Production and Distribution Planning for Major North American Manufacturing Company

Final Project

Anh Phuong Ngo

LINEAR OPTIMIZATION – ISEN742

5/10/22

Contents

Executive Summary

The goal of this analysis was to establish a production and distribution plan for a major North American manufacturing company. Given they have 3 manufacturing plants producing 6 different products, the goal was to determine how many warehouses they should open, and which warehouses should ship which products to which demand zones to minimize the company's cost of operations. Using linear and computer programming, it was determined that operating warehouses 2 and 8 to distribute products to the 15 demand zones met all demand at an operating cost of $70,734,617.04 for the first year. This includes the cost of opening and operating the warehouses in their first year. After the first year, the cost of operating the two warehouses on a yearly basis is $2,699,631. However, under the assumption that each demand zone can only be serviced by one warehouse, the optimal solution was shown to be operating warehouses 4, 8, and 10 at a first-year operating cost of $70,825,700, and an annual operating cost of $3,992,283 for the 3 warehouses after the first year. The initial solution would cost the company almost $100,000 less than the second solution in the first year. However, after the first year, the second solution becomes significantly cheaper assuming no changes to the cost of shipping and warehouse operation. Therefore, the second solution is the recommended production and supply chain plan, and each demand zone should only be serviced by a single warehouse.

1 Introduction

A major North American manufacturing company was looking to improve their supply chain operations and minimize their operating costs. They currently produce 6 different product families at 3 separate manufacturing facilities. No production facility produces all 6 of the product families, and each production facility has a limited capacity for production in each year. Table 1 breaks down which facilities make which products and the time it takes to produce them at that facility, the cost of making one unit of each product family at each facility, the volume of one unit of each product family, and the overall capacity of each of the three production facilities.

Table 1: Production capabilities and plant capacity

Products	*Production Requirements (hrs/1000units)*			*Production Cost (US$/Unit)*			*Volume (ft^3/unit)*
	Plant 1	Plant 2	Plant 3	Plant 1	Plant 2	Plant 3	
1	4		4.2	1		0.95	1.5
2	9		10	8.5		4	2
3	4.2	4.5		0.5	0.6		0.8
4		4	6		3	1.2	1.3
5	8.5	8		2	1.8		1.2
6		6	7.5		1.2	1.3	0.7
Capacity (hrs/year)	31,000	30,000	33,000	Note: A blank value indicates the product cannot be made at that plant!			

After production, products are shipped from the production facility to warehouses for distribution to the company's customers. The cost of shipping products from the production facilities to the warehouses was calculated to be \$1.45 per thousand cubic feet of product per mile. Table 2 gives a sample of the distances from each production facility to each potential warehouse location. The complete version of Table 2 can be found in the appendix at the end of this report.

Table 2: Sample of Distance (in miles) from Plants to Warehouses

#	*City*	*State*	*W1*	*W2*	*W3*	*W4*	*W5*	*W6*
Plant 1	Charlotte	NC	2781	1624	2445	2057	1174	1233
Plant 2	St. Louis	MO	2051	894	1842	1327	444	905
Plant 3	El Paso	TX	1628	724	814	866	1016	558

The company has divided its customers into 15 demand zones. The cost of shipping products from the warehouses to the customers was calculated to be \$1.75 per thousand cubic feet of product per mile. Table 3 gives a sample of the distances from each warehouse location to each demand zone. The complete version of table 3 can be found in the Appendix of this report.

Table 3: Distance (in miles) from warehouses to demand zones

#	*Demand Zone*	*Dz1*	*Dz2*	*Dz3*	*Dz4*	*Dz5*	*Dz6*
W1	West Coast	0	1158	967	761	1656	2070
W2	North Central	1158	0	1102	434	499	1026
W3	California	967	1102	0	688	1563	1372
W4	South Central	761	434	688	0	932	1308
W5	East Central	1656	499	1563	932	0	934
W6	South	2070	1026	1372	1308	934	0

The company was looking to determine the best locations to open warehouses to minimize their operating costs while meeting customer demand for their products. The demand for each product in each demand zone, and the initial and annual costs of opening a warehouse in that demand zone, is given in Table 4 below.

Table 4: Product Demand by Demand Zone and Operating Costs

#	*Demand Zones*	*Products (Demand in Thousands of Units)*						*Investment Cost ($)*	*Annual Operation Cost ($)*
		p1	p2	p3	p4	p5	p6		
dz1	West Coast	267.1	48.9	84.7	277.4	162.2	77.3	2488004	1260494
dz2	North Central	114.7	61.4	67.9	369.4	71.9	99.6	2508336	1350283
dz3	California	211.7	126.1	172.8	545.1	178.1	284.4	2662057	1270560
dz4	South Central	156.3	61	65	346.4	132.5	94.6	2351404	1358094
dz5	East Central	109.4	23.1	68.6	343.7	60.7	57.4	2467929	1324876
dz6	South	61.7	23.9	41	127.4	42.7	45.9	2468506	1316811
dz7	North Midwest	150.8	40.7	77.4	319.8	86.7	120.6	2612666	1250188
dz8	Mid-West	263.8	138.6	280.4	901	286.7	435.7	2318303	1349348
dz9	South Midwest	232.5	83.3	155.8	600.6	200.8	228.6	2383812	1305754
dz10	Gulf of Mexico	49.7	33.3	44.2	253.6	65.8	84.3	2545457	1284841
dz11	Northeast Coast	169.7	111	160.3	494.9	86	233.7	2429745	1328946
dz12	East Coast	125.9	43	39.5	228.1	89.4	114.1	2556851	1279363
dz13	Southeast Coast	168.1	52	53.7	255.5	91.2	136.8	2572823	1310278
dz14	Southern	80.4	34.9	39.5	162	74.7	64.6	2522879	1319870
dz15	Florida	283.7	120.4	201.3	749.9	267.6	220.9	2461272	1317743
	Total	2445	1002	1552	5975	1897	2229		

The company wanted to know the results of two scenarios: one where any open warehouse can ship to any demand zone, and the second where each demand zone can be serviced by only one warehouse. To determine the optimal warehouse locations and product routing, this problem was formulated as a linear programming problem and programmed in python to be processed through the CPLEX linear programming solver.

We have an assumption that we only consider the model solved in the first year only, so the investment cost and operational cost are combined into one type of cost.

Based on the given data, we define sets and index for the mathematical model:

- P: set of project types, $p \in P = \{1,2,3,4,5,6\}$
- I: set of factories, $i \in I = \{1,2,3\}$
- J: set of warehouses $j \in J = \{1,2,3, \dots ,15\}$
- K: set of demand zones $k \in K = \{1,2,3, \dots ,15\}$

2 Modeling, Analysis, and Results

The first step of a linear programming problem is to determine its objective. In this scenario, the objective was to determine the minimum cost plan to meet the demand for each product in each demand zone, shipping products from each production facility to each operating warehouse, and from each operating warehouse to each demand zone. Then take that analysis a step further and do a second analysis where each demand zone can only be serviced by a single warehouse. Therefore, to determine the total cost, it was necessary to determine the total cost of production of each product at each production facility, the cost of shipping each product from each production facility to each operating warehouse, the resulting investment and operating costs of those warehouses being in operation, and the cost of shipping each product from each warehouse to each demand zone. Thus, it was determined the decision variables should be:

- $y_j: a\ binary\ variable, equal\ to\ 1\ if\ warehouse\ j\ is\ opened, otherwise\ 0, for\ j = 1, \dots ,15$
- $f_{i,j,p}: units\ of\ product\ p\ shipped\ from\ plant\ i\ to\ warehouse\ j, for\ p = 1, \dots , 6;\ i = 1,2,3;\ and\ j = 1, \dots ,15$
- $de_{j,k,p}: units\ of\ product\ p\ delivered\ from\ warehouse\ j\ to\ demand\ zone\ k, for\ p = 1, \dots ,6;\ j = 1, \dots 15;\ and\ k = 1, \dots ,15$

To concisely express the objective function and constraints, other parameters were defined as:

- $D_{k,p}: the\ demand\ for\ product\ p\ in\ demand\ zone\ k, for\ p = 1, \dots ,6\ and\ k = 1, \dots ,15$

- $CAP_i: maximum\ capacity\ for\ production\ at\ plant\ i, for\ i = 1,2,3$
- $H_{i,p}: hours\ required\ to\ produce\ product\ p\ at\ plant\ i, for\ p = 1, \dots, 6\ and\ i = 1,2,3$
- $V_p: The\ volume\ of\ a\ unit\ of\ product\ p, for\ p = 1, \dots, 6$
- $PC_{i,p}: The\ cost\ to\ produce\ product\ p\ at\ plant\ i, for\ p = 1, \dots, 6\ and\ i = 1,2,3$
- $IC_j: The\ investment\ cost\ of\ warehouse\ j, for\ j = 1, \dots, 15$
- $OC_j: The\ annual\ operating\ cost\ of\ warehouse\ j, for\ j = 1, \dots, 15$
- $fd_{i,j}: the\ distance\ between\ plant\ i\ and\ warehouse\ j, for\ i = 1,2,3, and\ j = 1, \dots, 15$
- $ded_{j,k}: The\ distance\ between\ warehouse\ j\ and\ demand\ zone\ k, for\ j = 1, \dots, 15\ and\ k = 1, \dots, 15$
- $M: a\ big\ number, set\ to\ 1000000$

Then the objective function is the minimization of (production cost, transportation cost from plants to warehouses, transportation cost from warehouse, investment cost and operational cost) and was mathematically expressed as:

$$Minimize\ Z = \sum_{i \in I} \sum_{j \in J} \sum_{p \in P} \left(PC_{i,p} \times f_{i,j,p}\right) + \left(1.45 \times \sum_{i \in I} \sum_{j \in J} \sum_{p \in P} \left(f_{i,j,p} \times \left(\frac{V_p}{1000}\right) \times fd_{i,j}\right)\right) + \left(1.75 \times \sum_{k \in K} \sum_{j \in J} \sum_{p \in P} \left(de_{j,k,p} \times \left(\frac{V_p}{1000}\right)\right) \times ded_{j,k}\right) + \sum_{j \in J} \left(y_j \times \left(IC_j + OC_j\right)\right)$$

Subject to the constraints:

$\sum_{i \in I} f_{i,j,p} = \sum_{k \in K} de_{j,k,p}, \ \forall j \in J, \forall p \in P$ (1) (Balanced flow at warehouse)

$\sum_{j \in J} de_{j,k,p} = 1000 \cdot D_{k,p}, \ \forall k \in K, \forall p \in P$ (2) (Satisfied demand at each customer for each product)

$\sum_{i \in I} \sum_{p \in P} f_{i,j,p} \le M y_j, \quad \forall j \in J$ (3) (If warehouse j is opened, f is free, otherwise 0)

$\sum_{j \in J} \sum_{p \in P} \left(\left(\frac{f_{i,j,p}}{1000}\right) * h_{i,p}\right) \le CAP_i, \ \forall i \in I$ (4) (Capacity of each plant)

$\sum_{j \in J} f_{i,j,p} \le M h_{i,p}, \forall i \in I, \forall p \in P$ (5) (Each plant only produces some types of products, not all)

$y_j \in \{0,1\}$ (6) (Binary variable)

$f_{i,j,p} \ge 0, de_{j,k,p} \ge 0$ (Sign constraints)

The first constraint ensured that the flows into and out of the warehouses were equal. What was sent to the warehouse must be distributed from the warehouse. The second constraint ensures demand was met for each product in each demand zone. The third constraint ensures that products can be sent to each open warehouse. M was any arbitrarily large number and was necessary due to the possibility of only one or a small number of units of products being shipped to any warehouses. The fourth constraint is the production capacity constraint, ensuring that each plant is limited only to less than or equal to its possible working capacity. The fifth constraint is the constraint for producing only certain products. This constraint was necessary because inputting 0 for the empty cells with no constraint would make the program think the product(s) could be produced infinitely with no impact on the production time constraints. The constraint forces plant production to 0 for any products the plant should not be able to produce, while the M, again, allows for the potential of smaller production amounts without also forcing the production to be limited. The last constraints limit the binary constraint to 0 and 1 and require the other decision variables be greater than or equal to 0.

The above formulation generated a solution for the first scenario, where any warehouse could service any demand zone. To calculate results for **the second scenario**, in which each demand zone could only be serviced by one warehouse, an additional decision variable was added, and 3 additional constraints were added. **The decision variable was**

$z_{j,k}$: $A\ binary\ variable, equal\ to\ 1\ if\ warehouse\ j\ serves\ demand\ zone\ k, otherwise\ 0,$

$for\ j\ = 1, \dots, 15\ and\ k = 1, \dots, 15$

And the constraints were:

$de_{j,k,p} \leq Mz_{j,k}, for\ \forall\ j \in J, \forall\ k\ \in K, \forall\ p \in P$

(*Satisfied demand at each customer for each product*)

$\sum_{j \in J} z_{j,k} = 1, \forall\ k \in K$ (*Each customer can be served by only one warehouse*)

$z_{j,k} \in \{0,1\}$ (*Binary variable*)

These constraints ensure that demand is met for each demand zone and met by only one warehouse and that $z_{j,k}$ is a binary variable with values of 0 or 1.

These formulations were passed to the CPLEX solver via python coding. The optimal solution generated for the first scenario was an operating cost of **$70,734,617.04** for the first year, operating **warehouse 2** and **warehouse 8 (Question 1&2)**. The initial investment cost for these two warehouses was $2,508,336 and $2,318,303, respectively, for a total of $4,826,639 initial investment. The yearly operating costs were $1,350,283 and $1,349,348, respectively, for a total of $2,699,631 yearly to operate the warehouses in this plan. Table 5 shows the quantities of each product family shipped from each of the production facilities to each of the warehouses. Table 6 then shows a sample of the quantities of each product family shipped from each warehouse to each demand zone. The full table can be found in the Appendix at the end of this report.

Table 5: Products from each Plant to each Open Warehouse

	Product Family					
Routing	P1	P2	P3	P4	P5	P6
Plant 1-W2	0	0	0	0	0	0
Plant 2-W2	0	0	322500	0	472800	75743
Plant 3-W2	635100	483000	0	2910400	0	380557
Plant 1-W8	1809400	0	1229600	0	1306563	0
Plant 2-W8	0	0	0	3064400	117637	1852200
Plant 3-W8	0	518600	0	0	0	0

Table 6: Sample of Number of Products shipped from each Warehouse to each Demand Zone

	dz1	*dz2*	*dz3*	*dz4*	*dz5*	*dz6*	*dz7*	*dz8*
Product 1 - W2	267100	0	211700	156300	0	0	0	0
Product 2 - W2	48900	61400	126100	61000	23100	23900	0	138600
Product 3 - W2	84700	0	172800	65000	0	0	0	0
Product 4 - W2	277400	369400	545100	346400	343700	127400	0	901000
Product 5 - W2	162200	0	178100	132500	0	0	0	0
Product 6 - W2	77300	0	284400	94600	0	0	0	0
Product 1 - W8	0	114700	0	0	109400	61700	150800	263800
Product 2 - W8	0	0	0	0	0	0	40700	0
Product 3 - W8	0	67900	0	0	68600	41000	77400	280400
Product 4 - W8	0	0	0	0	0	0	319800	0
Product 5 - W8	0	71900	0	0	60700	42700	86700	286700
Product 6 - W8	0	99600	0	0	57400	45900	120600	435700

	dz9	*dz10*	*dz11*	*dz12*	*dz13*	*dz14*	*dz15*
Product 1 - W2	0	0	0	0	0	0	0
Product 2 - W2	0	0	0	0	0	0	0
Product 3 - W2	0	0	0	0	0	0	0
Product 4 - W2	0	0	0	0	0	0	0
Product 5 - W2	0	0	0	0	0	0	0
Product 6 - W2	0	0	0	0	0	0	0

Product 1 - W8	232500	49700	168700	125900	168100	80400	283700
Product 2 - W8	83300	33300	111000	43000	52000	34900	120400
Product 3 - W8	155800	44200	160300	39500	53700	39500	201300
Product 4 - W8	600600	253600	494900	228100	255500	162000	749900
Product 5 – W8	200800	65800	86000	89400	91200	74700	267600
Product 6 – W8	228600	84300	233700	144100	136800	64600	200900

Table 6 shows that for this formulation of the problem some demand zones are serviced by only one warehouse while others are serviced by both warehouses. Reformulating the problem as described above so that each demand zone can only be serviced by one warehouse and then passing that formulation to the CPLEX solver as well, the results gave an optimal plan costing $70,825,700. This is just under $100,000 more than the original formulation. However, the new formulation operates 3 warehouses, **opening warehouses 4, 8, and 10 (Question 3)**. The initial investment cost for these warehouses was $2,351,404, $2,318,303, and $2,545,457, respectively, for a total of $7,215,164 in the first year. The annual operating costs for these warehouses was $1,358,094, $1,349,348, and $1,284,841 for a total annual operating cost of $3,992,283. Table 7 shows the quantities of each product family shipped from each production facility to each open warehouse. Table 8 then shows a sample of the quantity of each product family shipped from each warehouse to each demand zone. The full table can be found in the Appendix at the end of this report.

Table 7: Products from each Production Facility to each open Warehouse

	Product Family					
Routing	P1	P2	P3	P4	P5	P6
Plant 1-W4	0	0	0	0	0	0
Plant 2-W4	0	0	322500	0	472800	197343
Plant 3-W4	635100	236000	0	1168900	0	258957
Plant 1-W8	1101400	0	747800	0	670163	0
Plant 2-W8	0	0	0	2912400	102437	1227900
Plant 3-W8	0	469800	0	0	0	0
Plant 1-W10	708000	0	481800	0	651600	0
Plant 2-W10	0	0	0	0	0	624300
Plant 3-W10	0	295800	0	1893500	0	0

Table 8: Sample of Number of Products shipped from each Warehouse to each Demand Zone

	dz1	*dz2*	*dz3*	*dz4*	*dz5*	*dz6*	*dz7*	*dz8*
Product 1 - W4	267100	0	211700	156300	0	0	0	0

Product 2 - W4	48900	0	126100	61000	0	0	0	0
Product 3 - W4	84700	0	172800	65000	0	0	0	0
Product 4 - W4	277400	0	545100	346400	0	0	0	0
Product 5 - W4	162200	0	178100	132500	0	0	0	0
Product 6 - W4	77300	0	284400	94600	0	0	0	0
Product 1 - W8	0	114700	0	0	109400	0	150800	263800
Product 2 - W8	0	61400	0	0	23100	0	40700	138600
Product 3 - W8	0	67900	0	0	68600	0	77400	280400
Product 4 - W8	0	369400	0	0	343700	0	319800	901000
Product 5 - W8	0	71900	0	0	60700	0	86700	286700
Product 6 - W8	0	99600	0	0	57400	0	120600	435700
Product 1 - W10	0	0	0	0	0	61700	0	0
Product 2 - W10	0	0	0	0	0	23900	0	0
Product 3 - W10	0	0	0	0	0	41000	0	0
Product 4 - W10	0	0	0	0	0	127400	0	0
Product 5 - W10	0	0	0	0	0	42700	0	0
Product 6 - W10	0	0	0	0	0	45900	0	0

	dz9	*dz10*	*dz11*	*dz12*	*dz13*	*dz14*	*dz15*
Product 1 - W4	0	0	0	0	0	0	0
Product 2 - W4	0	0	0	0	0	0	0
Product 3 - W4	0	0	0	0	0	0	0
Product 4 - W4	0	0	0	0	0	0	0
Product 5 - W4	0	0	0	0	0	0	0
Product 6 - W4	0	0	0	0	0	0	0
Product 1 - W8	0	0	168700	125900	168100	0	0
Product 2 - W8	0	0	111000	43000	52000	0	0
Product 3 - W8	0	0	160300	39500	53700	0	0
Product 4 - W8	0	0	494900	228100	255500	0	0
Product 5 - W8	0	0	86000	89400	91200	0	0
Product 6 - W8	0	0	233700	144100	136800	0	0
Product 1 - W10	232500	49700	0	0	0	80400	283700
Product 2 - W10	83300	33300	0	0	0	34900	120400
Product 3 - W10	155800	44200	0	0	0	39500	201300
Product 4 - W10	600600	253600	0	0	0	162000	749900
Product 5 - W10	200800	65800	0	0	0	74700	267600
Product 6 - W10	228600	84300	0	0	0	64600	200900

It is easy to see from Table 8 that the new formulation worked correctly, and each demand zone was serviced by only one warehouse, as desired for the purposes of the second scenario.

3 Recommendations and Conclusions

The initial inspection of the results would suggest that scenario 1, at a cost of $70,734617.04 was $91,082.96 cheaper than scenario 2, at a cost of $70,825,700. This would be true for the first year. However, scenario 2 operates 3 warehouses while scenario 1 only operates 2 warehouses. The initial investment required to open these warehouses was $4,826,639 for scenario 1, and $7,215,164 for scenario 2. These amounts were included in the total sum of the cost for both plans in the first year. Consequently, after the first year, assuming no changes to shipping costs or annual operation costs at the warehouses after the first year, scenario 1 would cost the company $65,907,978.04 per year, and scenario 2 would cost the company $63,610,536 per year. After the first year, scenario 2 becomes $2,297,442.04 cheaper than scenario 1. Breaking those numbers down further by removing the annual operating cost of the warehouses in each scenario results in totals of $63,208,347.04 for scenario 1 and $59,618,253 for scenario 2. These costs then represent only the production and shipping costs for the two scenarios, so scenario 2 would save the company $3,590,094.04 in production and shipping costs.

Further analysis of the production costs for each product at each plant in both scenarios shows that the production plan for scenario 2 saves the company $282,720 in production costs, meaning that the shipping costs in scenario 2 are $3,307,374.04 less than the shipping costs of scenario 1. Therefore, the company should adopt scenario 2, using a production plan of 1,809,400 units of product family 1, 1,229,600 units of product family 3, and 1,306,563 units of product family 5 for production facility 1. Production facility 2 should produce 322,500 units of product family 3, 2,912,400 units of product family 4, 590,437 units of product family 5, and 1,927,943 units of product family 6. Production facility 3 should produce 635,100 units of product family 1, 1,001,600 units of product family 2, 3,062,400 units of product family 4, and 258,957 units of product family 6. This production plan results in a production cost of $26,114,573.3 The company should open warehouses in the South Central, Mid-West, and Gulf of Mexico demand zones, corresponding with warehouses 4, 8, and 10, from the analysis formulations, respectively. The initial investment to open these warehouses would be $2,351,404, $2,318,303, and $2,545,457, respectively, for a total of $7,215,164 in the first year. The annual operating cost in the first year and for each year after would be $1,358,094, $1,349,348, and $1,284,841, respectively, for a total annual operating cost of $3,992,283. Table 7 shows what amounts of each product family should be shipped to each warehouse from each production facility in this scenario. It has been copied here for ease of reference.

Table 9: Products from each Production Facility to each open Warehouse

	Product Family					
Routing	P1	P2	P3	P4	P5	P6
Plant 1-W4	0	0	0	0	0	0
Plant 2-W4	0	0	322500	0	472800	197343
Plant 3-W4	635100	236000	0	1168900	0	258957
Plant 1-W8	1101400	0	747800	0	670163	0
Plant 2-W8	0	0	0	2912400	102437	1227900
Plant 3-W8	0	469800	0	0	0	0
Plant 1-W10	708000	0	481800	0	651600	0
Plant 2-W10	0	0	0	0	0	624300
Plant 3-W10	0	295800	0	1893500	0	0

According to the desired rules of scenario 2, each demand zone should only be serviced by a single warehouse. The South-Central warehouse should service demand zones 1, 3, and 4, servicing the West Coast, California, and South-Central regions. The Mid West warehouse should service demand zones 2, 5, 7, 8, 11, 12, and 13, servicing the North Central, East Central, North Midwest, Mid-West, Northeast Coast, East Coast, and Southeast Coast regions. Finally, the Gulf of Mexico warehouse should service demand zones 6, 9, 10, 14, and 15, servicing the South, South Midwest, Gulf of Mexico, Southern, and Florida regions. Table 8 shows the amounts of each product each warehouse should ship to each demand zone. As it is too large to include in its entirety in the body of this report, it can be found in the Appendix labelled as Table 13. Shipping products according to this distribution plan results in total shipping costs of $33,503,680. The total cost of this plan would be $70,825,700 in the first year, and $63,610,536 each year after the first, assuming no changes to production, shipping, and warehouse operation costs.

4 Appendix A: Given data

Table 10: Complete Version of Table 2

Plant #	*City*	*State*	*W1*	*W2*	*W3*	*W4*	*W5*	*W6*	*W7*	*W8*	*W9*	*W10*	*W11*	*W12*	*W13*	*W14*	*W15*
Plant 1	Charlotte	NC	2781	1624	2445	2057	1174	1233	878	598	628	623	841	636	321	203	520
Plant 2	St. Louis	MO	2051	894	1842	1327	444	905	371	246	285	498	1187	982	917	858	996
Plant 3	El Paso	TX	1628	724	814	866	1016	558	1500	1432	1087	1042	2403	2198	1986	1745	1718

Table 11: Complete version of Table 3

#	*Demand Zone*	*Dz1*	*Dz2*	*Dz3*	*Dz4*	*Dz5*	*Dz6*	*Dz7*	*Dz8*	*Dz9*	*Dz10*	*Dz11*	*Dz12*	*Dz13*	*Dz14*	*Dz15*
W1	West Coast	0	1158	967	761	1656	2070	2065	2272	2326	2454	3119	2925	2968	2909	3047
W2	North Central	1158	0	1102	434	499	1026	1099	1115	1190	1318	1962	1768	1811	1752	1890
W3	California	967	1102	0	688	1563	1372	2073	2088	1817	1856	3026	2824	2716	2573	2532
W4	South Central	761	434	688	0	932	1308	1442	1548	1602	1730	2395	2201	2244	2185	2323
W5	East Central	1656	499	1563	932	0	934	510	616	713	926	1463	1269	1363	1302	1440
W6	South	2070	1026	1372	1308	934	0	1276	1182	728	633	2044	1839	1548	1301	1161
W7	North Midwest	2065	1009	2073	1442	510	1276	0	278	626	839	1108	914	995	1006	1250
W8	Mid-West	2272	1115	2088	1548	616	1182	278	0	472	685	941	736	725	726	972
W9	South Midwest	2326	1190	1817	1602	713	728	626	472	0	213	1316	1111	899	756	808
W10	Gulf of Mexico	2454	1318	1856	1730	926	633	839	685	213	0	1426	1221	938	703	688
W11	Northeast Coast	3119	1962	3026	2395	1463	2044	1108	941	1316	1426	0	211	577	968	1285
W12	East Coast	2925	1768	2824	2201	1269	1839	914	736	1111	1221	211	0	372	763	1080
W13	Southeast Coast	2968	1811	2716	2244	1363	1548	995	725	899	938	577	372	0	431	748
W14	Southern	2909	1752	2573	2185	1302	1301	1006	726	756	703	968	763	431	0	379
W15	Florida	3047	1890	2532	2323	1440	1161	1250	972	808	688	1285	1080	748	379	0