2017

Supply chain network design case study

WAREHOUSE LOCATION- TRANSPORTATION COST MINIMIZATION

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SUMMARY

A Glass manufacturing company has 4 plants and serves 50 customers located across the US, each of which has demand for five different glass products. Currently, the company produces each product at one location only and serves each customer directly from the source plant. Chapter 1 explains the current state of the distribution network and finds the optimal flow of materials with given souring, transportation and production policies.

However, the services to the distant customers has been unreliable and there has been increase in the transportation cost due to various reasons. Now, the CEO wants to design a new supply chain network to improve the service level such that 80% of the demand should be served by the nearest facility. For that, proposal to build warehouses has been made and the company wants to figure out the minimum number of warehouses to be built, their location and the flow of the products. Chapter 2 solves this problem by using the developed facility location MIP model.

The company can reduce the transportation cost by 19.75% with investment of $50,000,000 to build 5 warehouses at the strategic locations suggested by the developed model. Though, the company would have reduction in profits and increase in overall network cost in the first year, but the savings in the transportation cost could break even in 2.5 years. All codes of the optimization models and input/output data is in the folder ‘Solutions’ for reference. Please feel free to connect with me in case of any difficulties in understanding the analysis and the model. Thank you!

CHAPTER I

BASELINE MODEL

1.1 Baseline distribution network:

- The company manufactures 5 products (Clear, Green, Red, Blue, and Gray) from its 4 plants (■) and distributes them directly to the respective 50 customers (△). As the company produces each product at one location only and serves each customer directly from the source plant, the following visualizations will help us understand the current situation better.
- **Figure 1.1-1.4** shows the current distribution network of respective products along with the visualization of the service area coverage of 500 miles from each plant in green.

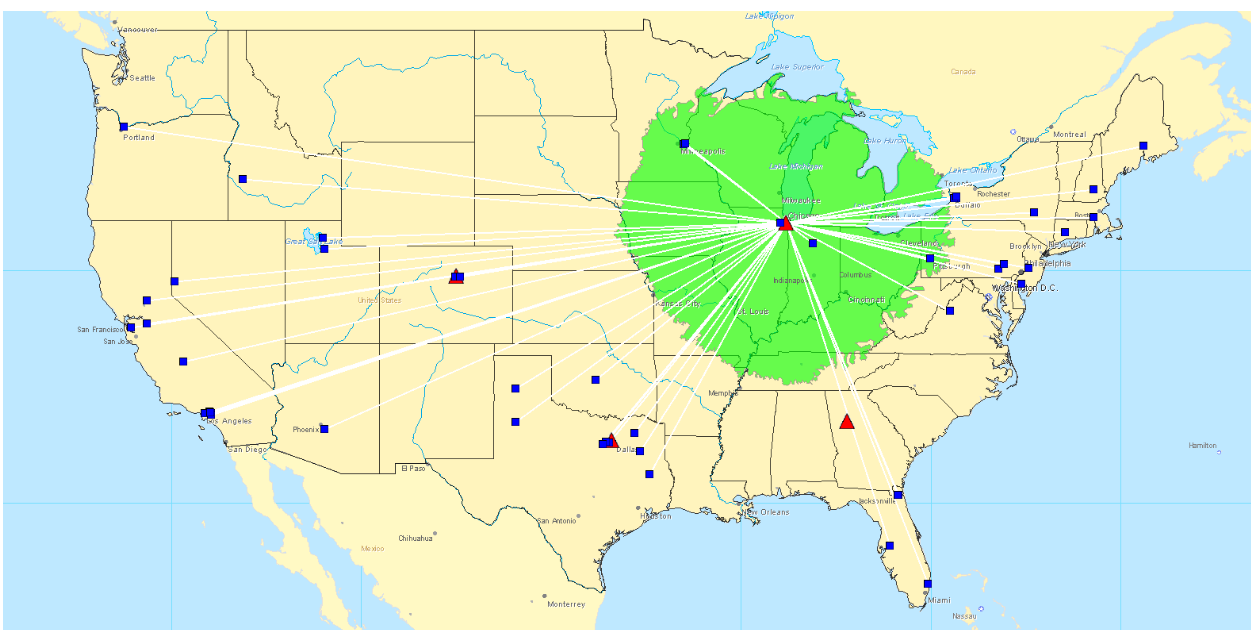

Figure 1.1: Distribution network of the 'Clear' product

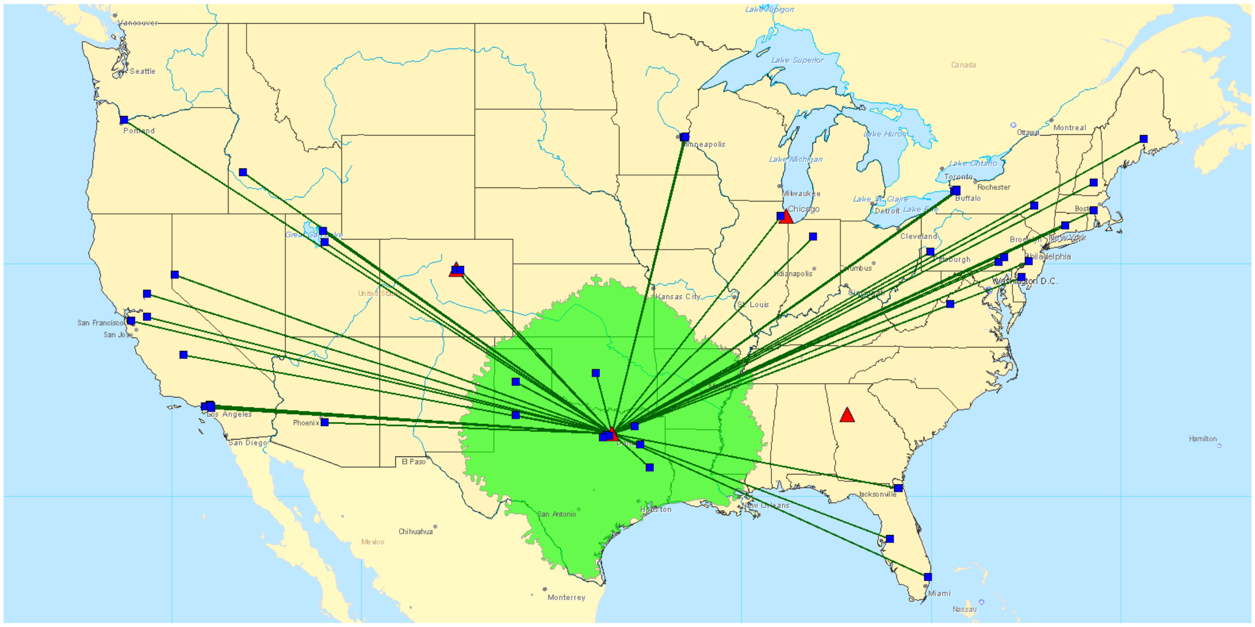

Figure 1.2: Distribution network of the 'Green' product

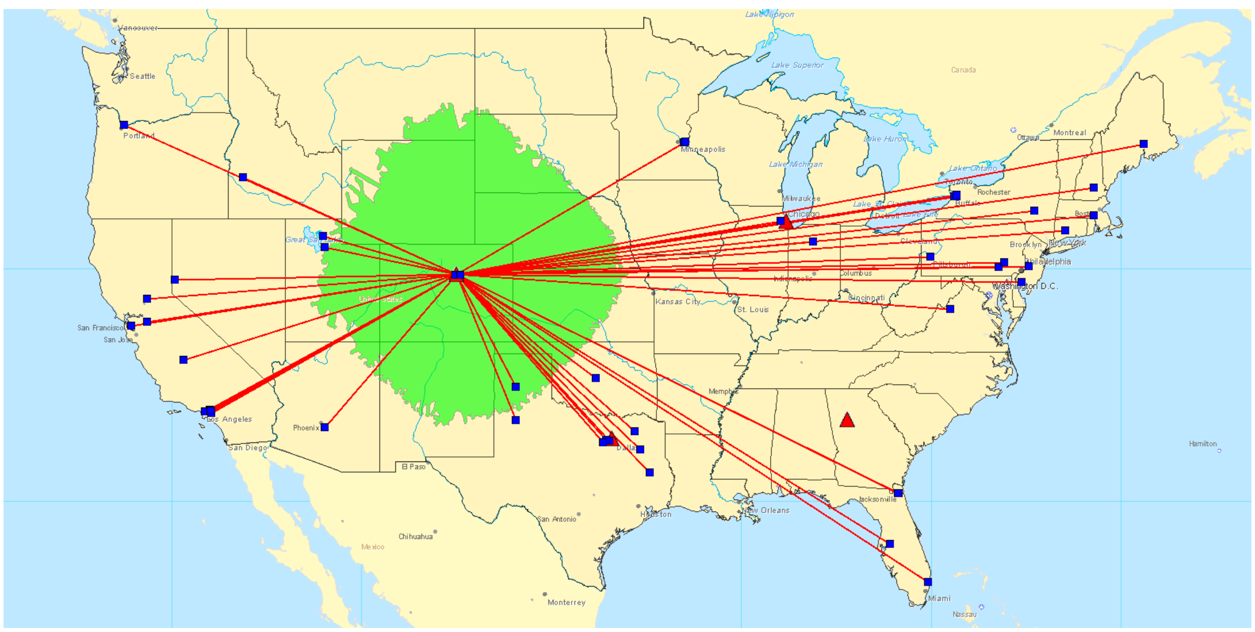

Figure 1.3: Distribution network of the 'Red' product

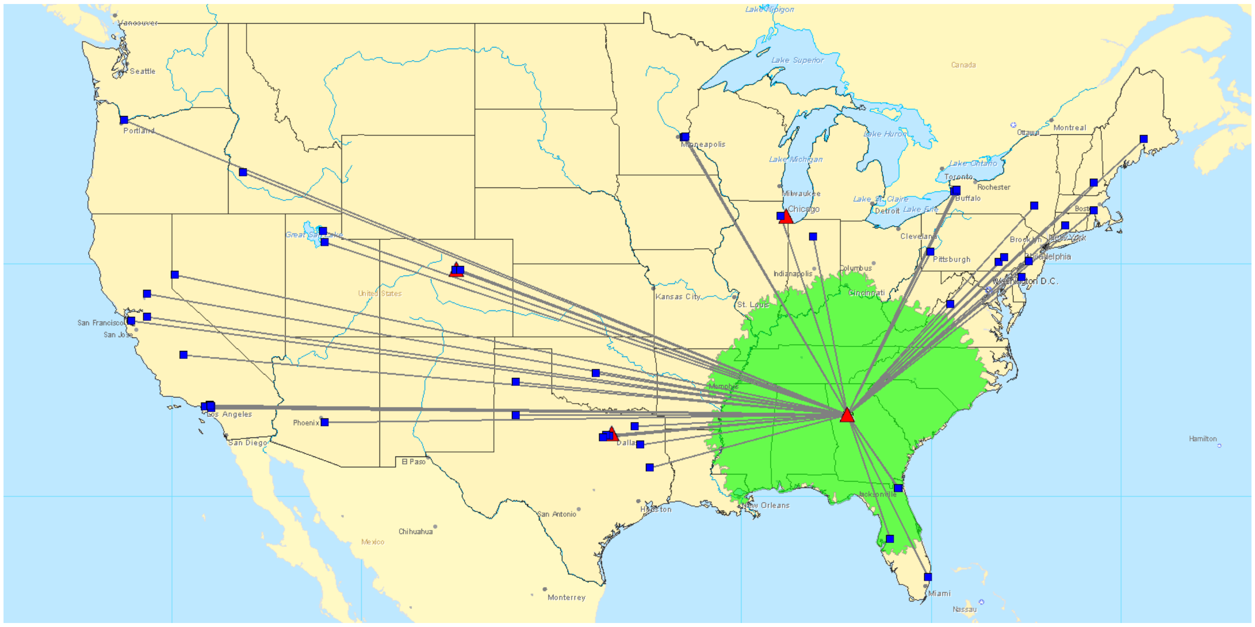

Figure 1.4: Distribution network of the 'Blue' and 'Gray' products

- **Table 1.1** summarizes the service levels of the current distribution network from each plant to the customers. Currently, only 11% of the total demand is served within 500 miles from the respective source plants, which is resulting in unreliable services to some distant customers.

Table 1.1: Coverage of the baseline model

Id.	Plant	Number of customers within 500 miles	Percentage of customers within 500 miles	Demand served within 500 miles (tons)	Total Demand served (tons)	Percentage of total demand within 500 miles
1	Plant A	5	10%	26160.35	295488.74	8.85%
2	Plant B	10	20%	16463.75	72580.14	22.68%
3	Plant C	4	8%	2215.13	29797.45	7.43%
4	Plant D	3	6%	910.73	17862.36	5.10%
		22	44%	45749.94	415728.68	11.00%

1.2 Preliminary information:

For the preliminary analysis, it is assumed that the total network cost consists of two contributors: Transportation cost and Production cost.

Folder location:

- Solutions\Baseline

Sourcing policy:

- Products flow directly from the plants to the respective customer demand location.

Transportation policy:

- Transportation costs are calculated at the rate of $0.2/ton/mile for Less than Truck Load (LTL)
- The distance between plants and customer is in the *'DistPlantCustomer.csv'* file.

Production policy:

- Plant A: makes Clear product, Plant B: makes Green product, Plant C: makes Red product, Plant D: makes Blue and Gray product. The plant production constraints which enforces, production of a particular at particular site only are mentioned in the *'PlantProductConstraints.csv'* file.
- The production capacity of each plant product wise is in the *'ProdCapPlantProduct.csv'* file.
- Each plant has 2880 hours/year of regular time production capacity and 1440 hours/year of overtime production capacity. The Production costs for overtime production is 50% more than regular time production.
- The production costs for each product in regular time and over time is in the *'CostProductRegOvrtime.csv'* file.
- Plant A can produce 100 tons/hour and Plant B,C and D can produce at 50 tons/hour

Demand policy:

- Demands for 2015 is considered as average of demands of 2012, 2013 and 2014.
- The 2015 demand of each customer product wise is in the *'DemandCustomerProduct.csv'* file.
- Demand for product 5 of customer 37 and 41 not given for any year, therefore need to ask but for the analysis, it is considered 0.

Revenue policy:

- As 100% of the demand is satisfied,

  Revenue= $\sum_{j=1}^{50}\sum_{k=1}^{5}$ (Revenue per ton)$_{jk}$*(demand)$_{jk}$

1.3 Model:

The following model minimizes the total production and transportation cost of the current supply network.

1.3.1 Notations:

- reg_k and ovr_k : the given regular and over time production cost for k^{th} product.
- x_{ijk} : is the quantity (tons) of the product k produced and shipped from plant i to customer site j in regular time.
- y_{ijk} : is the quantity (tons) of the product k produced and shipped from plant i to customer site j in over time.
- t : is the transportation rate, LTL= $0.2/ton/mile, FTL= $0.12/ton/mile (60% of LTL).
- $dist_{ij}$: is the distance between plant i and customer site j .
- i : denotes the plant, $i = 1, 2, 3, 4$.
- j : denotes the sites, $j = 1, 2, ..., 50$.

- k : denotes the products, $k = 1, 2, 3, 4, 5$.
- dem_{jk} : is the demand at the customer site j of product k.
- p_{ik} : is the plant product constant, 1 if plant i makes product k, else, 0.
- cap_{ik} : is the capacity of the plant i to produce product k.
- $regh$: Regular hour capacity = *2880* hours/year.
- $ovrh$: Over time hour capacity = *1440* hours/year.

1.3.2 Objective function:

To find the flow of product from plants to customers which has minimum production and transportation cost. First term in the objective function gives the production cost and second term gives the transportation cost.

$$\min \sum_{i=1}^{4} \sum_{j=1}^{50} \sum_{k=1}^{5} (reg_k * x_{ijk} + ovr_k * y_{ijk}) + \sum_{i=1}^{4} \sum_{j=1}^{50} \sum_{k=1}^{5} t * dist_{ij} (x_{ijk} + y_{ijk})$$

1.3.3 Constraints:

1) Demand satisfaction at each customer site constraint,

$$\sum_{i=1}^{4} (x_{ijk} + y_{ijk}) = dem_{jk} \qquad \forall j = 1, \ldots, 50, \ \forall k = 1, \ldots, 5$$

2) Production capacity and product constraint,

$$\sum_{j=1}^{50} (x_{ijk} + y_{ijk}) \le p_{ik} * cap_{ik} \qquad \forall i = 1, \ldots, 4, \ \forall k = 1, \ldots, 5$$

3) Production type and rate constraint,

Plant 1 Product 1

$$\sum_{j=1}^{50} x_{1j1} \le regh*100$$

$$\sum_{j=1}^{50} y_{1j1} \le ovrh*100$$

Plant 2 Product 2

$$\sum_{j=1}^{50} x_{2j2} \le regh*50$$

$$\sum_{j=1}^{50} y_{2j2} \le ovrh*50$$

Plant 3 Product 3

$$\sum_{j=1}^{50} x_{3j3} \le regh*50$$

$$\sum_{j=1}^{50} y_{3j3} \le ovrh*50$$

Plant 4 product 4

$$\sum_{j=1}^{50} x_{4j4} \le regh*50$$

$$\sum_{j=1}^{50} y_{4j4} \le ovrh*50$$

Plant 4 product 5

$$\sum_{j=1}^{50} x_{4j5} \le regh*50$$

$$\sum_{j=1}^{50} y_{4j5} \leq ovrh*50$$

Non negativity:

$$x_{ijk} \geq 0\,,\; y_{ijk} \geq 0$$

1.4 Output:

- The above optimization model minimizes the total network cost, and implemented in Python-Gurobi interface, the complete code is in the 'Basline_code.py' file.
- The output flow of the quantity of each products produced at their respective plants to the respective customer is in the *'BaselineOutputFlow.csv'* file.
- **Table 1.2** summarizes the current distribution networks transportation cost and production costs.

Table 1.2: Summarizes the baseline model costs

Sr.no	Description	Details	Cost
1	Production cost	Regular	$ 184,949,741.00
		Over time	$ 5,616,555.00
2	Transportation cost	LTL	$ 98,706,203.87
3	Total network cost		$ 289,272,499.87
4	Revenue		$ 431,191,066.00
5	Net Profit		$ 141,918,566.13

CHAPTER II

WAREHOUSE LOCATION SCENARIO

To improve the supply chain network of the company and to find out number of warehouses such that 80% of demand by tons is within 500 miles of the nearest source the following facility location mix integer model was created.

The objective is to the study the impact of addition of the warehouses in supply chain network. To find the best plant- warehouse-product-customer mix such that total network cost is minimized after satisfying the constraints, we divide the objective it in two parts. First, formulation (section 2.1) models the supply chain network from customers to warehouses and second (section 2.2) models the network from the warehouses to the plant.

2.1 Model 1:

This model gives the minimum number of warehouses to be opened in such a way that 80% of the demand by tons is within 500 miles of the nearest warehouse. It also minimizes the incurred transportation and warehouse opening cost. In addition, the solution we get from the model gives the location of the warehouses, flow of the products and transportation costs associated with the network.

Folder location:

- Solutions\Scenario_warehouse\part1_facilityloc

Sourcing policy:

- Warehouses can store all the products types and can receive from all the plants.
- Products flow from the potential warehouses to the respective customer demand location.

Transportation policy:

- Transportation costs are calculated at the rate of \$0.2/ton/mile for Less than Truck Load (LTL)
- The distance between plants and customer is in the *'DistancesWithinSites.csv'* file.

Demand policy:

- Demands for 2015 is considered as average of demands of 2012, 2013 and 2014.
- The 2015 demand of each customer product wise is in the *'DemandCustomerProduct.csv'* file.
- Demand for product 5 of customer 37 and 41 not given for any year, therefore need to ask but for the analysis, it is considered 0.

Revenue policy:

- As 100% of the demand is satisfied,

  $$\text{Revenue}= \sum_{j=1}^{50}\sum_{k=1}^{5} (\text{Revenue per ton})_{jk} * (\text{demand})_{jk}$$

2.1.1 Notations:

x_{ijk} : is the continuous quantity variable (tons) of the product k shipped from site i to site j

y_i : is the binary variable *{0, 1}*, 1 if warehouse is built at the i^{th} site, else, 0.

o_i : is the warehouse opening cost, assume to be \$10,000,000 each.

t : is the transportation rate, LTL= \$0.2/ton/mile

$dist_{ij}$: is the distance between site i and site j

r_{ij} : 1 if $dist_{ij} \le 500 miles$, else 0.

i : denotes the source sites, $i = 1, 2, ..., 50$.

j : denotes the destination sites, $j = 1, 2, ..., 50$.

k : denotes the products, $k = 1, 2, 3, 4, 5$.

dem_{jk} : is the demand at the customer site j of product k .

$wcap$: is the warehouse capacity, assume 100000 tons.

2.1.2 Objective function:

This first part is the warehouse opening cost and second part is the transportation cost

$$\min \sum_{i=1}^{50} o_i y_i + \sum_{i=1}^{50} \sum_{j=1}^{50} \sum_{k=1}^{5} t * dist_{ij} * x_{ijk}$$

2.1.3 Constraints:

1) Demand satisfaction at each customer site constraint,

$$\sum_{i=1}^{50} x_{ijk} = dem_{jk} \qquad \forall j = 1,...,50, \ \forall k = 1,...,5$$

2) Can only produce if selected and production capacity constraint,

$$\sum_{j=1}^{50} \sum_{k=1}^{5} x_{ijk} \le y_i * wcap \qquad \forall i = 1,...,50$$

3) Constraint to cover 80% of demand satisfied by any warehouse within 500 miles,

$$\sum_{j=1}^{50} \sum_{k=1}^{5} r_{ij} x_{ijk} \ge 0.8 * \sum_{j=1}^{50} \sum_{k=1}^{5} x_{ijk} \qquad \forall i = 1,...,50$$

4) Non negativity and binary constraints,

$$x_{ijk} \ge 0, \ y_i \in \{0,1\}$$

2.1.4 Output:

- The above model is in the *'Objective1Code_facilityloc.py'* file. The output of the site selected by the model is in *'y_facilitySite_output.csv'* and the flow of product from the sites selected as warehouses to customers is in the *'xijk_flowWarehouse2Customers.csv'*.
- The following sites were selected as the warehouse sites:

Table 2.1: Selected warehouse locations

site_id	warehouse_id	City	State	Zip Code	Country	Latitude	Longitude
5	Warehouse1	Dallas	TX	75236	USA	32.68833	-96.9384
23	Warehouse2	Mountville	PA	17554	USA	40.04372	-76.4256
24	Warehouse3	West Seneca	NY	14224	USA	42.84152	-78.7613
25	Warehouse4	City of Industry	CA	91746	USA	34.049	-117.98
35	Warehouse5	North Salt Lake	UT	84054	USA	40.8373	-111.919

- **Figure 2.1** shows the utilization of the warehouse capacity. The Warehouse2 at PA is 90% utilized and still the demand in the region is not satisfied, which explains the need of opening another Warehouse3 in NY even though we have warehouse at PA as can be seen in the **Figure 2.2**.

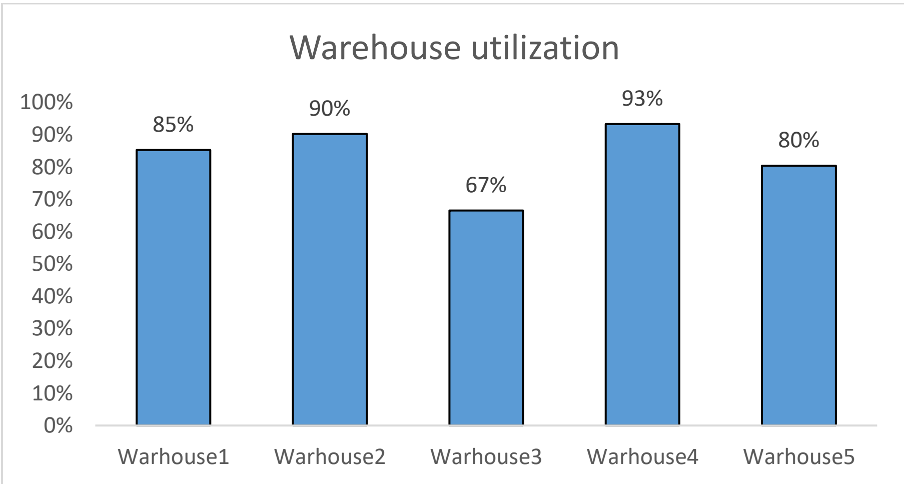

Figure 2.1

- The warehouses are shown in the **Figure 2.2** by (◇) and the service level coverage of 500 miles is represented in the green. Only 7 customers are out of 500 miles from the nearest warehouse.

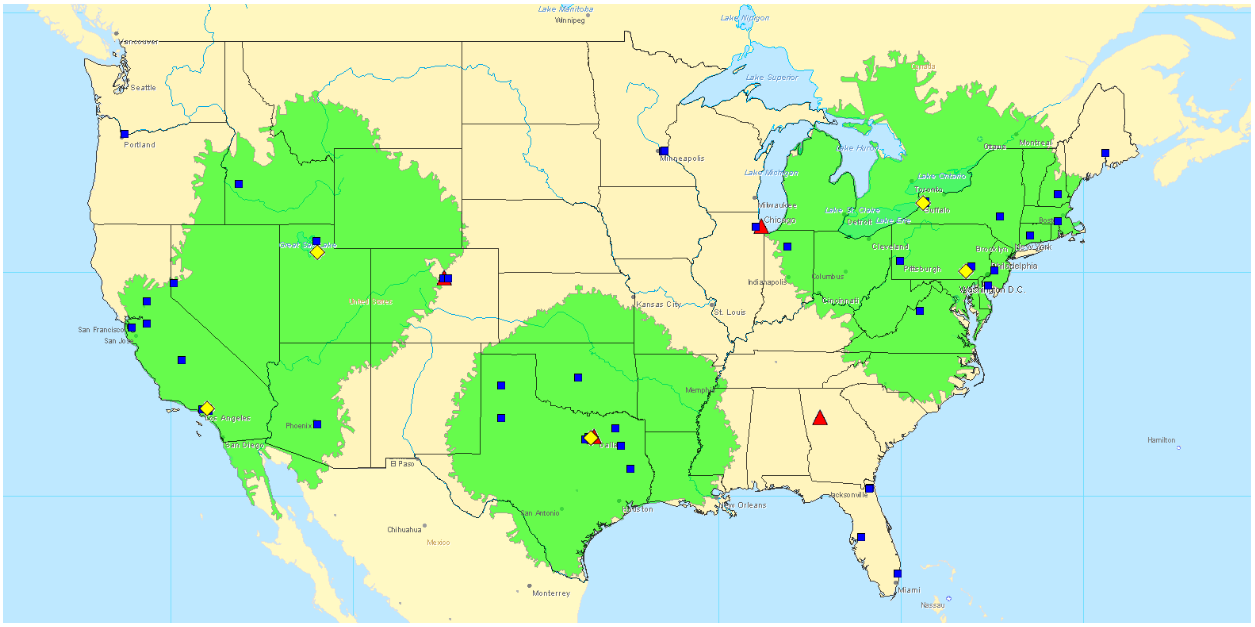

Figure 2.2: Visualization of the plants, warehouses and customer sites with coverage

- **Table 2.2** summarizes the costs associated with the part 1 of the entire network,

Table 2.2: Objective 1 : warehouse to customers output

Sr.no	Description	Details	Costs
1	Warehouse opening cost	5 Warehouses	$50,000,000
2	Transportation cost part1	LTL	$22,893,542.79
3	Network cost	Part 1	$72,893,542.79

2.2 Model 2:

This model minimizes the incurred transportation and production cost. In addition, the model gives the flow of the products and transportation costs associated with the network.

2.2.1 Preliminary information:

Folder location:

- Solutions\Scenario_warehouse\part2_prod

Sourcing policy:

- Products flow from the plants to the warehouses.

Transportation policy:

- From plants to warehouse, Full Truck Load transportation rate is considered.
- Transportation costs are calculated at the rate of $0.12/ton/mile for FTL.
- The distance between plants and customer is in the *'DistPlantWarehouse.csv'* file.

Production policy:

- Plant A: makes Clear product, Plant B: makes Green product, Plant C: makes Red product, Plant D: makes Blue and Gray product. The plant production constraints which enforces, production of a particular at particular site only are mentioned in the *'PlantProductConstraints.csv'* file.
- The production capacity of each plant product wise is in the *'ProdCapPlantProduct.csv'* file.
- Each plant has 2880 hours/year of regular time production capacity and 1440 hours/year of overtime production capacity. The Production costs for overtime production is 50% more than regular time production.
- The production costs for each product in regular time and over time is in the *'CostProductRegOvrtime.csv'* file.
- Plant A can produce 100 tons/hour and Plant B,C and D can produce at 50 tons/hour

Demand policy:

- Demand requirements at each warehouse for each product is the input for production at plants. This obtained as the output of the Model 1.

Revenue policy:

- As 100% of the demand is satisfied,

$$\text{Revenue}= \sum_{j=1}^{50}\sum_{k=1}^{5} \text{(Revenue per ton)}_{jk}*\text{(demand)}_{jk}$$

2.2.2 Notations:

- reg_k and ovr_k : the given regular and over time production cost for k^{th} product.
- x_{ijk} : is the quantity (tons) of the product k produced and shipped from plant i to warehouse j in regular time.
- y_{ijk} : is the quantity (tons) of the product k produced and shipped from plant i to warehouse j in over time.
- t : is the transportation rate, FTL= $0.12/ton/mile (60% of LTL).
- $dist_{ij}$: is the distance between plant i and warehouse j.
- i : denotes the plant, $i = 1, 2, 3, 4$.
- j : denotes the warehouse, $j = 1, 2, ..., 5$.
- k : denotes the products, $k = 1, 2, 3, 4, 5$.
- dem_{jk} : is the demand at the warehouse j of product k.
- p_{ik} : is the plant product constant, 1 if plant i makes product k, else, 0.
- cap_{ik} : is the capacity of the plant i to produce product k.
- $regh$: Regular hour capacity = *2880* hours/year.
- $ovrh$: Over time hour capacity = *1440* hours/year.

2.2.3 Objective function:

To objective is to find the flow of the products from the respective plants to the warehouses which has minimum production and transportation cost. First term in the objective function gives the production cost and second term gives the transportation cost.

$$\min \sum_{i=1}^{4}\sum_{j=1}^{5}\sum_{k=1}^{5}(reg_k * x_{ijk} + ovr_k * y_{ijk}) + \sum_{i=1}^{4}\sum_{j=1}^{5}\sum_{k=1}^{5} t * dist_{ij}(x_{ijk} + y_{ijk})$$

2.2.4 Constraints:

1) Demand satisfaction at each warehouse constraint,

$$\sum_{i=1}^{4}(x_{ijk} + y_{ijk}) = dem_{jk} \qquad \forall j = 1,...,5,\ \forall k = 1,...,5$$

2) Production capacity and product constraint,

$$\sum_{j=1}^{5}(x_{ijk} + y_{ijk}) \le p_{ik} * cap_{ik} \qquad \forall i = 1,...,4,\ \forall k = 1,...,5$$

3) Production type and rate constraint,

Plant 1 Product 1

$$\sum_{j=1}^{5} x_{1j1} \le regh * 100$$

$$\sum_{j=1}^{5} y_{1j1} \le ovrh * 100$$

Plant 2 Product 2

$$\sum_{j=1}^{5} x_{2j2} \le regh * 50$$

$$\sum_{j=1}^{5} y_{2j2} \le ovrh * 50$$

Plant 3 Product 3

$$\sum_{j=1}^{5} x_{3j3} \leq regh*50$$

$$\sum_{j=1}^{5} y_{3j3} \leq ovrh*50$$

Plant 4 product 4

$$\sum_{j=1}^{5} x_{4j4} \leq regh*50$$

$$\sum_{j=1}^{5} y_{4j4} \leq ovrh*50$$

Plant 4 product 5

$$\sum_{j=1}^{5} x_{4j5} \leq regh*50$$

$$\sum_{j=1}^{5} y_{4j5} \leq ovrh*50$$

Non negativity:

$$x_{ijk} \geq 0\ ,\ y_{ijk} \geq 0$$

2.2.4 Output:

- The above model is coded in Python and the complete code is in the *'Objective2code_production.py'* file. The output is obtained in the *'x_flow.csv'* and *'y_flow.csv'* is the flow of products manufactured and transported at regular time costs and overtime costs respectively.

- Table 2.3 gives the costs associated with the supply chain network in Model 2.

Table 2.3: Objective 2: Plants to warehouse output

Sr.no	Description	Details	Costs
1	Production	Regular	$184,949,743.00
		Over time	$5,616,547.49
		Total Production cost	$190,566,290.49
2	Transportation cost part 2	FTL	$56,314,862.92
3	Network cost	Part 2	$246,881,153.41

2.3 Final network costs:

- The following **Table 2.4** summarizes the costs in the complete supply chain network with the scenario of opening 5 warehouses.

Table 2.4: Complete network output

Sr.no	Description	Details	Cost
1	Total Production cost		$190,566,290.49
2	Total Transportation cost	LTL+FTL	$79,208,405.71
3	Total network cost	Part1+ Part2	$319,774,696.21
4	Revenue		$431,191,066.00
5	Net Profit		$111,416,369.79

CHAPTER III

CONCLUSION

With an investment of $50,000,000 to build 5 warehouses the company will have the following changes in the supply chain as mentioned in **Table 2.5** and **Table 2.6**.

Table 2.5: Metrics comparison

Sr.no.	Metric	Current Model	Warehouse Model
1	Revenue	$431,191,066.00	$431,191,066.00
2	Total Transportation cost	$98,706,203.87	$79,208,405.71
3	Total Network cost	$289,272,499.87	$319,774,696.21
4	Profit	$141,918,566.13	$111,416,369.79

From **Table 2.5** we can derive the following insights.

Table 2.6: Insights

Sr.no.	Metric	With same revenue	by	by
1	Total Transportation cost	Decrease by	$19,497,798.16	19.75%
2	Total Network cost	Increase by	$30,502,196.34	10.54%
3	Profit	Decrease by	$30,502,196.34	21.49%

For an investment of $50,000,000 onetime to build 5 warehouses, there is a yearly savings of $19,497,798.16 in transportation cost in the entire supply chain network. This seems to be sound decision to be made by the management as the investment could be recovered in 2.5 years by the savings and the company will be able to provide reliable services the customers as over 80% of the demand is within 500 miles of the closest warehouse.