workstations centers space requirement will be calculated based on Little's law.

$$L = \lambda W$$

Where L is the queue length (pallet positions requirement), lambda is the throughput, and W is the estimated process time on each workstation. The processing time per pallet unit at each station was estimated in term of hours and them multiplied by the average throughput per day obtained from task 5 to get the queue length in the workstation. This queue length represents how many pallets will be in the workstation. The pallet number is used to calculate the space needed for each center by multiplying the estimated space needed per pallet.

The inventory centers include the bulk storage and the forward picking, these two stations need storage positions based on the maximum inventory level each year. The calculation for space requirement is based on multiplying the ground space occupied by the pallet. For example, bulk storage has 5 pallets high stack, thus, the ground space required for each pallet is divided by 5. The percentage of pallets allocated to the bulk storage is 85% of maximum inventory and the percentage for forward picking is 15%

Finally, to account for the office spaces, bathrooms and inter centers aisle, the total space obtain from the model is multiplied by the factor of 120%.

Center	Type	Pallets in the location a given time	UPH	Processing time	Requirement per pallet		Total Space needed (sqft)
					Space occupied by pallet	Aisle/ Processing area	
Unloading area	Workstation	-	52	0.0192308	13.3	26.67	1061
Inspection area	Workstation	-	200	0.005	13.3	26.67	276
Quarantine area	Workstation	-	400	0.0025	13.3	26.67	138
Outbound loading area	Workstation	-	34.7	0.0288462	13.3	26.67	1591
Bulk Storage	Inventory	85%		-	2.67	2.67	61250
Forward picking area	Inventory	15%		-	4.44	8.89	27022
Sorting station	Workstation	-	6.67	0.15	13.3	26.67	8272
Packing station	Workstation	-	70	0.0142857	13.3	26.67	788
						Total Space	100397
						Adjusted space	120476

Table 5.17 - space requirement model
(Scenario 1: Throughput = 2068 units/day, max inventory = 13511 pallets)

Space requirement is calculated from: Task 5 Space requirement.xlsx

Utilities requirements

Typically, the average warehouse without air-con systems will use around 6.1 Kilowatt-hours of energy per square foot annually. The total energy consumption is estimated from the total area of the warehouse building excluding the docking area outside the building. With total space of 120476 square foot for the building at year 2023, the total electric consumption per year for scenario one at year 2023 is 6.1 * 120476 = 734,903.6 kWh or $110,235.54 per year (based on $0.15 per kWh)

Financial Requirements

Financial requirements are based on the operating cost of the distribution center and the investment of equipment and building. The financial requirements of the distribution center at year 2023 is given below.

It can be observed that the investment is significantly lesser than the operating cost since the design is very human centric which leads to high labor cost.

Financial requirement is calculated from Task 5 Resource requirement_working.xlsx

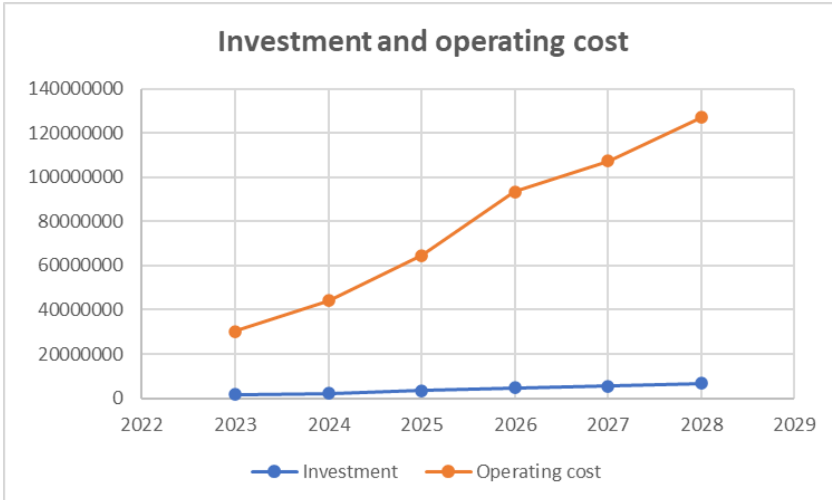


Figure 5.7 Operating cost and investment of DC

Year	Investment in USD	Operating cost in USD
2023	1550900	30150560
2024	2207500	44256400
2025	3451200	64681080
2026	4763400	93466240
2027	5531000	107490320
2028	6726100	126992280

Table 5.18 Operating cost and investment of DC

Task 3.1.5.(VIII)

Site Layout

The facilities in the site are same for both design but the arrangement and size of them are not the same. Since the design A will have the inbound and outbound at the opposite side and the design B has the inbound and outbound at the same side. The facilities inside the site and the site layout are given below. The size shown in the layout is in the unit of 10 feet.

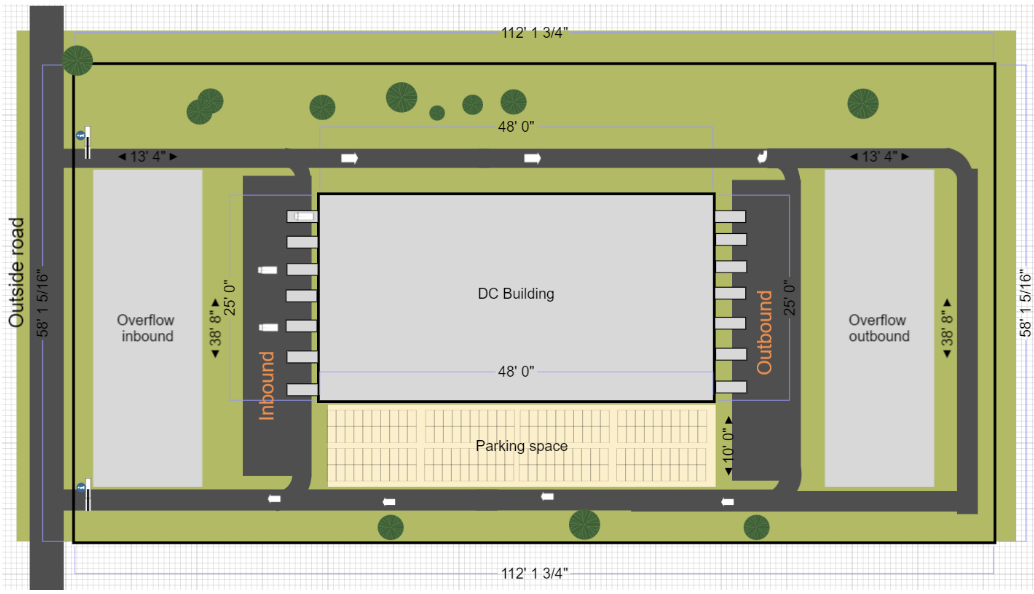


Figure 5.8 Site layout of design A

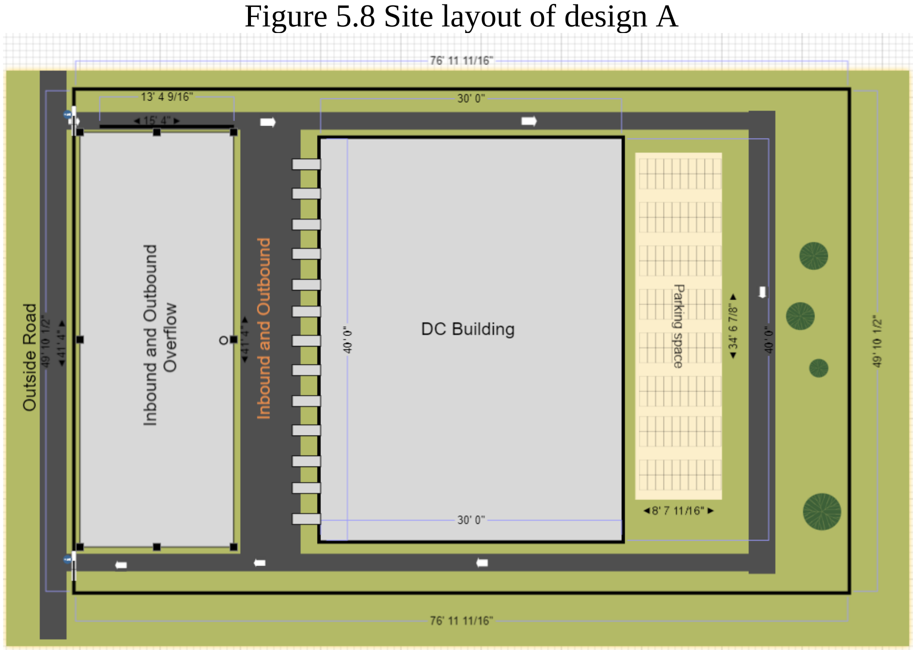


Figure 5.9 Site layout of design B

Inbound and Outbound dock
The truck is designated to move only in one direction inside the warehouse. The trucks enter the dock area from the north and exit at the south

Building
The DC dimension is determined from the total space requirement in 3.1.5. The length of the building in design A is greater than length from design B, resulting in longer rectangle shape. The building in design B has more balance between the length and width of the building.

Gate
To ensure the security of the area, there need to be security check for the incoming trucks. The perimeter of the site is fenced and monitored with CCTV and security team. There are two gates for the site: one for entry and another for exit.

Overflow Inbound/Outbound
Since the delivery time can be uncertain, there need to space for trucks which have schedule conflict.

Parking space
Total number of parking slot is calculated by the number of workers multiplied by 120% to have enough parking space to accommodate any visitors or vendors.

Facility layout

In this casework, facility 3D layouts are created in Sketchup and are not drawn to the exact scale of the size requirement of the center, but the relative location of each center remains accurate. Each center is painted in the same color of its color in the block diagram.

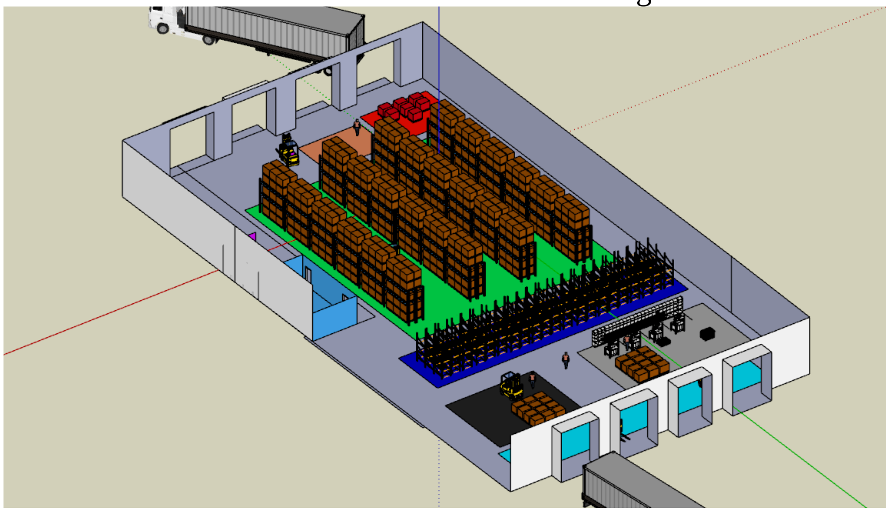


Figure 5.10 - 3D module layout of Distribution Center Design A

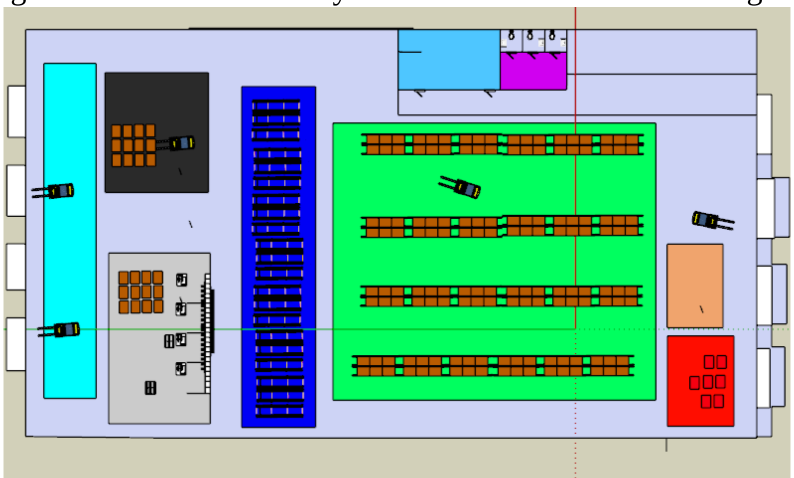


Figure 5.11 Top view of 3D module layout of Distribution Center Design A

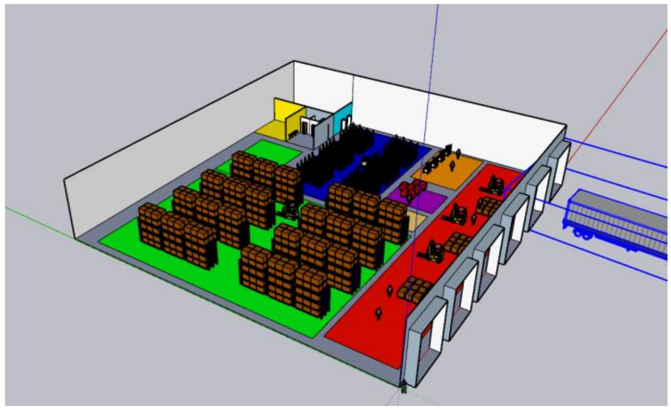


Figure 5.12 - 3D module layout of Distribution Center Design B

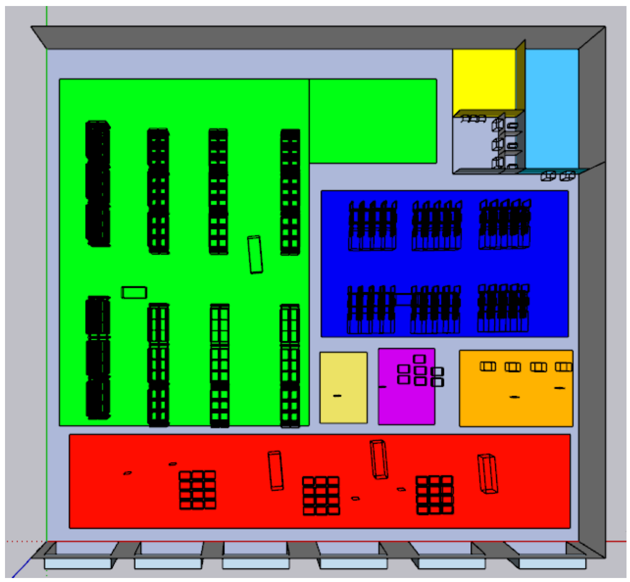


Figure 5.13 - Top view of 3D module layout of Distribution Center Design B

Center level

Design A

Forward picking center

This area is reserved for items which have high demand with the goal to enable faster and cheaper picking compared to slow moving items. From the graph below, all SKU are ranked by their demand in year 2023 (deterministic case). The top 100 SKUs contributes to approximately 63% of the total demand in year 2023. Our team determined that the forward picking area should have at least 100 locations for the module. The assignment for the products is dedicated storage where one position on the rack is reserved for a single SKU.

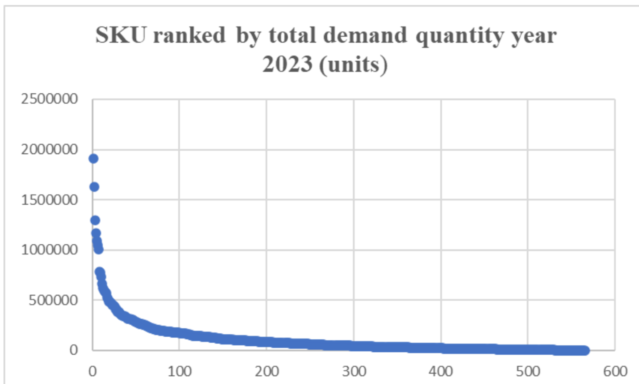


Figure 5.14 - Graph showing SKU ranked by their yearly demand

Since the replenishment of the SKUs in the forward picking area is done by the pallet. The flow racks which are used for the forward area have to be large enough to store a pallet on it. Each flow rack has 3 level and 3 pallets deep. The width and the length of each flow rack is 120’’ * 48”.

With the 100 SKU locations, the total area of the flow rack is 4000 sqft. The total pallet locations for the forward location have to be at least 300 pallets.

For the detailed slotting of the SKUs, each SKU will be judge by the bang-for-bucks equation for product placement in Task 3.1.5.iii

Bulk storage center

Size of the bulk storage center is calculated from the total inventory needed subtracted by the number of pallets being on the forward picking location. The aisle size of the center is approximate to be 2 pallets length or 96 inches wide.

The convenient locations for locations in the storage area is calculated from the rectilinear distance to each location from the receiving and packing area. The starting point is at the middle of the aisle and assumed be 0. Traveling in the horizontal will be 48 inches per cell and traveling in the vertical distance will be 40 inches per cell.

In design A, the convenient locations for the put-away operation are the same for the picking operations. For the replenishment at forward picking area, the design A will have the same convenient locations as the picking operation where the design B will have different convenient locations due to the forward area being situated to the side of the bulk storage.

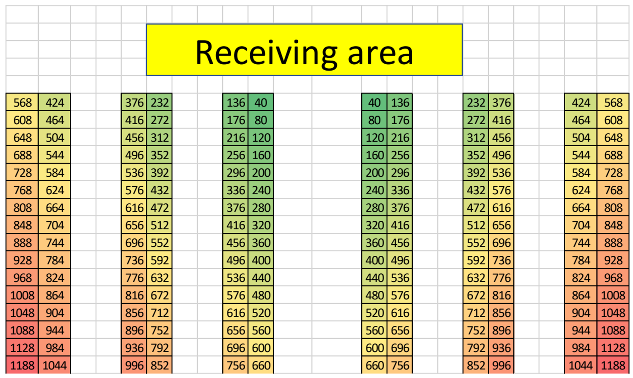


Figure 5.15 - Convenient locations for put away operation

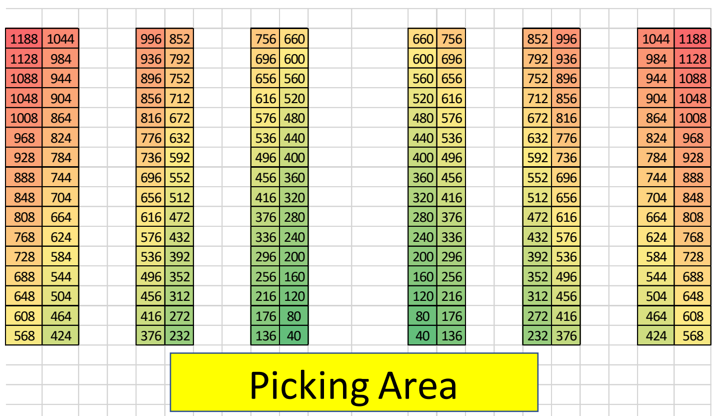


Figure 5.16 - Convenient locations for picking operation.

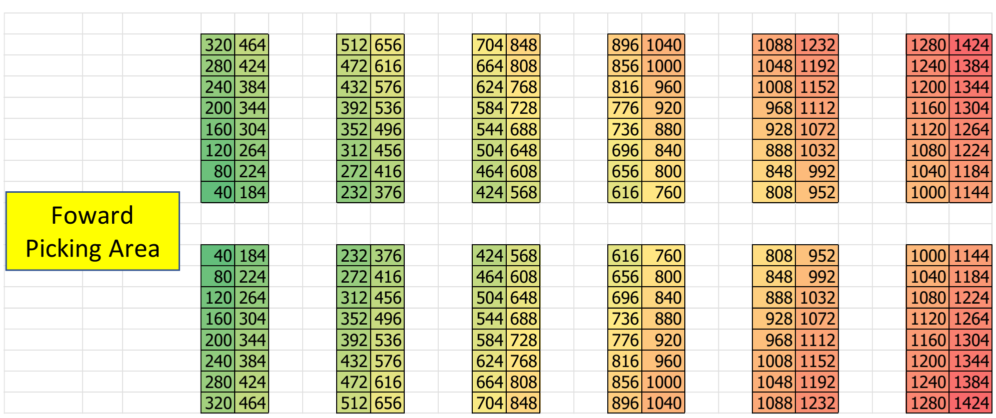


Figure 5.17 - Convenient locations for forward pick replenishments in design B

Sorting center

Size of one block on the put wall is calculated by the biggest size of the case. The biggest possible size for a single item is (24’’x 16’’ x 16’’), thus, the block size is set at (30’’ x 30’’ 30’’) size in order to facilitate the movement of the cases in and out of the block.
According to number from an apparel company’s DC in Georgia, the output of one worker at the sorting location is 300 units per hour (UPH). This number will be used to calculate the size of the put wall and the number of workers need for the sorting location.

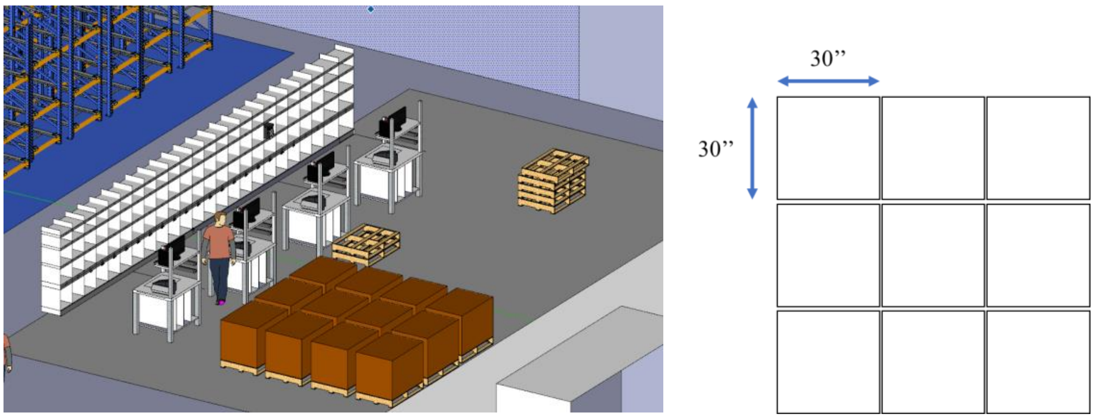


Figure 5.18 - 3D layout of Sorting station of design A and Size of the put wall

Office spaces and toilets

The number of bathrooms needed are scaled according to the OSHA standards. The number needed is dependent on the total number of employees. The requirements are given in the table below.

Number of employees	**Minimum number of water closets**
1 to 15	1
16 to 35	2
36 to 55	3
56 to 80	4
81 to 110	5
111 to 150	6
over 150	1 for every 40 employees

Table 5.19 OSHA requirements

Inbound area
Since the incoming shipments from manufacturers are in 40 ft container which has the external dimension of 40' long x 8' wide x 8' 6” high. The dock door in the inbound area has to be at least 8’ wide and 8’6’ high in the design A whereas in design B where the inbound area and outbound area are shared, the dock door need to be at least 9’ 6’’ high and 8’ 6’’ wide to accommodate the 53ft high-cube containers which are used to shipped items to the fulfilment centers.

Outbound area
The size of the outbound area is proportional to the inbound area with the factor of 152% The calculation of the outbound area size can be derived by the ratio of the loading time compared to the loading time. It is assumed that the flow of SKUs and out of warehouse must be the same which means that if the loading operation is slower, it needs more resource allocation in order to achieve the same level of unloading the SKUs otherwise there would be an accumulation of pallets inside the distribution center building. The loading time of each pallet is assumed to be 1.72 minutes. Thus, the outbound area needs more equipment, labor, and area than the inbound area by 52 percent

Task 3.1.5.(IX)

The team designed the two distribution center designs in Simio in order to compare the key performance indicators that the team chose in task 5.2. Simio is an object-oriented language that helps one simulate models and processes and observe how they perform in steady state. Experiments were generated for both designs to account for uncertainty and witness how both systems will perform. The team made assumptions regarding process times for centers, however, the team kept the same assumptions for both design for the design of experiments law to hold true (changing one factor at a time). The team treated each entity entering the system as a pallet. The team assumed 52" trailers that hold 26 pallets double stacked for a total of 52 pallets arriving at a single time. Moreover, the team assumed that 10% of the pallets will be inspected. From those inspections, 5% will be sent to the quarantine area as damaged and 95% will be moved to bulk. The team also assumed that when coming to pick from the forward picking area and bulk storage that 2% of the pallets will be damaged and need to be sent to quarantine area. The team added a logic in the simulations for both designs that capture that pallets aren't packed unless all the pallets for a specific order have arrived. The team created random order combinations in Simio. One of the main differences between the two designs is Design B doesn't have a sorting station due to cluster picking instead of batch picking. Moreover in Design A pallets will not have any queue time entering the center due to space being dedicated, however, the team accounted for queue in Design B because reserve area is shared storage. Both designs are shown below in figures 5.9.1 to 5.9.4.

The team used the traffic endured as the average number of entities in queue in steady state equilibrium in each center. For simplicity in simulation, the team used the number of resources required for each center from 5.7 for all trials inside an experiment per design.

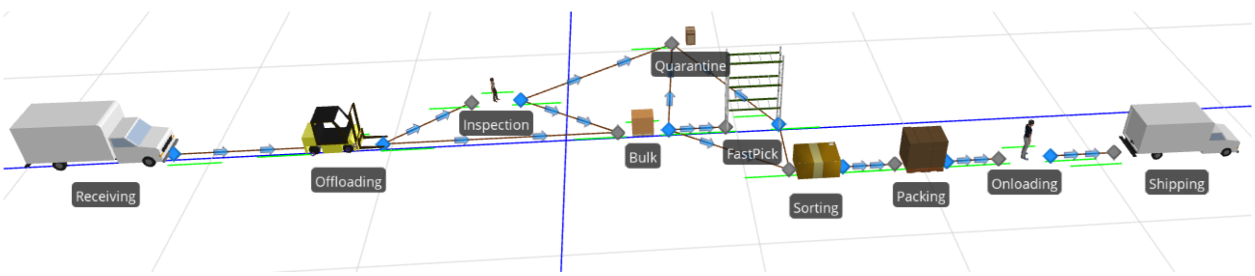


Figure 5.9.1 – 3D representation of simulation model for Design A

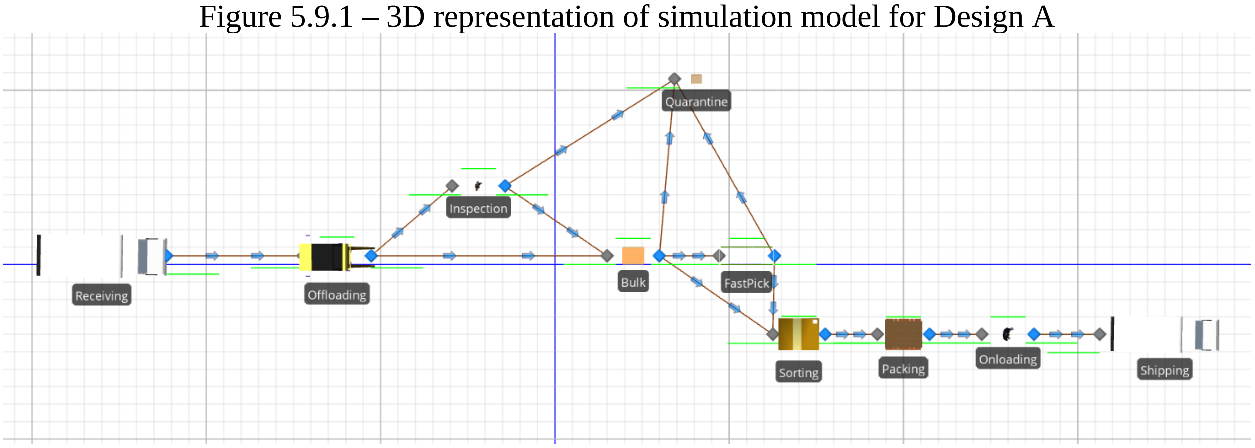


Figure 5.9.2 – 2D representation of simulation model for Design A

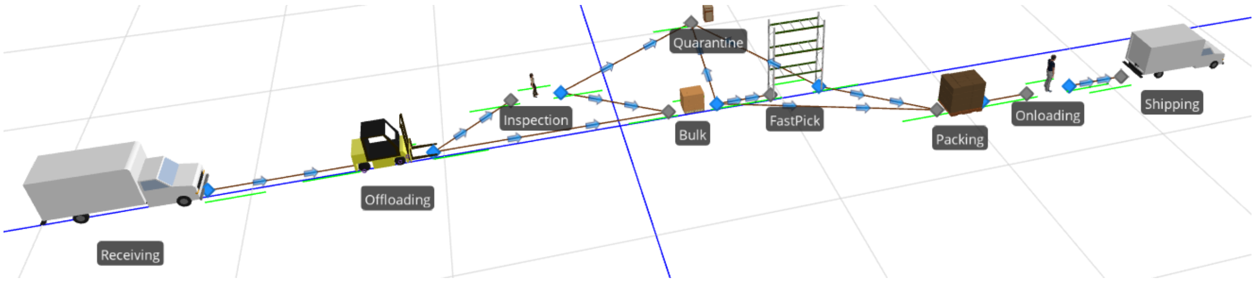


Figure 5.9.3 – 3D representation of simulation model for Design B

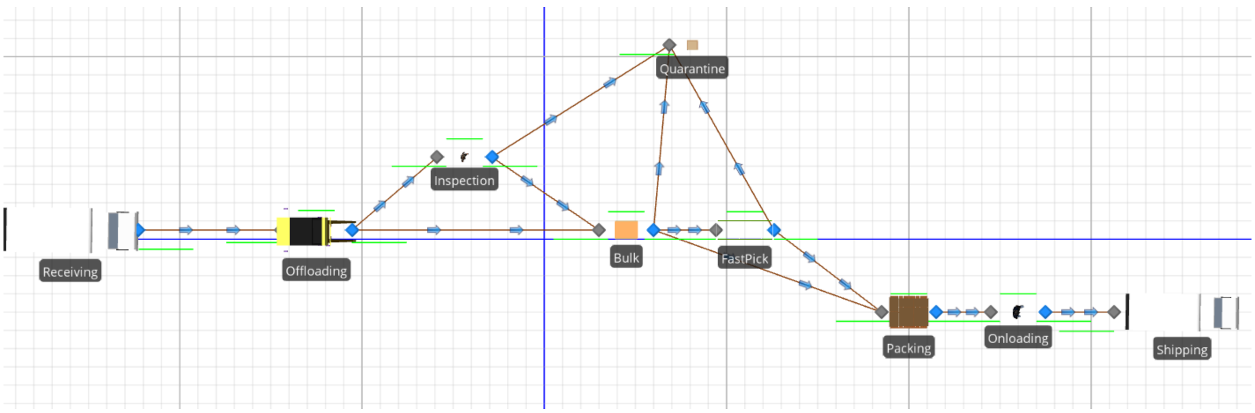


Figure 5.9.4 – 2D representation of simulation model for Design B

In steady state equilibrium, in a 16-hour work-day design A shipped 5,749 pallets in comparison to design B which shipped 6,957 pallets. Moreover, in design B the capacity utilization of the packing station is higher being 96% in comparison to 80% in design A. This is because the process of sorting acts as a bottleneck in comparison to packing. Sorting requires more time and requires all products to be present for the sorting process to be completed.

In design A, the sorting center is utilized 99% of the time, the input buffer had 7,001 pallets enter through the day and only 5,752 pallets exited. This implies that at a certain time there was around 1,250 pallets picked and waiting to complete orders to be fully sorted and sent to the packing station. Design A has more entities in the system at a certain time, 4,425 pallets while Design B has 3,973. This means that at a certain time, design A has more money tied in their DC not increasing throughput while design B is moving pallets faster. Design B has pallets that spend 26% less time in the DC than design A.

A full detailed report from Simio on the key performance indicators and the simulation model are posted under *"simio task 5."*

From the two designs, design B has a higher design score in the qualitative relationship, it requires less workers and equipment. Moreover, pallets stay in the system less time in design B and therefore, the maximum number of pallets shipped is higher. Design B has the ability and eases the use of dual-command cycles due to the cross aisles and convenience of locations.

Task 3.1.6 Human-Centric Fulfillment Center Design

<u>3.1.6.a(I)</u>

The team assumes that the fulfillment centers will receive pallets of different products and will ship pallets and cases depending on the order size. Each pallet received is assumed to be single uniform SKU but the pallets shipped may be single uniform SKU pallets or mixed SKU pallets. The team proposes the following two designs for the largest new fulfillment center: Maspeth.

- Design A – Receiving and shipping on the opposite sides, no cross aisles, dedicated storage in the forward pick area and shared storage for bulk storage. The items are picked with batch picking method.
- Design B – Receiving and shipping on the same side with cross aisles, dedicated storage in the forward pick area and shared storage for bulk storage. The items are picked with cluster picking method.

Centers for Design A

- **Receiving docks**

The area where the trucks back up and park to proceed with the unloading. This area must be adjacent to the unloading area and account for the maximum number of incoming trucks that the fulfillment center can experience at a single time.

- **Unloading area**

The unloading area takes the pallets out from truck into the building where they are prepared to be stored in the bulk storage area or fast pick area according to WMS determination.

- **Outbound docks**

The area where the trucks backup and park to proceed with the loading. This area must be adjacent to the outbound loading area and account for the maximum number of outgoing trucks that the fulfillment center can experience at a single time.

- **Outbound loading area**

This is the area next to the packing station in which full orders are placed awaiting for the truck to back up and proceed with the loading activities. This is also where the outbound team crosscheck order accuracy.

- **Inspection area**

A portion of the incoming pallets pass through this area to be checked by the inspectors. The criteria that inspectors check on will be based on weight, packaging guidelines, damages, label accuracy, and accurate quantities. If the pallets are verified, they are moved into bulk storage area. If they do not pass the inspection criteria, they are moved to the quarantine area.

- **Quarantine area**

The inspected items that do not pass the inspection criteria must be placed in the quarantine area and then returned to the factory. This prevents items that have not passed quality control from being mixed with those that have passed quality control and allows for accurate inventory tracking. Items subsequently found to be damaged are also sent to the quarantine area.

- **Bulk Storage**

This is where most of the inbound would go to. It is a storage for incoming pallets with shared storage between all the SKUs. It is located close to the forward pick area to minimize the replenishment time. Size of this center is dependent on 99% robust inventory level of 2 months.

- **Forward picking area**

The fast-moving SKUs will be allocated here to reduce the cost of picking compared to picking from the storage. Pickers will pick from forward pick area less than pallet quantities (cases). The most popular SKUs picked in less than pallet quantities are stored in this area.

- **Sorting station**

In this design, the picking methodology will be batch-picking, therefore, the items will need to be sorted. Each picker will be assigned to pick items for multiple orders, and they will then go to this station to sort each order independently.

- **Packing station**

The sorted items are then moved to the packing station where the pallets are wrapped up with shrink ensuring that they meet the packaging guidelines.

- **Bathroom**

The number of water closets will be determined following the Occupational Safety and Health Standards (OSHA).

- **Office**

The office space is the work area of the fulfillment center administration team as well as all white-collar workers that manage people and resources. It is also used to host meetings, conduct trainings and administrative storage.

- **Equipment storage area**

This is the place in the facility where all the equipment is stored at the end of each shift. It will include the storage of all weighing scales, forklifts, pallets, motorized pallet jacks, excess racks, and any other equipment.

Design A flowchart

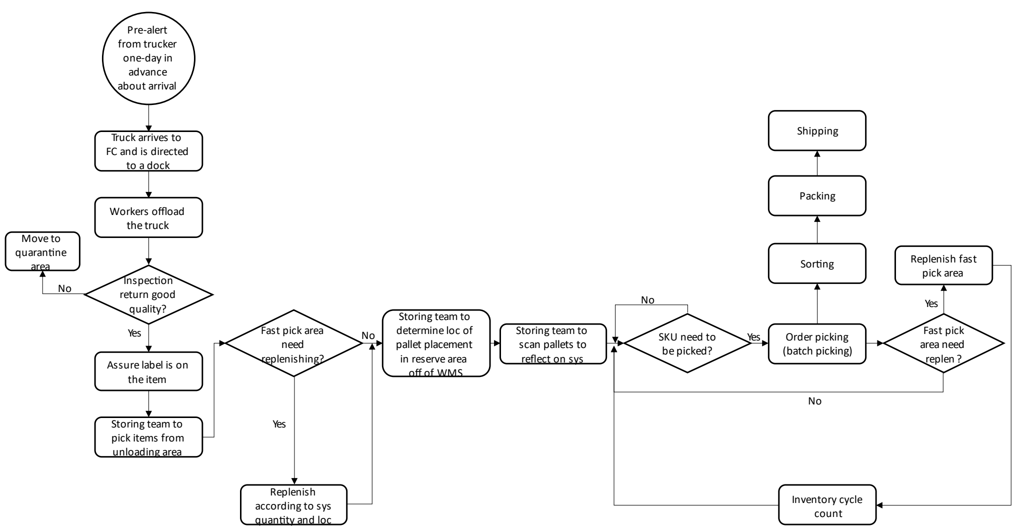


Figure 3.6.1 – Flowchart of the movements along the FC in Design A

The relationships between the centers are analogous to what was presented for distribution centers, see Task 3.1.5.(I).

Centers for design B

- **Receiving and shipping docks**

The area where the trucks back up and park to proceed with the unloading/loading. This area must be adjacent to the unloading/outbound area and account for the maximum number of incoming/outgoing trucks that the fulfillment center can experience at a single time.

- **Unloading and Outbound loading area**

This area is split in two: the unloading area where takes the pallets out from truck into the building where they are prepared to be stored in the bulk storage area or fast pick area according to WMS determination and the outbound loading area, that is located next to the packing station in which full orders are placed awaiting for the truck to back up to proceed with the loading activities. This is also where the outbound team crosscheck order accuracy.

- **Inspection area**

A portion of the incoming pallets pass through this area to be checked by the inspectors. The acceptance criteria will be based on weight, packaging guidelines, damages, label accuracy and accurate quantities. If the pallets are accepted, they are moved into bulk storage or forward pick area depending on the storage location of that particular SKU. If the items received do not pass the inspection, they are moved to quarantine area.

- **Quarantine area**

The inspected items that do not pass the inspection criteria must be placed in the quarantine area and then returned to the factory. This prevents items that have not passed quality control from being mixed with those that have passed quality control and allows for accurate inventory tracking. Items subsequently found to be damaged are also sent to the quarantine area.

- **Bulk Storage**

This is where most of the inbound would go to. It is a storage for incoming pallets with shared storage between all the SKUs. It is located close to the forward pick area to minimize the replenishment time. Size of this center is dependent on 99% robust inventory level of 2 months.

- **Forward picking area**

The fast-moving SKUs will be allocated here to reduce the cost of picking compared to picking from the storage. Pickers will pick from forward pick area less than pallet quantities (cases). The most popular SKUs usually picked in less than pallet quantities are stored in this area.

- **Packing station**

After each order is picked individually considering the cluster picking methodology from the bulk and/or forward pick area, the units picked are then moved to the packing station where each order is wrapped up with shrink ensuring it meets the packaging guidelines.

- **Bathroom**

The number of water closets will be determined following the Occupational Safety and Health Standards (OSHA).

- **Office**

The office space is the work area of the fulfillment center administration team as well as all white-collar workers that manage people and resources. It is also used to host meetings, conduct trainings and administrative storage.

- **Equipment storage area**

This is the place in the facility where all the equipment is stored at the end of each shift. It will include the storage of all weighing scales, forklifts, pallets, motorized pallet jacks, excess racks, and any other equipment.

Design B Flow chart

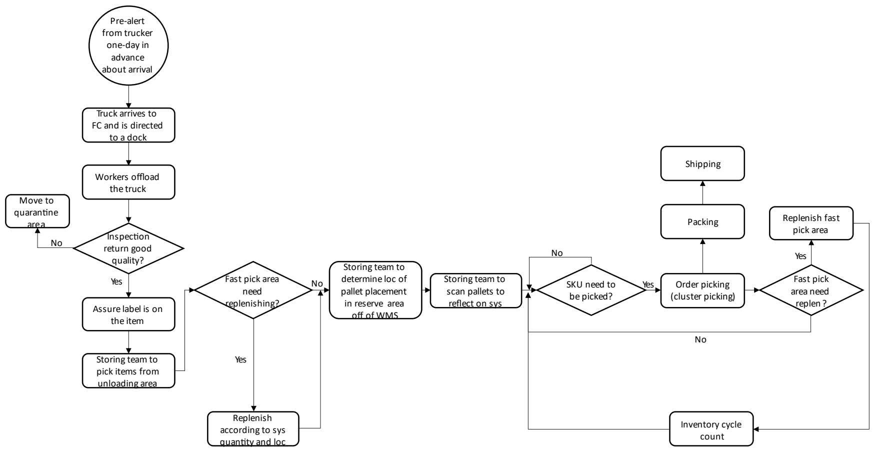


Figure 3.6.2 – Flowchart of the movements along the FC in Design B

The relationships between the centers are analogous to what was presented for distribution centers, see Task 3.1.5.(I).

<u>3.1.6a</u>(II)

In order to measure performance of the fulfillment center, the team considers that it is needed to measure the performance of each internal team inside the fulfillment center and measure their contributions to the overall goal of the fulfillment center: shipping the right items, in the right quantities, to the right place and at the right time. Both designs will have the same team regardless of a different layout, therefore same performance indicators. The team broke up the fulfillment center team into three teams:

- First Mile team: team in charge of receiving the items, offloading from truck and performing inspections
- Put away and retrieving team: team in charge of storing all the items and picking for dispatch
- Last mile team: team in charge of loading the pallets to the truck and pallet positioning inside the truck

Team	KPI	Objective	Target
First mile	Receiving efficiency	Number of pallets per hours	60 pallets/hour/dock
	Receiving cycle time	Time it takes to process new stock received in the FC	3 min/pallet

	Incoming order accuracy	Ensures inbound is what was ordered	100% of inaccurate inbound orders detected
Put away and retrieving	Put-away cycle time	Time it takes to put-away items in FC	5 min
	Put-away accuracy	Percentage of inventory put away correctly in the first time	100%
	Picking cycle time	Time it takes to pick per order	5 min
	Picking efficiency	Number of units picked per hour	250
	Picking accuracy	Percentage of orders picked without errors	100%
Last mile	Packing efficiency	Number of orders packed per hour	250
	Truckload utilization	Percentage of TL capacity used per truck	100%
	Damage rate	Number of orders fully packed that cannot be shipped due to damages	0%

Table 3.6.1: Performance measures

3.1.6.a.(III)

Design A consists of receiving and shipping on opposite sides of each other. The fulfillment center will operate with no cross aisles and there will be dedicated storage forward and shared storage in reserve. The design will have a fast pick area from where the most popular SKUs that are usually ordered in less than a pallet quantity will be picked from and a bulk/reserve storage in which full pallets quantity are stored and picked from.
Analogous to what was described in Task 3.1.5, the team will perform a bang-for-buck calculation to identify the SKUs that are the best candidates to go to the forward area maximizing the benefit. Dual-command cycles will not be performed in design A as there are no cross-aisles. The orders will be batch picked and a sorting station will be in place to sort all the items picked into their individual orders.

Design B consists of receiving and shipping on the same side of the fulfillment center, cross aisles will be in place allowing dual-command cycles. The bulk storage area will be shared storage to maximize space utilization and the fast pick area will be dedicated storage to minimize picking time. A bang-for-buck calculation will be performed to identify which SKUs are the best candidates to be stored in the forward area. The picking method considered in this design is cluster picking method, allowing to maintain order integrity and decreasing the order cycle time since the combined productivity of batch pick and then sort is lower than the cluster picking productivity.

Regarding product placement, analogous to what was considered for the distribution centers, the team will use the same product placement strategy for design A and design B. The bang-for-buck

expression will be used to define which products to store in the fast-pick area, this mean that the products that return the most benefit from being given the convenient fast-pick area location will be allocated there.
SKUs that are assigned locations in the fast pick area will be given convenient locations in the reserve storage closer to the fast pick area to minimize the restocking minutes to the fast pick area. Finally, products with high demand will be placed closer to the packing station.

Once the candidates to be stored in the fast pick area have been defined, the determination of the number of pallets to place in the forward area is done by estimating the minimum and maximum number of pallet locations required for each product. If the bang-for-buck is larger for the minimum, then the minimum is placed, if it is larger for the maximum then the maximum is placed.

3.1.6.a(IV)

The teams divided the operation flow of the fulfillment center in the following three stages:

First mile

1. The DC facility sends a notification alert to the FC one day in advance stating the items they will deliver to the FC as well as the time window in which the FC should receive the items.
2. The shift leader is required to acquire the data of all items that will be delivered next day from the DC and allocate resources accordingly.
3. The First Mile (FM) team is required to assign the driver to a specific dock station (receiving dock) when he arrives.
4. If the truck driver does not adhere to the originally agreed time window and there are other drivers waiting to deliver their items; the driver is required to wait until all other drivers have finished.
5. Two members from the FM team are required to offload all pallets of the truck using a forklift.
6. A FM specialist is required to check if the material received complies with the specified packaging guidelines, meaning pallets are sealed with shrink wrap and cases are closed.
7. If the material follows the specified guidelines a quality control check is made on 10% of the shipment, if it is of good quality, the FM specialist places labels on the pallets received that include: Pallet ID, Order ID and scan them in order to reflect on the system as FC - Received. If the shipment does not comply with the quality control, the FM specialist documents the reason for rejection in the receiving document, places the material in the quarantine area, arranges the pickup of the flawed merchandise and reflects it in the system as FC - Rejected.
8. If the item does not follow the specified packaging guidelines, FM specialist is required to label the item as “packaging required” for the packaging team to fully package the pallet.
9. If the item has a status of FC – Rejected the system is supposed to automatically open a ticket to the DC with the rejection reason mentioned.
10. The key performance indicators for First Mile team are Receiving efficiency, Receiving cycle time, and Incoming order accuracy.

Put away & Picking

11. If the item reflects on the system as FC – Received, system notifies, and alerts the Put away & Picking team supervisor for picking from the dock station.
12. Put away & Picking team member is required to check in the system in which dock station the pallets are, the number pallets, the ID and the storage location within the FC in which the material should be stored,
13. If the item is labeled as "packaging needed", a worker from the packaging team, that is part of the Last Mile team, picks up the item from the dock station, performs packaging and documents the activities on the system to bill to the DC and then moves the repackaged material to the indicated location in the storage area.
14. If the item is not labeled as "packaging needed", a Put away & Picking team member picks up material from the dock and moves it to the storage area using a forklift.
15. Put away & Picking supervisor has the location clean and ready for when items arrive for storing.
16. Put away & Picking team member stores the items in the specified location according to system determination. Put away & Picking supervisor overlooks placement of items.
17. Put away & Picking specialist scans the items to reflect the material on the system as FC – Allocated.
18. The fulfillment center receives a purchase order from the customer (orders are assigned automatically to each fulfillment center depending on the customer's home zip code). The order is scheduled in the FC operations.
19. Once the status for the order is reflected as FC– Scheduled, a Put away & Picking team member team proceeds with the picking. For design A (batch picking) the picking includes picking and sorting activities and for design B (cluster picking) order integrity is preserved and sorting is not needed. Once the picking activities have been finalized, the order is sent to packing.
20. The order is packed and then staged on the dispatch area number mentioned on the system.
21. The key performance indicators for Put away & Picking team are Put-away cycle time, Put-away accuracy, picking cycle time, picking efficiency, and picking accuracy.

Last Mile

22. Once the customer confirms the delivery, the LM team changes the status of the item on the system to FC – Scheduled. The LM planner then prepares a plan off an LMS with items in delivery run based on cubic meters, material fragility, zip code, and volume and include in the form delivery run number (this indicates truck).
23. LMS then informs the trucking agency of the delivery run to ensure they received the information and assign drivers.
24. Once the picking team places the items in the specified dispatch area number, the LM team then scans the items and onloads the items in the truck. The truck must enter the zip-code. Once scanned, the system will reflect the item status as Customer – In Transit.
25. The LM supervisor then ensures that the driver has on the system the cases or pallets with case/pallet ID and delivery location.
26. Customer confirms – the driver then updates the system which reflects to the LM supervisor of delivered pallets.

27. The key performance indicators for the LM team include packing efficiency, truckload utilization and damage rate.

3.1.6.a(V)

Regarding picking and sorting technologies, the team decided to consider the following:

Technology	Usage and benefit	Price of installation
Batch picking technology: Light weight motorized cart with multiple bins + pick by voice system	The pick by voice system enables the picker to have the most efficient path through the warehouse, minimizing travel time. This approach increases the efficiency of the selection process, while dramatically increasing accuracy as well.	$300,000
Sorting technology: Pick to light Put-wall	Once the operator scans an item the system lights the section of the put wall to which the scanned item belongs. The light is blue as long as the order has not been completely unitized. Once all the items that make up the order have been placed in the designated location, the light turns green and the order is ready to be packed. This unitizing system requires short capacitation for workers, increases accuracy and decreases lead time.	$250,000
Cluster picking technology: Light weight motorized cart with multiple bins+pick to light system	Increased productivity since no sorting is required for this process. Pick to light included in the cart to define in which bin each item has to be placed and increase accuracy.	$325,000

Table 3.6.2: Picking and sorting technologies

Regarding workers, the following job positions are required to enable the FC operations. Salaries were considered using Massachusetts minimum wage.

Positions	Salary/hour
Supervisor	$61
Shipping and Receiving clerk	$35
Forklift operator	$37
Inspector	$51
Material handler	$43

Security	$35
Delivery driver	$34
Positions	**Salary/hour**
Manager	$179,945

Table 3.6.3: Work positions required for operation

Regarding equipment requirements for unloading, storing, retrieving and loading the following:

Equipment	Unit cost
Forklift	$30,000
Pallet Jack	$400
Motorized pallet jacks	$4,500
Flow Rack	$10,000
Rack	$22,000

Table 3.6.4: Equipment required for unloading, storing, retrieving and loading

Regarding software, analogous to what was discussed for the distribution centers, for the fulfillment center to operate efficiently, capture key performance indicators, and apply changes to enhance operations, some systems need to be put in place. These systems will help management drive changes and provide full visibility for how the floor is operating.

Technology	Usage and benefit	Price of installation
WMS	A warehouse management system is needed in order to determine accurate arrival and departure time of all pallets/cases in the system. The WMS is also where the logic for product placement and locations assignment in the forward pick area is embedded. This system helps manage inventory inside the FC and assigns SKU to locations in order to maximize efficiency and increase throughput.	$25,000
LMS (Logistics Management System)	A logistics management system is required to manage the dispatch of orders to customers. A LMS will provide the vehicle routing that minimizes costs, connects and informs 3PLs of their deliveries. An LMS gives the team a clear and live view of all trucks on the road and collects all proofs of delivery for all the delivered orders.	$15,000
ERP	The enterprise resource planning software will receive the notifications when orders are being sent to the FC	$50,000

	and receive orders from customers. ERP system will help forecast demand, improve inventory planning, DC relationship management. It will be the focal system between the FC and the DC.	
Labor Management System	A labor management system is used in order to record attendances of all the workers inside the distribution center. It helps set shifts for all the workers and assign tasks.	$10,000

Table 3.6.5: Software required

All the systems must be integrated, and information must sync from one system to another. When incoming orders are processed in the ERP and after resource planning is achieved, the orders will sync into the WMS. The WMS will be the start point for on-ground operations and this is where orders will be scanned as received and used for inventory management throughout. When orders from the customers are received in the ERP, a trigger is sent to the WMS to sync the order into the LMS in which planning is performed to get the orders ready for picking and dispatch.

The equipment needed, such as forklifts, is detailed in Task 3.1.6.(VI).

3.1.6.a(VI)

In terms of storage capacity, the team decided that Maspeth's fulfillment center must handle all the incoming shipments and no third-party vendor will be used to help with the excess demand. The overall storage capacity requirement for each year is calculated from the maximum daily inventory level of each year.

Year	**Maximum Inventory level (units)**
2023	30,480
2024	52,165
2025	79,034
2026	94,413
2027	89,159
2028	113,125

Table 3.6.6: Daily maximum inventory of each year in Maspeth's FC

Inside the fulfillment center, the items are stored in pallet quantities. Thus, the number of pallet positions required needs to be estimated. The number of units inside one pallet is calculated by taking the standard size of the pallet (L*W*H) = (48'' * 40'' * 48'') and fit as many cases as possible inside this dimension. The number of cases per pallet of each product category is given below.

Category	L (in)	W (in)	H (in)	Cases/pallet
A	24	16	12	24
B	12	12	8	72
C	24	16	8	36
D	12	12	12	48
E	4	4	4	1440
F	8	8	4	360
G	12	12	12	48
H	4	4	4	1440
I	12	12	4	144
J	4	4	4	1440
K	20	12	12	24
L	24	12	12	24
M	24	16	8	36
N	16	16	8	54
O	16	16	16	27
P	20	12	12	24
Q	24	16	8	36
R	4	4	4	1440
S	16	16	16	27
T	20	16	16	18
U	24	12	12	24
V	16	16	4	108
W	8	8	4	360
X	20	12	12	24
Y	12	8	8	120

Table 3.6.7: Number of items per pallet for each product category

Our team found that the average items per pallets for any scenario is approximately 43 items per pallets. Thus, this number will be used to convert the quantities in units to quantities in pallets. The maximum inventory level in pallet quantities is given in the following table.

Maximum inventory in pallet quantities						
Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**
Scenario 1	579	807	1,378	1,445	1,701	2,104
Scenario 2	692	955	1,455	1,387	1,445	2,428
Scenario 3	579	984	1,217	1,364	1,901	1,976
Scenario 4	557	906	1,575	1,436	1,795	2,402
Scenario 5	621	1,175	1,450	1,240	1,767	2,054

Scenario 6	609	1,001	1,312	1,837	1,824	1,961
Scenario 7	636	1,205	1,401	1,393	2,059	1,795
Scenario 8	606	1,111	956	1,092	1,314	2,198
Scenario 9	534	792	1,232	1,337	1,123	2,613
Scenario 10	704	685	1,825	2,180	1,934	1,578

Table 3.6.8: Maximum number of pallets of items per pallet for each product category

Regarding the throughput capacity, the number of pallets that the fulfillment center must handle in each day will be used to calculate the requirement of the equipment and personnel. In order to obtain this number, the average daily demand of the distribution in each year and each scenario. Since the fulfilment centers have the robust inventory level to achieve autonomy. It is assumed that the peak demand on the distribution center can be aggregated to be on average level. Thus, the team concluded to use the average daily demand in pallet quantity to measure the throughput capacity that the distribution center need to have. Given that the distribution center receives items in pallet quantity and ships out as pallets. The base unit to consider is the pallet unit.

	Maximum throughput in units for each scenario					
	2023	**2024**	**2025**	**2026**	**2027**	**2028**
Scenario 1	142,755	100,011	98,068	135,036	170,349	167,632
Scenario 2	42,432	86,881	99,954	139,232	202,438	241,522
Scenario 3	46,191	84,068	86,608	114,943	189,389	160,365
Scenario 4	77,738	60,625	116,146	150,751	147,274	180,294
Scenario 5	49,093	102,698	147,627	108,261	200,218	180,459
Scenario 6	72,375	254,316	252,121	151,870	235,032	209,495
Scenario 7	67,590	90,100	106,189	146,578	154,192	179,683
Scenario 8	41,864	85,473	94,385	102,381	132,766	212,048
Scenario 9	203,571	177,297	151,308	149,859	153,362	273,701
Scenario 10	46,445	53,784	148,578	150,430	169,863	171,381

Table 3.6.9: Maximum throughput in units for each scenario

3.1.6.a(VII)

To estimate the dynamically evolving requirements across the 2023-2028 horizon the team proceeded to calculate the equipment requirements for each center within the fulfillment center for each year and for each stochastic scenario analyzed. The results for scenario 1 are presented in the table below. The results for all the scenarios can be found in the Excel file calculations_Task6_working.

		Scenario 1 Units required						Scenario 1 Cost (KUSD)					
Center	**Equipment**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**
Unloading area	Forklift	4	3	3	4	5	5	120	90	90	120	150	150
	Dock doors	4	3	3	4	5	5	6	4.5	4.5	6	7.5	7.5
	Scanners	4	3	3	4	5	5	8	6	6	8	10	10
Inspection area	Scale	1	1	1	1	1	1	2.4	1.2	1.2	1.2	2.4	2.4
	Pallet jack	1	1	1	1	1	1	0.8	0.4	0.4	0.4	0.8	0.8
	Scanners	1	1	1	1	1	1	4	2	2	2	4	4
Quarantine area	Pallet jack	1	0	0	0	1	1	0.4	0.4	0.4	0.4	0.4	0.4
Outbound loading area	Forklift	6	4	4	6	7	7	180	150	150	180	240	210
	Dock doors	6	4	4	6	7	7	9	7.5	7.5	9	12	10.5
	Scanners	6	4	4	6	7	7	12	10	10	12	16	14
Bulk Storage	Racks	2	3	6	6	7	9	66	88	132	154	176	198
	Forklift	8	6	5	7	9	9	240	180	180	240	300	300
	Pallet jack	52	36	35	49	61	60	20.8	14.8	14.4	19.6	24.8	24.4
	Tote cart	8	6	5	7	9	9	20	15	15	20	25	25
	Scanners	8	6	5	7	9	9	16	12	12	16	20	20
Forward picking area	Flow rack	4	6	10	10	12	15	50	60	100	110	120	150
	Pallet jack	26	18	18	24	31	30	10.4	7.6	7.2	10	12.4	12.4
	Scanners	26	18	18	24	31	30	52	38	36	50	62	62
Sorting station	Manual put wall	36	25	24	34	42	42	9,000	6,250	6,250	8,500	10,750	10,500
	Sorting station	36	25	24	34	42	42	1,080	750	750	1,020	1,290	1,260
Packing station	Label printers	36	25	24	34	42	42	18	12.5	12.5	17	21.5	21
	Forklift	4	3	3	4	5	5	120	90	90	120	150	150
		277	198	201	272	342	341	11,035.8	7,789.9	7,871.1	10,615.6	13,394.8	13,132.4

Table 3.6.10: Equipment requirements and associated costs over the years for scenario 1

The calculations were performed considering the throughput and inventory requirements per year and the capacity of each equipment.

Analogously, the workforce requirements were calculated. The results for scenario 1 are presented in the following table. The results for all the scenarios can be found in the Excel file calculations_Task6_working.

			Scenario 1 Workers required						Scenario 1 Cost (KUSD)					
Center	**Equipment**	**Operators per equipment**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**
Unloading area	Forklift	1	4	3	3	4	5	5	250	187	187	250	312	312
	Dock doors	2	8	6	6	8	10	10	499	374	374	499	624	624
	Scanners	1	4	3	3	4	5	5	250	187	187	250	312	312
Inspection area	Scale	1	2	1	1	1	2	2	125	62	62	62	125	125
	Pallet jack	1	2	1	1	1	2	2	125	62	62	62	125	125
	Scanners	1	2	1	1	1	2	2	125	62	62	62	125	125
Quarantine area	Pallet jack	1	1	1	1	1	1	1	62	62	62	62	62	62
Outbound loading area	Forklift	1	6	5	5	6	8	7	374	312	312	374	499	437
	Dock doors	2	12	10	10	12	16	14	749	624	624	749	998	874
	Scanners	1	6	5	5	6	8	7	374	312	312	374	499	437
Bulk Storage	Racks	1	3	4	6	7	8	9	187	250	374	437	499	562
	Forklift	1	8	6	6	8	10	10	499	374	374	499	624	624
	Pallet jack	1	52	37	36	49	62	61	3,245	2,309	2,246	3,058	3869	3,806
	Tote cart	1	8	6	6	8	10	10	499	374	374	499	624	624
	Scanners	1	8	6	6	8	10	10	499	374	374	499	624	624
Forward picking area	Flow rack	1	5	6	10	11	12	15	312	374	624	686	749	936
	Pallet jack	1	26	19	18	25	31	31	1,622	1,186	1,123	1,560	1,934	1,934
	Scanners	1	26	19	18	25	31	31	1,622	1,186	1,123	1,560	1,934	1,934
Sorting station	Manual put wall	1	36	25	25	34	43	42	2,246	1,560	1,560	2,122	2,683	2,621
	Sorting station	1	36	25	25	34	43	42	2,246	1,560	1,560	2,122	2,683	2,621

Packing station	Label printers	1	36	25	25	34	43	42	2,246	1,560	1,560	2,122	2,683	2,621
	Forklift	1	4	3	3	4	5	5	250	187	187	250	312	312
			295	217	220	291	367	363	18,408	13,541	13,728	18,158	22,901	22,651

Table 3.6.11: Labor requirements and associated costs over the years for scenario 1

In terms of space requirements, analogous to task 3.1.5, the model was divided into two categories. Workstations space calculated with Little's Law and storage space with maximum inventory levels. Results are shown in table 3.6.12. This squared foot value results in a monthly rental cost of $103,398.

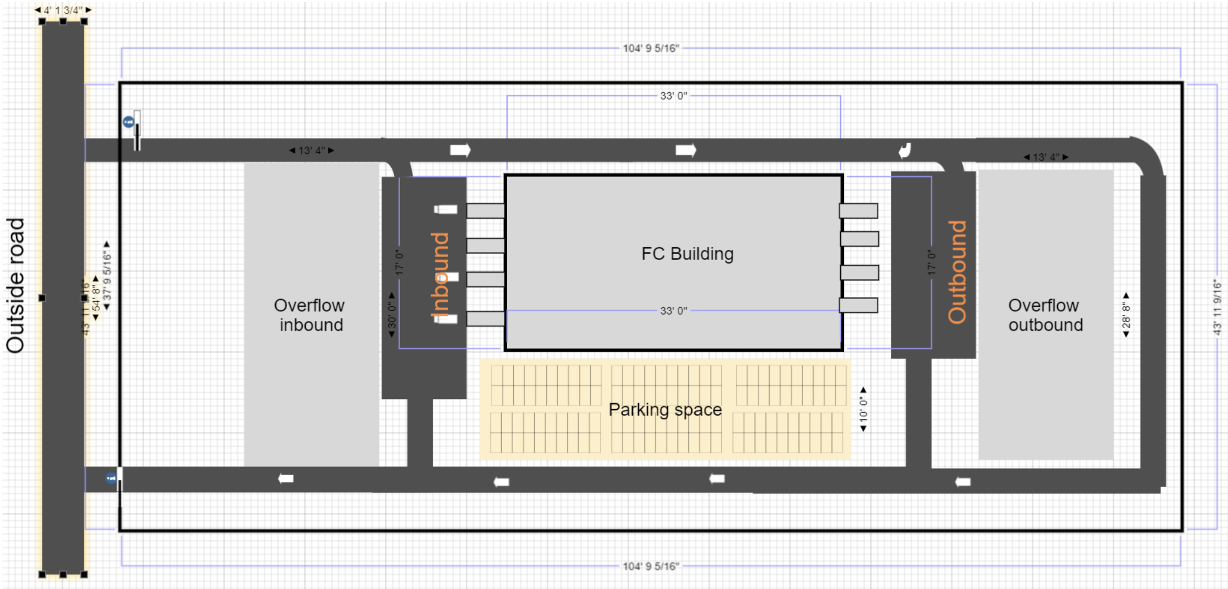
Center	Type	Pallets in the location a given time	UPH	Processing time	Requirement per pallet		Total Space needed (sqft)
					Space occupied by pallet	Aisle/ Processing area	
Unloading area	Workstation	-	52	2%	13.33	26.67	544
Inspection area	Workstation	-	200	1%	13.33	26.67	141
Quarantine area	Workstation	-	400	0%	13.33	26.67	71
Outbound loading area	Workstation	-	34.7	3%	13.33	26.67	815
Bulk Storage	Inventory	85%		-	2.67	2.67	31,395
Forward picking area	Inventory	15%		-	4.44	8.89	13,851
Sorting station	Workstation	-	6.67	15%	13.33	26.67	4,238
Packing station	Workstation	-	70	1%	13.33	26.67	404
						Total Space	51,458
						Adjusted space	61,749

Table 3.6.12: Space requirements

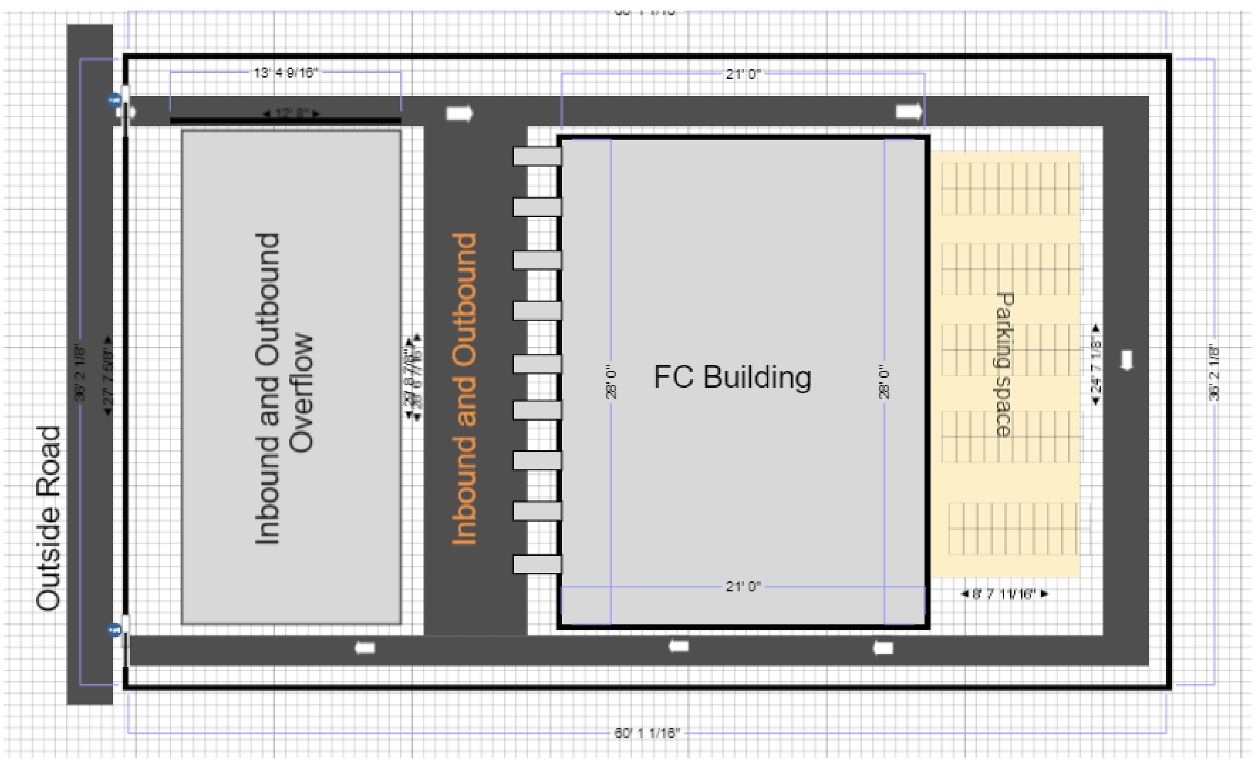
Regarding utilities, typically, the average warehouse without air-con systems will use around 6.1 Kilowatt-hours of energy per square foot annually. The total energy consumption is estimated from the total area of the warehouse building excluding the docking area outside the building. With total space of 61,749 square foot for the building, the total electric consumption is 6.1 * 61,749 = 376,669.7 kWh, resulting in a monthly cost of $33,900.
Regarding the financial requirements, the cost for each concept throughout the years was stated in Tables 3.6.10 and 3.6.12 for Scenario 1. The results for all the scenarios can be found in the Excel file calculations_Task6_working.

3.1.6.a(VIII)

Similar to the design of the distribution center, the designs of the fulfilment centers are proposed as design A where the inbound and outbound are on the opposite side of the building and the design B where the inbound and outbound docks are located on the same side of the building. The main difference between the distribution center and fulfillment centers is that the size requirements is lower. The facility and centers remain relatively the same as the distribution center. However, the total overall size of the site will change. In this task, the site layout for design A and B are provided. The site layout is based on the



Site layout of the design A (based on Maspeth, NY 2023)
Units in 10 feet



Site layout of the design B (based on Maspeth, NY 2023)
Units in 10 feet

3.1.6.a(IX)

The team designed both fulfillment centers in the same means used for designing the distribution centers. One of the main differences was the the distribution between the SKUs that went into the forward pick area and reserve area. Moreover, the interarrival times between pallets entering the system was decreased for the FC, meaning more entities were entering the system in the FC in comparison to the DC. There were multiple sinks (or entities exiting the system) in the FC design in comparison the DC. The fulfillment center shipped products to multiple states as shown in table 6.9.1 below. The team assumed the same percentage of pallets being inspected, 10%, from those inspections, 5% will be sent to the quarantine area as damaged and 95% will be moved to bulk like in the DC. Design B doesn't have a sorting server relative to Design A which has one because of batch picking. The team assumed that an order can go to any of the 4 states at random as long as in steady state they have the distribution mentioned in the table 6.9.1. The team used the traffic endured as the average number of entities in queue in steady state equilibrium in each center. For simplicity in simulation, the team used the number of resources required for each center from 6.7 for all trials inside an experiment per design. Both designs are shown below in figures 6.9.1 to 6.9.4.

State	Distribution of orders
New York	64%
New Jersey	22%
Pennsylvania	2%
Connecticut	12%

Table 6.9.1 – Distribution of orders for FC

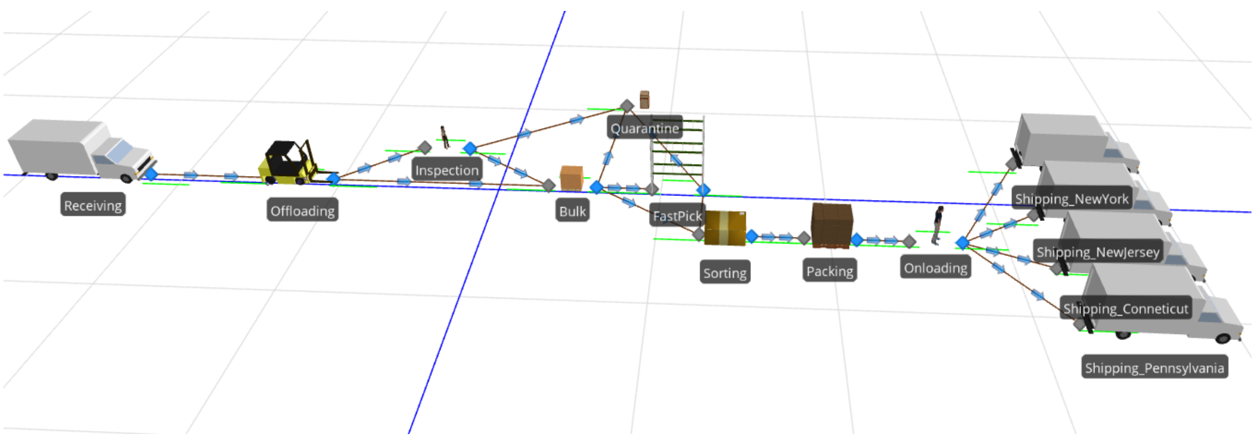


Figure 6.9.1 – 3D representation of simulation model for Design A

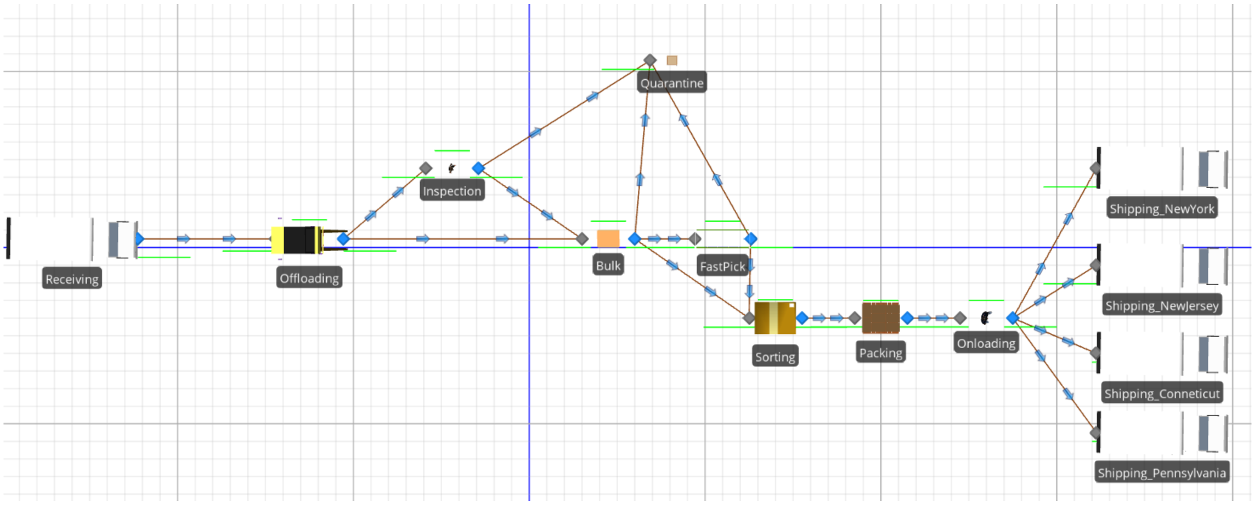


Figure 6.9.2 – 2D representation of simulation model for Design A

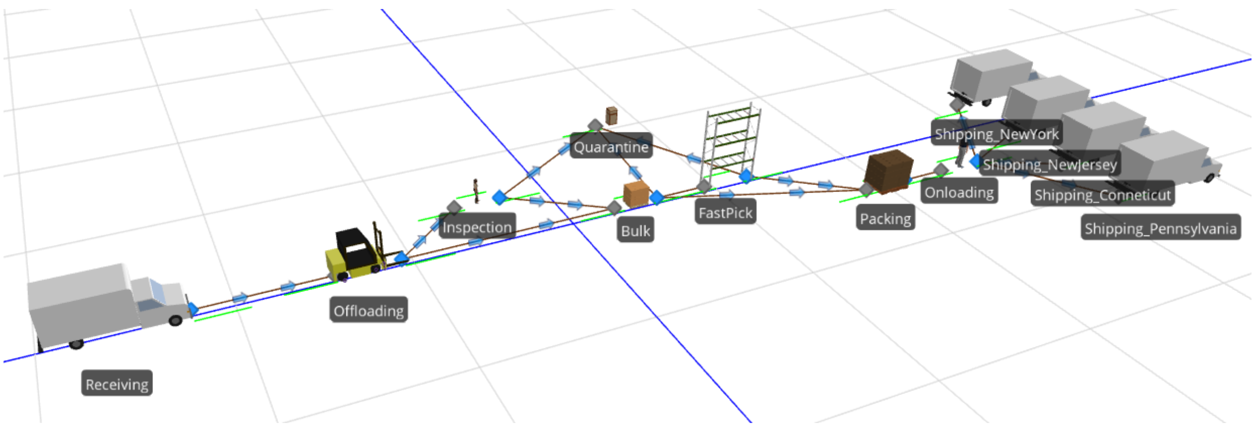


Figure 6.9.3 – 3D representation of simulation model for Design B

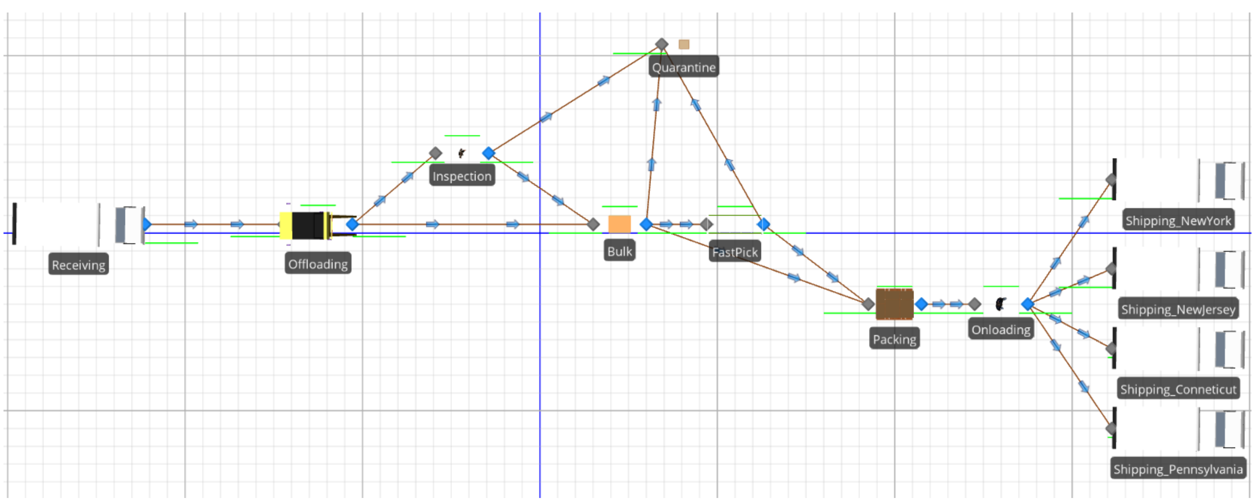


Figure 6.9.4 – 2D representation of simulation model for Design B

The results from the simulation for design A showcases 735, 1255, 3643, and 119 pallets shipped from the fulfillment center to Connecticut, New Jersey, New York, and Pennsylvania in comparison to design B which had 839, 1541, 4455, and 113. Design B allows for more shipments made from the fulfillment center to customers. The results are obtained from both designs being in steady state equilibrium. Design B has on average 8845 pallets in the fulfillment center at once while design A has 10,048 pallets at a time. This means that design A moves pallets slower and more money is tied in the systema as once.

A full detailed report from Simio on the key performance indicators and the simulation model are posted under *"simio task 6."*

From the two designs, design B has pallets that stay in the system less time and therefore, the maximum number of pallets shipped is higher. Design B has the ability and eases the use of dual-command cycles due to the cross aisles and convenience of locations.

3.1.6.b Fulfillment Center Costs

The Maspeth fulfillment center from 2023 was chosen as the modular size in order to calculate the fulfillment center costs. Using the design developed in Task 3.1.6.a, the total investment and operating costs for the Maspeth FC in 2023 were calculated and the results are shown in Table 3.6.13.

Maximum Daily Throughput	Investment Cost	Operating Cost
203,571	$12 M	$18.5 M

Table 3.6.13: Modular Size Characteristics

In order to calculate the investment and operating costs for the 19 remaining fulfillment centers, each location was scaled against the Maspeth center using the maximum daily throughput for each year. For Marpeth FC, the maximum value occurred in Scenario 9 as shown in Table 3.6.14.

Scenario	1	2	3	4	5
Max Daily Throughput	142,755	42,432	46,191	77,738	49,093
Scenario	6	7	8	**9**	10
Max Daily Throughput	72,375	67,590	41,864	**203,571**	46,445

Table 3.6.14: Marpeth FC Maximum Daily Throughput 2023

In order to be consistent with the conditions under which the modular size was calculated, the maximum daily throughput units for each fulfillment center for each year were taken from the data generated in Scenario 9. Using these values, the following formula was utilized to calculate the scaled weight for each fulfillment center $\boldsymbol{i}$ in year $\boldsymbol{j}$:

$$Scale_{ij} = \frac{throughput_{i,j}}{throughput_{Maspeth,2023}}$$

To calculate the investment costs, it was assumed all currently existing fulfillment centers are replaced and new centers are constructed in 2023. As such, the investment cost in 2023 is the product of fulfillment center ***i*** in year 2023's scale and the modular size investment cost ($12M). For each subsequent year, the investment cost needs to capture growth that has taken place since the implementation of the new fulfillment center design. In the event of a decrease in throughput and, consequently, scale, previously purchased equipment, real estate, and technologies are still retained from one year to the next. The investment cost simply needs to capture additional purchases necessitated by the fulfillment center's growth. The following formula was used to capture the investment cost for fulfillment center ***i*** in year ***j:***

$$Total\ Growth_{i,j} = Scale_{i,j} - \max\left(Scale_{i,j-1}, Scale_{i,j-2}, \ldots\right) \forall\ i = \{2023, \ldots, 2028\}$$

$$Investment_{i,j} = \$12M \cdot \begin{cases} Total\ Growth & Total\ Growth > 0, \\ 0 & Total\ Growth \leq 0 \end{cases}$$

To calculate the operating costs, the calculation was the product of the scale of fulfillment center ***i*** in year ***j*** and the modular size operating cost ($18.5M). The operating cost is directly related to the scale of the fulfillment center and can be modulated from year to year depending on the throughput.

$$Operating_{i,j} = Scale_{i,j} \cdot 18.5M$$

Using these formulas, the investment and operating costs were calculated for each fulfillment center. Tables 3.6.15 through 3.6.17 provide the results of those calculations for the investment, operating, and total costs, respectively. All values are in millions of dollars.

Fulfillment Center	2023	2024	2025	2026	2027	2028
Atlanta	10.853	0	0	0	0	4.979
Boston	5.051	0.491	0	0	0	2.557
Bridgeview	9.595	0	0	0	0	4.224
Clare	4.332	0	0	0	0	1.408
Denver	3.440	0	0	0	0	1.532
Fort Lauderdale	8.203	0	0	0	0	0.477
Fort Worth	4.369	0.032	0	0	0	2.521
Houston	5.974	0	0	0	0	2.428
Kansas City	4.162	0.053	0	0	0	3.480
Manteca	7.732	0	0	0	0	1.411
Maspeth	12.000	0	0	0	0	4.134
Parkville	11.738	0	0	0	0	3.501
Philadelphia	4.325	0	0	0	0	2.057
Phoenix	3.467	0	0	0	0	0.706

Pittsburgh	5.760	0.448	0	0	0	4.577
Portland	5.242	0	0	0	0	2.119
Russellville	5.420	0	0	0	0	3.136
Salt Lake City	2.199	0	0	0	0	1.083
Victorville	8.855	0	0	0	0	1.559
Williston	0.503	0.076	0	0.02	0	0.853

Table 3.6.15: Fulfillment Center Investment Cost

Fulfillment Center	2023	2024	2025	2026	2027	2028
Atlanta	16.731	15.771	12.216	12.749	11.682	24.407
Boston	7.787	8.544	6.725	6.742	6.149	12.487
Bridgeview	14.792	13.237	11.750	10.889	10.251	21.304
Clare	6.678	5.536	4.990	4.874	4.478	8.848
Denver	5.304	4.797	3.719	3.850	3.937	7.665
Fort Lauderdale	12.647	10.369	8.773	8.025	8.272	13.382
Fort Worth	6.735	6.785	5.382	4.768	5.083	10.671
Houston	9.210	8.420	7.668	6.896	6.159	12.954
Kansas City	6.417	6.498	5.771	5.524	4.859	11.863
Manteca	11.920	9.742	7.814	7.780	7.472	14.096
Maspeth	18.500	16.112	13.750	13.619	13.937	24.873
Parkville	18.096	15.657	12.557	12.191	11.491	23.494
Philadelphia	6.668	6.114	5.220	5.191	5.280	9.840
Phoenix	5.345	4.749	4.146	3.927	3.875	6.433
Pittsburgh	8.881	9.571	7.850	7.816	7.344	16.628
Portland	8.082	7.908	6.311	6.128	5.786	11.349
Russellville	8.356	8.135	7.031	6.651	5.789	13.191
Salt Lake City	3.391	3.059	2.552	2.681	2.692	5.061
Victorville	13.652	12.000	10.370	8.927	9.228	16.056
Williston	0.775	0.892	0.853	0.930	0.771	2.245

Table 3.6.16: Fulfillment Center Operating Cost

Fulfillment Center	Total Investment Costs	Total Operating Costs	Total Cost
Atlanta	15.832	93.556	109.388
Boston	8.100	48.434	56.534
Bridgeview	13.819	82.224	96.043
Clare	5.739	35.405	41.144
Denver	4.972	29.272	34.244
Fort Lauderdale	8.680	61.468	70.149
Fort Worth	6.922	39.424	46.346
Houston	8.402	51.307	59.710
Kansas City	7.695	40.932	48.627
Manteca	9.143	58.823	67.966
Maspeth	16.134	100.792	116.926

Parkville	15.239	93.486	108.726
Philadelphia	6.382	38.312	44.695
Phoenix	4.173	28.476	32.649
Pittsburgh	10.785	58.090	68.876
Portland	7.361	45.564	52.925
Russellville	8.556	49.153	57.709
Salt Lake City	3.282	19.436	22.719
Victorville	10.414	70.232	80.647
Williston	1.456	6.466	7.923
TOTAL	173.090	1,050.855	1,223.945

Table 3.6.17: Fulfillment Center Total Costs

SwiftHelper can anticipate investing close to $1.2 billion over the course of the six-year planning horizon to implement and operate the improved fulfillment center design. While this is a staggering amount of money, it is a necessary investment in order to make good on its delivery time commitment and reach its aggressive sales target. If the capital is not readily available, a viable option would be prioritizing the fulfillment centers that service the ZIP codes with the greatest demand share. As shown in Figure 3.6.6, the initial costs are extremely high and then decrease by a factor of # following the implementation year.

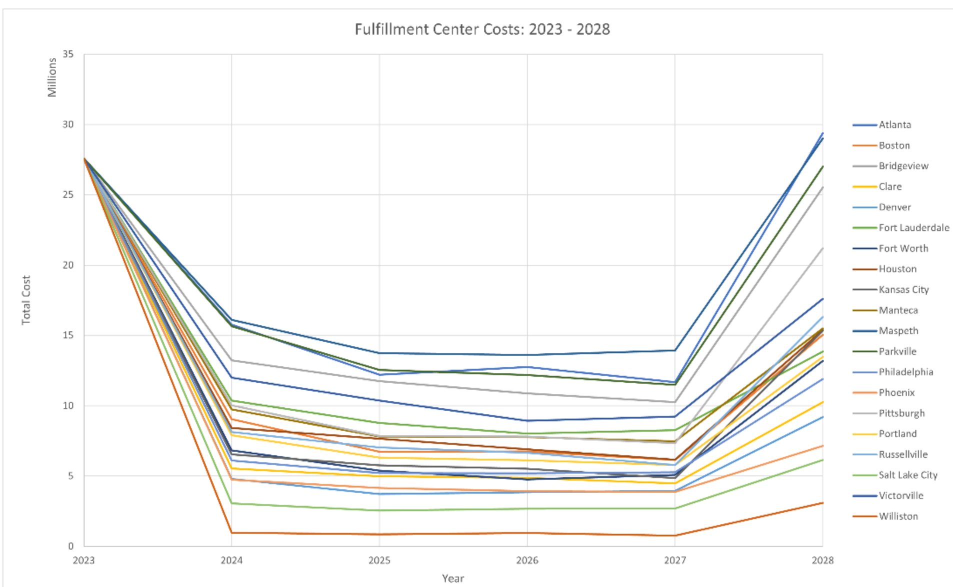


Figure 3.6.6: Fulfillment Center Cost over Time

The value of this estimation process is the speed and efficiency of obtaining an approximation for a computational complex value. It provides a ball-park figure from which planning assumptions can be made. However, speed and ease of computation come at a cost. The limitation of this process is the underlying assumption that the proportioned scale remains constant. However, product demand is dynamic and even minor injections of variation in the simulated demand has cascading effects that would ultimately be felt by the fulfillment centers. Additionally, the estimates are dependent entirely on the selected modular size. In this case, it was Maspeth FC in 2023 based on the results generated in Scenario 9. An alternative approach could include taking an average of the maximum daily throughput across all scenarios for each year. For a considerably more conservative approach, the maximum daily throughput across all scenarios for every year and fulfillment center could be used to determine the fulfillment center's proportion to the module design.

Refer to calculations_Task 6(b)_working.xlsx for the full table of investment and operating cost calculations for each fulfillment center.

Task 3.1.7: Key Learnings

Our team learned a tremendous amount in completing this casework. The demand analysis solidified our understanding of calculating, visualizing, and explaining the root cause of variations in demand share. Numerous data visualization techniques were explored to best communicate our findings. Building the simulator for customer, fulfillment center, and distribution center orders challenged our understanding of the forecasting methodology as well as implementing technology to aid in data generation (Python).

It is hard to estimate the warehouse space requirement or make the design at the site level without designing the smaller parts of the warehouse first. Our team had to readjust the site level and the facility level after making changes in the level of centers. We also observed the bullwhip effect when designing the warehouse, when we took any assumptions or estimation on the lower level, those inaccuracies translated into the higher level of the warehouse components as well.

Performing the simulation model allowed the team to understand how distribution centers or fulfillment centers run in a long period of time. The team also made changes in the design in the simulation model to examine how the system reacts and made changes to the designs based on that.

Works Cited

“List of United States cities by population.” *Wikipedia*, Wikimedia Foundation, 13 October 2022, https://en.wikipedia.org/wiki/List_of_United_States_cities_by_population.

“List of U.S. states and territories by population.” *Wikipedia*, Wikimedia Foundation, 30 October 2022, https://en.wikipedia.org/wiki/List_of_U.S._states_and_territories_by_population.

Appendices

Appendix 1:

- 1. Orders – MetaDat.csv
- 1a Demand Share.xlsx
- 1b Demand Share.xlsx
- 1c Demand Share.xlsx
- 3.1 Data Pre-Processing.html
- 3.1.1a-c – Demand Analysis

Appendix 2:

- 2a Forecasted Demand
  - Forecast 2023.csv
  - Forecast 2024.csv
  - Forecast 2025.csv
  - Forecast 2026.csv
  - Forecast 2027.csv
  - Forecast 2028.csv
- 3.1.2a Forecasted Demand.html

Appendix 3:

- Scenario 1 – 10:
  - Orders
  - FC Orders
  - FC Inventory
  - DC Orders
  - DC Inventory
  - Metrics
- 3.1.2b thru 4d – Simulator

Appendix 4:

- FC robust forecast per year – 3(b)
- DC robust forecast per year – 4

Appendix 5:

- Calculations_task 3(a)_working.xlsx
- Calculations_task 3(b)_working.xlsx
- Calculations_task 4_working.xlsx
- Calculations_task 6(a)_working.xlsx
- Calculations_task 6(b)_working.xlsx

Appendix 6:

- Simio task 5
- Simio task 6

Appendix 7

- Task 5 Resource requirement_working.xlsx
- Task 5 Space requirement.xlsx
- Task 5 Inventory level for each scenario_working.xlsx
- Task 5 Heatmap_working.xlsx

- Layout_working
    - Design A 3D.skp
    - Design B 3D.skp

    - Site Layout A.sdr
    - Site Layout B.sdr
    - FC Layout A.sdr
    - FC Layout B.sdr