KSE network optimization

Cost cutting and next day delivery solutions

Optimal Prime
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Table of **Content**

Introduction

KSE is a distributor of kitchen appliances with an annual revenue of more than $500M. Within their Northeast and Southeast regions, KSE operates a network of 11 warehouses, totalling 2.1 MM sqft of warehouse space, supporting products across many divisions.

Below are the illustrations of KSE’s sales distribution and warehouse locations. Figure 1.1 shows the geographic spread of sales and the cities with highest sales in each state while Figure 1.2 shows the geographic location of 11 warehouses and their size in square feet.

Based on Figure 1.1, Florida is the state with highest total sales generated by all zip codes in the state followed by Georgia and Massachusetts. Meanwhile, Kentucky and Mississippi have extremely low sales and West Virginia has none.

As for the warehouses, KSE operates 11 warehouses out of 10 states. Currently, they are assigned to serve specific divisions, i.e., WH_011 may only hold product from the “GLC” division. This creates a problem where a single order from a customer in Florida could potentially result in shipments from Texas, Massachusetts, and Pennsylvania.

Based on Figure 1.2, Texas has one of the largest warehouses, but it is visibly distant from the zip codes that are being served. If next-day delivery becomes a priority, the Texas warehouse may not have any zip codes assigned to it. Additionally, Georgia has two warehouses with similar capacities, making one of them potentially redundant. Before that decision could be made, warehouse capacity must first be examined.

Figure 1.1: Heatmap of spread of KSE sales by state with highest sale cities in each state

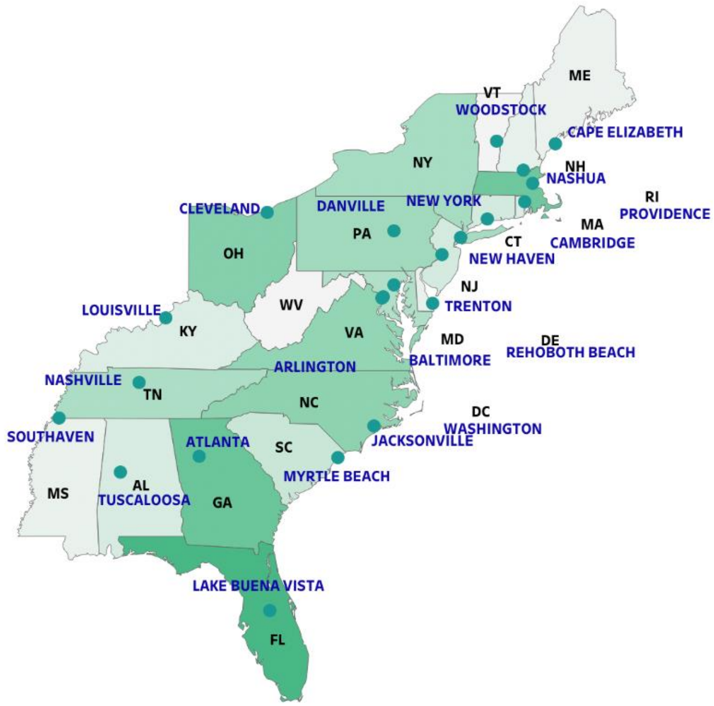
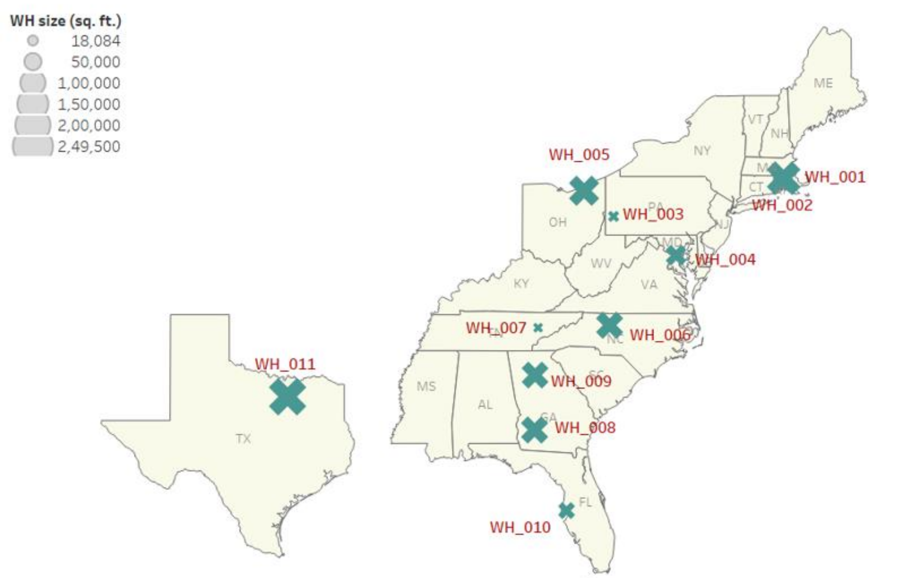


Figure 1.2: Location and size of KSE warehouses



Executive Summary

In this project, linear programming was used to create three (3) models that reflected different desired next-day delivery radii. Model 1 had a next-day delivery radius of 300 miles, Model 2 had a next-day delivery radius of 250 miles and Model 3 had a next-day delivery radius of 150 miles.

Model 1 resulted in the operating of 5 warehouses and the closure of 6. Model 2 resulted in the operating of 7 warehouses and the closure of 4. And due to the model constraints covered in Parts 4 through 6 of this paper, no feasible solution was found for Model 3. All of the warehouses that were kept open in Model 1 had low fixed costs while the warehouses kept open in Model 2 were a mixture of low and medium fixed costs.
One of the goals of this analysis was to ensure that at least 90% sales were being were offered next-day delivery. Model 1 resulted in an average service level of 91.8% across warehouses and Model 2 resulted in an average service level of 90.7% across all warehouses.

In this project, warehouse capacity could not be included in the model. Therefore, capacity was analysed after the model output results, based on the zip assignments under each model. It was found that in both Model 1 and 2, all warehouses were operating within capacity except for warehouse 7, which was operating above maximum capacity levels. All other warehouses had 30% – 70% unused space. This allows for inventory redistribution as one method of relieving the pressure on warehouse 7.

Overall, Model 1 resulted in a 60% reduction in warehouse fixed cost, compared to KSE’s previous network configuration. It also saw a 67% reduction in miles driven when compared to KSE’s prior setup. Model 2 saw a 50% reduction in warehouse fixed costs and a 71% reduction in total miles driven, as well.

Part 3: Project Objectives

The primary objective of this project is to establish a new warehouse network that would allow KSE to offer next day delivery services to clients. Additionally, by optimizing the network and reassessing the number of current warehouses, the project will also subsequently help minimize the delivery costs and fixed warehouse costs, increasing the bottom line.

The network optimization would change certain operational aspects:

01 Currently, each of the 11 warehouses only support orders from their assigned divisions but in the future all the warehouses would be designed to support sales from any division.

02 As of now, each warehouse serves every zip code, which adds to the transportation costs. An efficient way to deal with deliveries would be to serve customers based on their proximity to the warehouses (Each zip would be serviced based on a mileage cut-off range around the warehouse).

Part 4: Linear Programming Overview

To develop a more efficient zip code to warehouse assignment and to achieve all the other objectives described above, linear programming is being used.

Linear Programming (LP)* is a mathematical technique used in solving resource allocation/optimization problems involving but not limited to time, warehouse location and space, vehicle routing, and scheduling.

These are formulated as constrained optimization models which are user controlled. That makes the models flexible to any additional changes in constraints and objectives that may arise with new business needs. Apart from the model being inexpensive, additional advantages are quick and logical solutions to complex business problems.

When it comes to inner workings of the model, it is important to distinguish the major components. The model consists of; **(i)** decision variables, **(ii)** constraints that account for various limitations and **(iii)** linear objective function.

In more detail LP model components are the following:

Decision variables: Target variables that are to be estimated by the model. The problem is solved when the best/ most optimal values are found for decision variables.

Constraints: A set of equalities/inequalities that are imposed on decision variables, limiting the values that may be chosen for them by the model.

Objective function: A linear equation that consists of decision variables and is subject to constraints. Depending on the problem, the objective function is either minimized or maximized.

For more details on the theory of linear programming refer* ***Appendix I.*

Part 5 Optimization Model: The Objective Function

The objective function is set to minimize the costs for KSE, more specifically the costs associated with delivery and fixed costs that are required to maintain a warehouse.

The model will achieve this objective in two folds: 1) by creating the optimal assignment of zips to the closest warehouses or due to constraints 2) suggesting warehouses that are incurring costs and not adding value thus need to be closed.

The formula for the objective function:

$$\text{Min} \sum_{i=1}^{11} \sum_{j=1}^{3192} TC_{ij} x_{ij} + \sum_{i=1}^{11} FC_i w_i$$

Where:

$TCij$ = transportation cost between warehouse i and zip j.

FCi = fixed cost for warehouse i.

xij = 1 if zip j is assigned to warehouse i otherwise 0.

wi = 1 if warehouse i is kept open, otherwise 0.

In simple terms, the model will create binary values of 0 or 1 for each combination of zip code and warehouse, which would represent the assignment of zips to warehouses (xij). Similarly, the model will choose 0 or 1 depending on whether a warehouse is serving at least one zip code and needs to stay open (wi).

Optimization Model: Constraints

To arrive at the accurate solution, the model needs to consider a few constraints:

1. A single zip code can be serviced only by one warehouse

To increase efficiency and optimize the warehouse network, it's crucial to ensure that each warehouse focuses on servicing a specific area of clients. So, by restricting the model to assign only one warehouse to a single zip code we allow for that efficiency of product delivery and client satisfaction.

Mathematically, the formula for the constraint is as follows:

$$\sum_{i=1}^{11} x_{ij} = 1$$

For each zip code j = 1,2,3 … 3192

Where:

xij = 1 if zip j is assigned to warehouse i otherwise 0.

2. ***Next Day delivery must be available to 90% of the total sales generated by all the zip codes***

With increasing customer expectations on next day delivery, it's important for KSE to optimize their network to provide fast delivery options in order to increase market share and remain competitive. The model will provide a solution for optimal zip code to warehouse assignment that would allow to offer the next day delivery option to 90% of all sales generated. Next day delivery will be defined by a specific radius around a warehouse that makes fast delivery possible.

Mathematically, the constraint consists of two parts. The left-hand side will assign a 1 or 0 to a value c, indicating whether a zip code is within the specified radius. Once this coefficient is multiplied by xij it dictates the model to keep (if c=1) or ignore (if c=0) the zip code. The right-hand side will ensure that 90% of total sales can be delivered within the next day.
The formula for the constraint is as follows:

$$\sum_{i=1}^{11} \sum_{j=1}^{3192} cij\, x_{ij} S_j < 0.9\text{*TS}$$

Where:

cij = if zip j is within next day delivery radius of warehouse i.

3,192 – total number of zip codes serviced.

Sj = Sales generated by Zip code j.

TS = Total Sales generated by all zip codes.

3. ***If at least one zip code is assigned to a warehouse, the warehouse needs to stay open***

This constrains ensures that KSE doesn't close the warehouses that are optimal for serving certain zip codes of clients. The logic behind the mathematical equation is that for each warehouse if at least one combination of zip code-warehouse is 1 then a coefficient responsible for keeping a warehouse open (w_i) is forced to become 1.

The formula for the constraint is as follows:

$$\sum_{j=1}^{3192} \boldsymbol{x_{ij}} - \boldsymbol{M} * \boldsymbol{w_i} \leq 0$$

For each warehouse i = 1,2,3 … 11

Where:
M is a variable with a predefined value that ensures that no matter how many zip codes (x_{ij}) are assigned to a particular warehouse the equation isn't violated. *M* is any reasonably big value that is equal to or greater than the total number of zip codes.

4. ***A constraint that would track warehouse capacities to ensure assigned sales do not exceed the maximum warehouse capacity***

Due to lack of information on warehouse capacity in dollar amounts, this constraint is going to be analysed once the results of the model will become available. The approach would include comparing assigned sales volumes with historical volumes and utilization rates.

Optimization Model: Model Variations

The model presented above in terms of the objective function and constraints will be replicated 3 times with a small variation in next day delivery radius. In the initial model, 300 miles is chosen as the next day delivery radius. However, to understand the effects of choosing different radii, the model will also be tested with a radius of 250 miles and 150 miles.

When the radius decreases from 300 miles to 250 miles, the expected result is a reduction in the actual level of next-day delivery achieved. Since the delivery radius is only being reduced by 50 miles, the resulting reduction in deliveries is not expected to be significant.

When the radius is decreased to 150 miles, a significant reduction in service level is expected. The consequences in this case are decrease in customer satisfaction and potential loss of market share. But it is to be noted that since one of the constraints accounts for a service level of 90% or greater, the sales delivered within next day for all three models cannot be below 90%. These models can also be tested for different service levels of 85% or 95% but that is out of the scope for this report.

Part 6 Results and Analysis

The objective function and the constraints seen in are used to set up three linear programming models, each one with a different next-day delivery radius and next-day delivery service level at 90% of total sales. The models were:

1

Model 1: 300 miles delivery radius

2

Model 2: 250 miles delivery radius

3

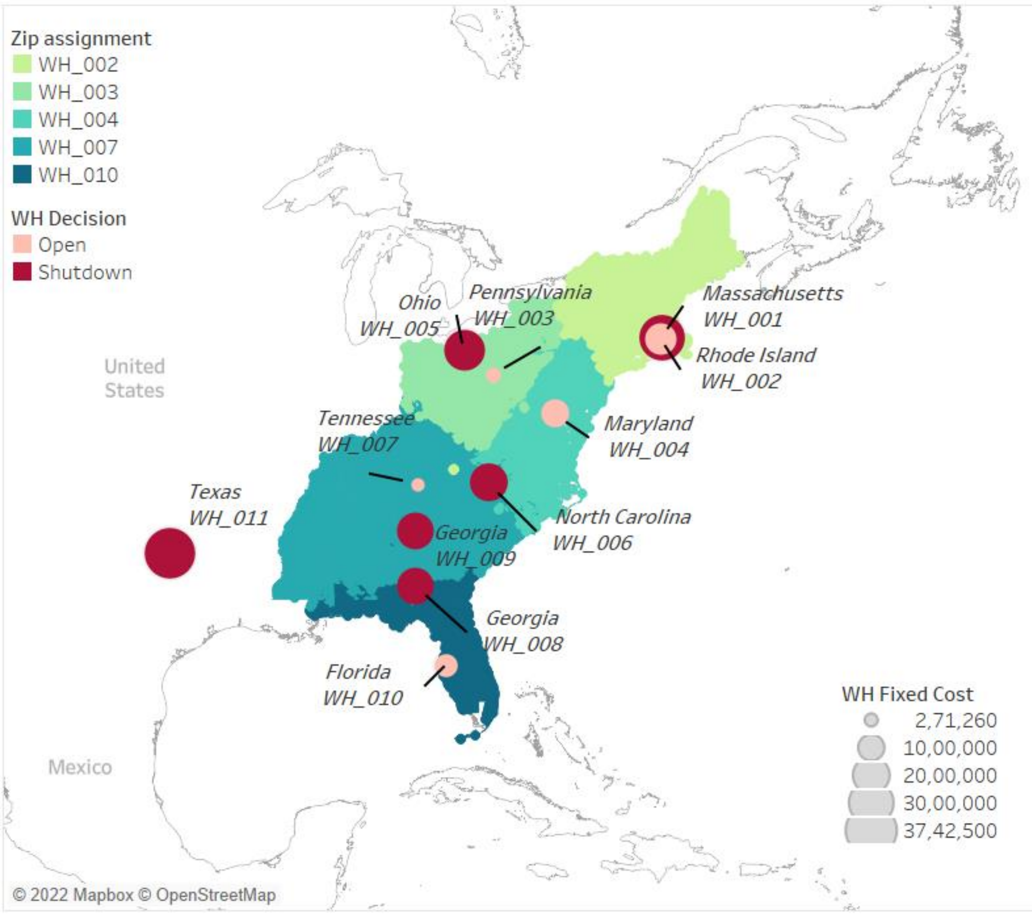
Model 3: 150 miles delivery radius

Model 3, with a 150-mile radius, rendered no feasible solution. This meant that for that model an optimal value for the decision variables could not be obtained given all three constraints. This might be because 150 miles was small for all zips to be assigned to a warehouse while keeping costs down and simultaneously trying to achieve a next-day delivery level of 90%. Since Model 3 did not have a feasible output, the rest of the report is focused on analysing results for Model 1 and Model 2. The output analysis has been organized under 5 major themes, namely: zip code assignment, next-day delivery level (Service level), sales, warehouse capacity, and product mix.

Results and Analysis:
Zip Code Assignment

One of the main objectives of this project is that each zip code gets assigned to a unique warehouse. This is ensured by building it as a constraint into the model as seen in Part 4. ***Figures 6.1 and 6.2*** show the assignments of 3192 zip codes in the eastern region to different warehouses because of Models 1 and 2. They also show the warehouses that were kept open and the once that were shut down along with the warehouse fixed costs. This can also be seen from ***Table 6.1***.

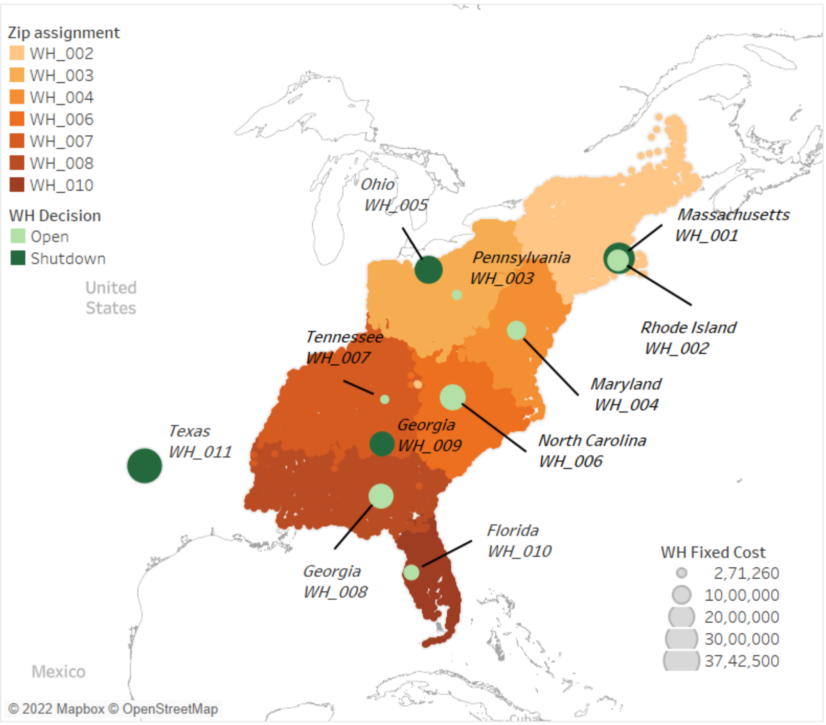
Figure 6.1: Map of zip code assignments for 300 miles next day delivery radius



It has been observed that when a 300-mile radius is chosen, 5 warehouses must be kept open and all of them have a lower fixed cost. On the other hand, for a 250-mile radius model, 7 warehouses are kept open which includes the slightly larger warehouses 6 and 8 in North Carolina and Georgia, respectively. This is because as 300 miles is a higher service radius more zip codes can be assigned to a single warehouse. Thus, some zip codes that are assigned to the Tennessee warehouse under model 1, are redistributed between warehouses in Georgia and North Carolina under model 2, while the Georgia warehouse also takes over some zips that are allocated to the warehouse in Florida under the former model.

Results and Analysis: Zip Code Assignment

Figure 6.2: Map of zip code assignments for 250 miles next day delivery radius



It is also observed that the highest number of zips are assigned to warehouse 7 in Tennessee for model 1 and to warehouse 2 in Rhode Island for model 2. One drawback of choosing a service radius of 300 miles is that many zips are being assigned to one of the smallest warehouses in Tennessee. Thus, it is recommended to go through the warehouse capacity analysis before choosing a feasible service radius. ***Table 6.1*** shows that all warehouses as closed under 150-mile model signifying the infeasibility of a solution.

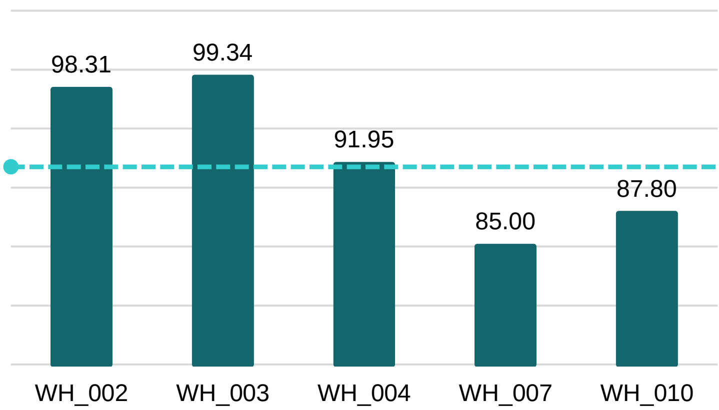
Table 6.1: Shutdown of warehouses for different service radii

Warehouses	Location	150mi Model	250mi Model	300mi Model
WH_001	MA	Closed	Closed	Closed
WH_002	RI	Closed	Open	Open
WH_003	PA	Closed	Open	Open
WH_004	MD	Closed	Open	Open
WH_005	OH	Closed	Closed	Closed
WH_006	NC	Closed	Open	Closed
WH_007	TN	Closed	Open	Open
WH_008	GA	Closed	Open	Closed
WH_009	GA	Closed	Closed	Closed
WH_010	FL	Closed	Open	Open
WH_011	TX	Closed	Closed	Closed

Results and Analysis: Next-day Delivery (Service) Level

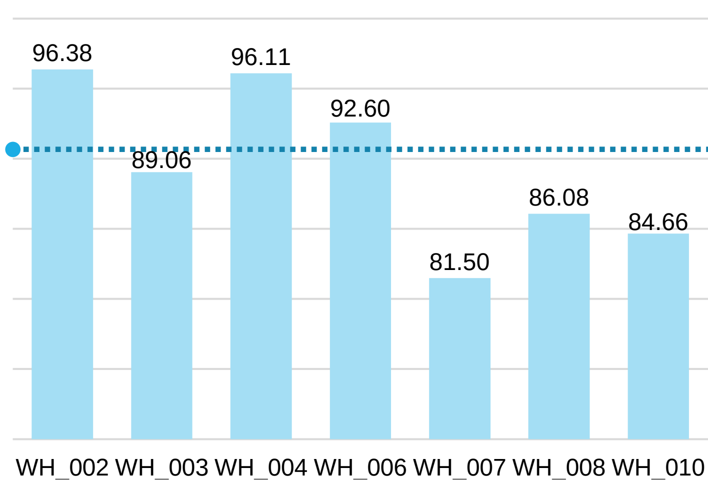
The two ***Figures 6.3 and 6.4*** show the percentage of sales that can be achieved by each warehouse that is kept open for a chosen service radius. In the constraint 2 in Part 4 we set the service level to be 90% and above, which means that on an average all the models will have a service level of 90% or higher but the exact next-day delivery level achieved under each of the models are given as follows:

Figure 6.3: Percentage of sales delivered within the next day for 300-miles model



Model 1: **91.75 %** of sales can be fulfilled by the five warehouses that are not shut down by the next day. **60%** of the warehouses have above the average next day delivery satisfaction.

Figure 6.4: Percentage of sales delivered within the next day for 250-miles model



Model 2: **90.68 %** of sales can be fulfilled by the five warehouses that are not shut down by the next day. **43%** of the warehouses have above the average next day delivery satisfaction.

From the results it could be observed that that the average service level achieved by model 1 is only 1.07% higher than model 2. Although there is no significant difference between the models with respect to average service level, there is significant difference in the number of warehouses that can achieve the 90% benchmark. If 250-mile radius is chosen only 3 out of 7, warehouses will be able to deliver at-least 90% of sales within the next day which is significantly lower than if 300-mile radius is chosen.

Results and Analysis: Sales

Figure 6.5: Total sales across warehouses

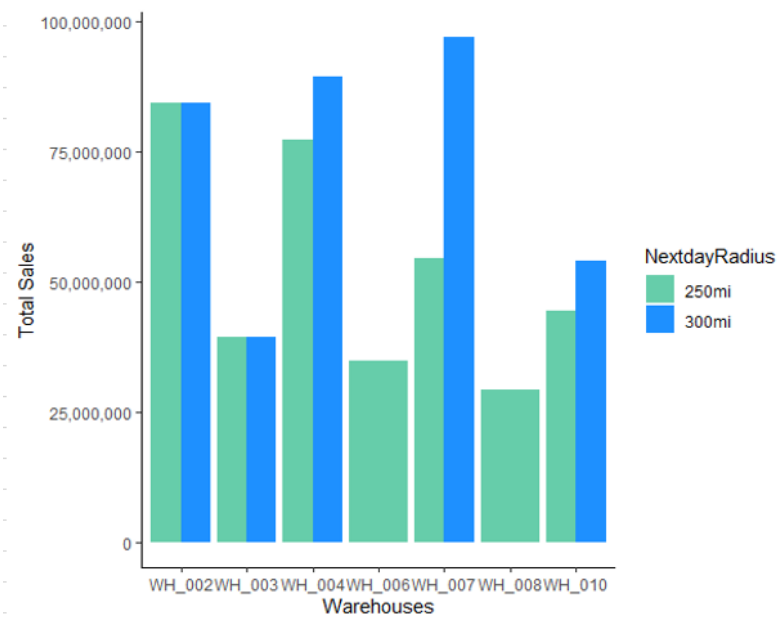
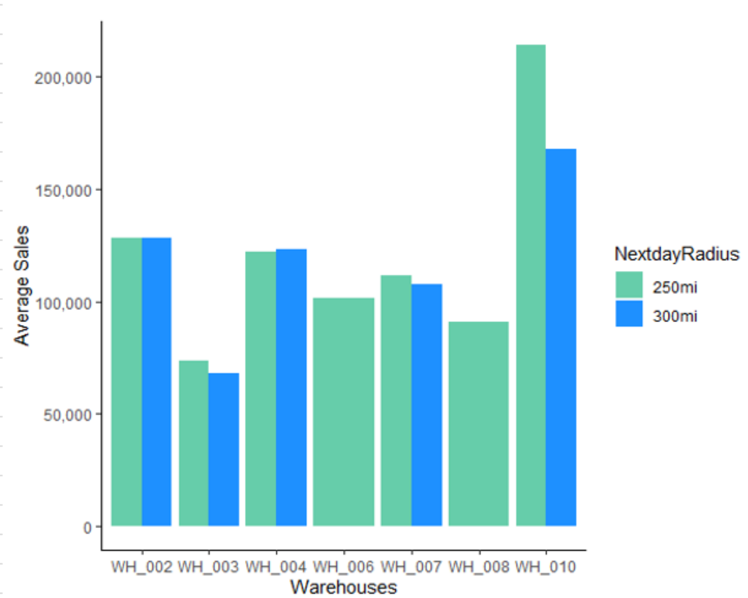


Figure 6.6 Average sales across warehouses



- For models 1 and 2, ***Figures 6.5 and 6.6*** show the total and average sales for each open warehouse.

- The key takeaways regarding sales are that irrespective of the chosen next-day delivery radius, the total sales generated by zips allocated to warehouse 2 in Rhode Island is the same, despite the model 2 utilizing more warehouses.

- Additionally, when looking at average sales, warehouse 10 in Florida has a much higher average sales for both models. This is because the Florida warehouse has the fewest zip codes assigned to it, elevating its average sales above that of other warehouses.

Results and Analysis: Warehouse capacity

Due to lack of information on warehouse capacity in dollar amounts, this constraint has not been included in the model but needs to be considered alongside the output results.

The suggested approach is based on conversion of sales and sqft into cartons based on the assumption that $100 equals one carton/box (KSE provided information). The exact steps of the approach to warehouse capacity model can be found in the Appendix II.

Model 1

Based on the results, the model kept 6 warehouses open, all of which are the smallest out of the 11 in terms of their capacities.

Table 6.2: Warehouse capacity Vs. Assignment in terms of volume

Warehouse	Cubic feet warehouse capacity	Cubic feet assigned	Cubic feet difference
WH_002	2,607,795	874,527	1,733,268
WH_003	621,000	408,822	212,178
WH_004	2,079,000	928,416	1,150,584
WH_007	488,268	1,005,344	(517,076)
WH_010	1,395,279	561,549	833,730

Table 6.3: Warehouse capacity Vs. Assignment in terms of number of boxes

Warehouse	Boxes capacity	Boxes assigned	Boxes difference
WH_002	419,101	140,546	278,555
WH_003	99,801	65,702	34,099
WH_004	334,118	149,206	184,911
WH_007	78,470	161,569	(83,100)
WH_010	224,236	90,247	133,989

Comparing the assigned volumes with the capacity as shown in ***Table 6.2 and 6.3***, there are two key issues that arise:

Issue 1: For the Tennessee warehouse (warehouse 7) the assigned sales exceed that of its capacity. Almost 17% of total assigned sales violated the capacity constraint of warehouse 7. This is the smallest warehouse with capacity below the national average[1]

[1] "Typical Warehouse Square Footage Sizes - Space Planning Tips." *Warehouse1*, 24 Nov. 2020, https://www.wh1.com/warehouse-square-footage-tips/#:~:text=In%20the%20past%2C%20most%20warehouses,50%2C001%20square%20feet%20or%20larger.

and since the model is blind to the capacities, the end user needs to be aware of this risk and be ready to create a manual intervention.

Recommended solutions:

- *Redistribute to other nearby warehouses the assigned sales that do not fit.* The closest warehouse that would stay open is warehouse 10 in Florida and it has excess capacity of almost a million cubic feet. Looking at the distribution of assigned to warehouse 7 zip codes, it is observed that 97% of them are in Florida or Georgia, which makes them perfect candidates for re-assignment. 17% of total warehouse seven sales represent 650,000 cubic feet that would fit into the warehouse ten in Florida and not exceed its capacity. However, KSE needs to be aware of the potential risk that such reassignment can lead to decreased service level for warehouses 7 and 10, and next day delivery may not be available to the zip codes that were reassigned due to the constraint.

- *Expand warehouse 7 through one or a combination of these methods:* 1) increasing operational efficiency of warehouse seven, 2) leasing/ buying additional space nearby (includes new space as well renting some excess space of other distributors in the area) 3) implementing crossdocking approach to next day deliveries. Without doubt, each option has its own advantages and limitations, and further analysis would need to be conducted to find the optimal solution for KSE.

Issue 2: significant underutilization of the rest of the warehouses. Most of the warehouses have large amounts of extra space available

Recommended solutions:

- *Consolidate operations into a designated area of a warehouse and use the rest of the space for what is called customizing*: using the space to add value to a product such as repairs, labeling or packaging of products.

- *Alternatively, the extra space could also be simply leased out to other distributors.*

Results and Analysis: Warehouse capacity

Model 2

The output result kept seven warehouses open, including warehouses six and eight that have large storage space available.

Table 6.4: Warehouse capacity Vs. Assignment in terms of volume

Warehouse	Cubic feet warehouse capacity	Cubic feet assigned	Cubic feet difference
WH_002	2,607,795	874,527	1,733,268
WH_003	621,000	408,822	212,178
WH_004	2,079,000	801,147	1,277,853
WH_006	3,780,000	362,499	3,417,501
WH_007	488,268	566,664	(78,396)
WH_008	3,564,000	303,450	3,260,550
WH_010	1,395,279	461,547	933,732

Table 6.5: Warehouse capacity Vs. Assignment in terms of number of boxes

Warehouse	Boxes capacity	Boxes assigned	Boxes difference
WH_002	419,101	140,546	278,555
WH_003	99,801	65,702	34,099
WH_004	334,118	128,753	205,365
WH_006	607,486	58,258	549,229
WH_007	78,470	91,069	(12,599)
WH_008	572,773	48,768	524,005
WH_010	224,236	74,176	150,061

In this model, the same two issues of warehouse seven being stretched out and all the rest of the warehouses being underutilized persist.

Issue 1: For the Tennessee warehouse (warehouse 7) the assigned sales exceed that of its capacity.

Recommended solutions:

- Solutions to the excess sales of warehouse seven are the ones that were described in Model 1 output: reassignment or expansion.

Issue 2: Significant underutilization of the rest of the warehouses. Most of the warehouses have large amounts of extra space available

Recommended solutions:

- *Consolidation of warehouses six, seven, and eight are in nearby states of North Carolina, Tennessee, and Georgia.* Consolidations of all sales to the biggest warehouse of the three (warehouse six in NC) and closure of the other two would allow us to avoid wasting warehouse space already paid for in fixed costs. However, as mentioned in Model 1, this has a considerable risk of reducing the service level and the feasibility of next day delivery.

- *Leasing out the extra space or customizing as suggested in Model 1 output analysis.*

Results and Analysis: Product mix

Table 6.6: Percentage of sales by product type and warehouse under Model 1

WH_ID	Equipment	error	Leasing	NULL/Misc	Service	Supply	(blank)
WH_002	32%	0.03%	0.02%	24%	0.25%	44%	0.002%
WH_003	35%	0.00%	0.01%	43%	0.35%	22%	0.00%
WH_004	36%	0.00%	0.03%	32%	1%	32%	0.00%
WH_007	52%	0.00%	0.09%	34%	2%	12%	0.00%
WH_010	53%	0.03%	0.16%	35%	3%	9%	0.01%

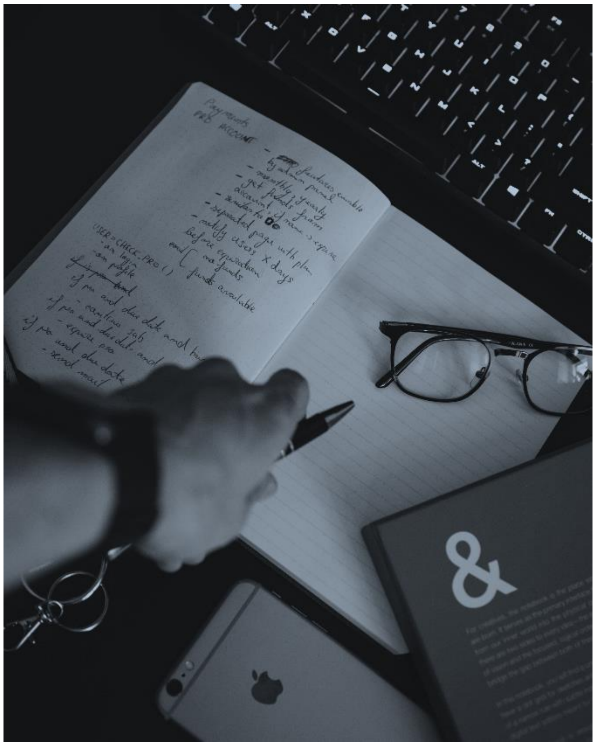
Table 6.7: Percentage of sales by product type and warehouse under Model 2

WH_ID	Equipment	error	Leasing	NULL/Misc	Service	Supply	(blank)
WH_002	32%	0.03%	0.02%	24%	0.25%	44%	0.002%
WH_003	35%	0.00%	0.01%	43%	0.35%	22%	0.003%
WH_004	36%	0.00%	0.04%	27%	0.75%	36%	0.001%
WH_006	39%	0.00%	0.00%	55%	1.27%	5%	0.000%
WH_007	55%	0.01%	0.14%	29%	2.55%	13%	0.005%
WH_008	59%	0.00%	0.04%	26%	3.29%	12%	0.000%
WH_010	49%	0.04%	0.20%	38%	3.29%	9%	0.008%

By taking zip allocations into consideration along with historical divisional sales the three main product types recommended for focusing inventory of warehouses in service under both the models are Equipment, Miscellaneous and Supply.

- On average across all the warehouses, **equipment** generates the highest sales with 41.6% and 43.57% under models 1 and 2, respectively.
- 33.6% of sales are generated on average under model 1 and 34.57% under model 2 by **miscellaneous** category.
- **Supply** contributes third highest sales of 23.8% and 20.14% under the respective models 1 and 2.
- If a 300-mile radius is chosen**,** warehouses 7 and 10 are best suited to house **service.** Alternatively, warehouses 6, 7, 8 and 10 can house services when 250-mile radius is chosen. This is a crucial factor to consider for to make provisions for after sales services like warranty service, training, or repair for a product.

Part 7:
Final Recommendations



Tables 7.1 and 7.2 display some key metrics important for both models. The final recommendations are based on these Key Performance Indicators (KPIs). The choice of the next-day delivery radius is dependent on which KPIs the company chooses to prioritize and its capabilities. The recommended model based on different priorities are given as follows:

Next-day delivery Level:

If service level, in terms of the percentage of sales that are fulfilled within the next day, is the priority for the company then the 300-miles model is recommended. This is due to Model 1’s next day delivery level of 91.8%, compared to Model 2’s 90.8% service level. Additionally, Model 1 is recommended in this case, as 60% of warehouses can exceed the average service level while only 43% of warehouses will be able to exceed the average service level if a 250-mile radius is chosen.

Overall Cost Reduction:

If overall cost reduction is the priority, then, the **300-miles model** offers 60% reduction in warehouse costs. This is achieved by shutting down warehouses in Massachusetts, North Carolina, Georgia, Ohio, and Texas which have a large capacity and thus incur higher costs. This loss of capacity would not be an issue as we see from analysis in Part 6 that the remaining warehouses operate with excess capacity. Another important advantage is that Model 1 results in the lowest total costs of $ 10,595,857.

One potential drawback of Model 1 is that the Tennessee warehouse is operating above its capacity limit and therefore the zips assigned to this would have to be reassigned to the nearest warehouse in Florida. This would mean the transportation costs would be higher and the next day delivery goal would not be met for these zips. One solution to this could be to expand the capacity of the warehouse in Tennessee to accommodate these zips. The choice between the two options would depend on resource and budget allocation capabilities.

Reduction in miles driven for delivery:

If reducing the miles driven is the priority, then **250-miles model** (Model 2) is recommended as it reduces the miles driven for delivery by 71. 2%, which is much higher than the reduction achieved under Model 1. Simultaneously Model 2 offers a nominal reduction in warehouse costs compared to original network, while also cutting down miles driven by 71.2%, since this model will be operating with a greater number of warehouses. However, the unused excess warehouse capacity is greater in this option than with Model 1. To cut down on some of the warehouse fixed costs, Tennessee can be serviced by the nearest larger warehouse in North Carolina. But reassigning some of customer zip codes to warehouses farther away, this could also potentially mean reducing the capability to serve some of them by the next day.

Table 7.1: Key metrics for model 1

Metrics	Values
Warehouse Fixed Costs Reduction	60%
Reduction in miles	67.65%
Next Day Delivery Level	91.75%
Minimum Cost (Model Output)	$ 10,595,857
Excess Warehouse Capacity	3,672,976

Table 7.2: Key metrics for model 2

Metrics	Values
Warehouse Fixed Costs Reduction	50%
Reduction in miles	71.20%
Next Day Delivery Level	90.68%
Minimum Cost (Model Output)	$13,654,982
Excess Warehouse Capacity	9,578,708

Part 8:
Next Steps

Upon a proper rollout of the model in the concentrated Northeast America region, a perspective can be reached on certain obstacles that can occur while putting the model into action and this model will eventually have to be tailored and customized to achieve most timely and profitable results. Once these challenges have been met, the model can be rolled out to the rest of the North American region, gradually, as tests are set out to see regions that can meet their own goals to support the goal of achieving 90% delivery of sales orders within the next day. Eventually, they will be able to set up warehouses across North America and thereby facilitate orders across the region based on zonal demand.

Long-term solutions to further optimize logistics

Once the model has been successfully integrated, KSE can consider the following options to further optimize the network:

1) **Inventory planning & management**: Based on the model and to achieve the main goal of warehouses to deliver 90% of sales, recommendations can be made on three fronts:
    - Inventory-warehouse space planning: Recommendations can be made to have a proper mix across divisions to maximize warehouse space efficiently to optimally deliver a variety of products across various categories based on varied customer orders.
    - Different product category: Since the warehouses will have to support products across various categories, inventory within each warehouse should be aligned with zip/zonal demand. The assortment of SKUs that would be distributed to each warehouse has to reflect the stock planning needs to align with the demand. After analyzing sales across divisions inventory demand from the zip codes assigned to each warehouse.
    - Just-in-time Inventory: A big concern for companies is finding the perfect balance between frozen stock and lost sales. KSE needs to ensure that with next day deliveries the stock out levels do not increase. To avoid the potential risk, vendor shipment schedules need to be re-evaluated and KSE might need to increase frequency of deliveries from vendors.

2) **Logistics planning and optimization:** The success of the model can help one make decisions on rolling out a de-centralized logistics strategy which includes some certain criteria to consider:

- Private fleet vs. Common carrier: A decentralized network as per this model will help KSE to not only ship the product to the customer within the next day, but it will also give KSE the added advantage to circumvent shipping costs. Based on warehouse location and logistical overheads, recommendations can be made for KSE to choose from their own transportation fleet to fulfil orders through 3PL (third Party logistics). Once these logistical structures are in place a minimum order value can also be determined for customers who would like their order to be shipped for free.

- Yard Management: KSE could leverage the yard management solutions to optimize inbound and outbound fleet movement at the warehouses and increase efficiency.

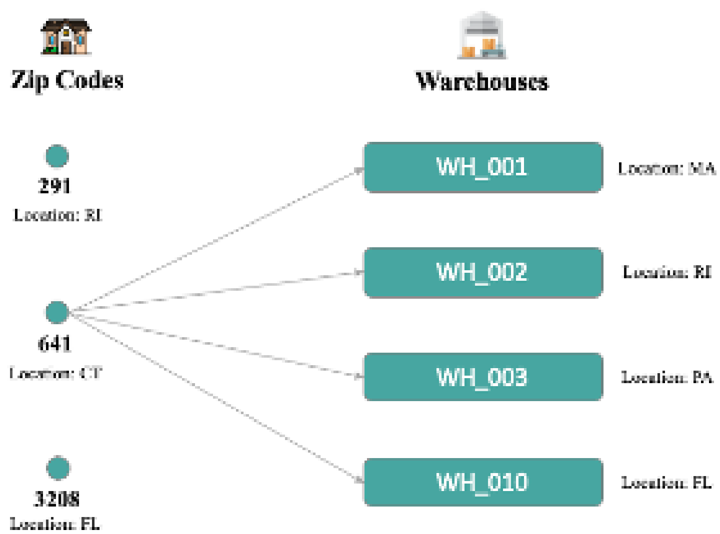
3) **Order Fulfilment:** Key recommendations can be made to automate order flow once decentralized network is established. By conducting proper what-if scenarios through the model we can see if the network can support 85% or even 95% of orders within the next day and compare it to the current goal of 90%

Appendix I

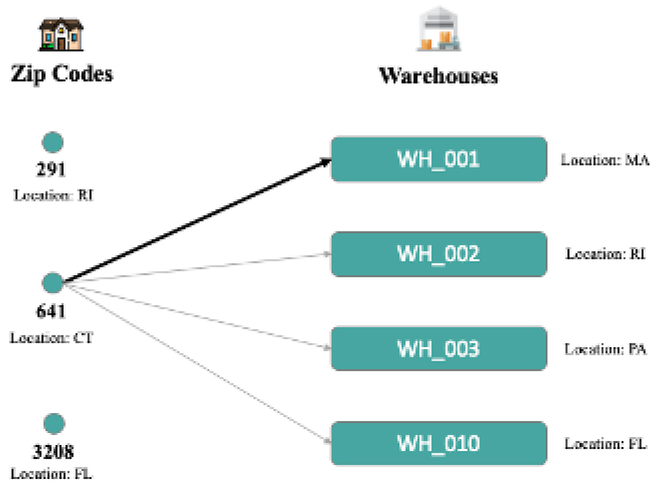
This part of the paper is optional and is designed with the intention of expanding on the theory of linear programming described on page X for those that are interested in learning more.

The network optimization model relies on a more complicated type of linear programming called *binary integer linear programming.* The main distinction is that decision variables within the objective function are binary and represent an assignment decision: 0 if the zip code is not assigned to a particular warehouse based on distance and constraints or 1 if it is. Visually, the assignment problem will look the way it is illustrated below:

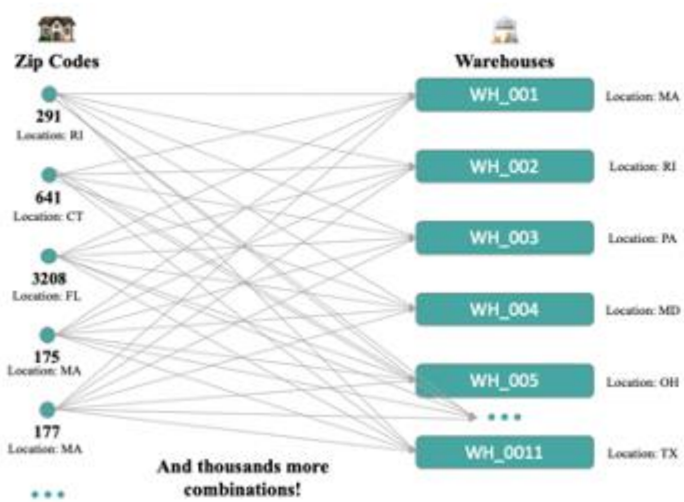
In this small example, a household in Connecticut can be serviced by warehouses all around the North-eastern region.



One optimal solution that would reduce the miles a truck spends on the road to deliver the package is to service the household from neighbouring Massachusetts.



But that is just one solution. Scaling the problem to all zip codes and warehouses, we have thousands of zip codes and 11 warehouses, making the final problem look something like this but even more complex.



Mathematically, the model will be responsible for finding out the optimal assignments illustrated above based on a matrix table that was created ahead of time. Based on the logic of binary variables described in part IV of the paper, the zip-warehouse pairings create a matrix table that is multiplied by the corresponding transportation and warehouse costs in the objective function. Below is an example of such table:

Warehouse/ Zip code	Zip 291	Zip 641	Zip 3208
WH 1	0	0	1
WH 2	1	0	0
WH 3	0	1	0

Appendix II

Warehouse capacity calculation

The suggested approach is based on conversion of sales and square feet into cartons based on the assumption that $100 equals one carton/box.

The exact steps of the approach are as follows:

Part 1: Calculate the number of boxes possible to store for a given warehouse:

1. *Usable sqft = total sqft - non-storage space*

   Where:

   a. Non-storage space: such as offices, bathrooms.
   b. Non-storage space is assumed to be 10% of the total space.
2. Assumed average height of a warehouse in the US is 36 ft[2].
3. *Total of a warehouse (WH)= usable sqft * height*
4. *Weighted average V of a box = average medium box*weight + average small box*weight* Where:
   a. V – volume.
   b. Medium box size is estimated based on the equipment product types (such as a dishwasher).
   c. Small box size is estimated based on the supply product types (for example, utensils).
   d. Weights are the estimated share of sales of each type of product sales.
5. *Capacity in number of boxes = Total WH / Average V of a box*

Part 2: Calculate number of assigned SKUs and their cubic feet per TBPO (time between purchase orders):

1. Use historical data of zip4 sales to calculate sales of each warehouse based on the assigned zips from the model. If one TBPO lasts 1.5 months;
2. Total boxes assigned per TBPO= WH sales / $100
3. Total   assigned per TBPO = Total cartons assigned * A*verage V of a box*

Part 3: Compare the difference between the cubic feet capacity and the assigned cubic feet capacity and adjust if necessary.

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[2] Placek, Martin. "Logistics Industry: Average Height of Distribution Center Networks U.S. 2016-2021." *Statista*, 12 Apr. 2022, https://www.statista.com/statistics/947267/logistics-distribution-center-network-average-height-united-states/.