"Transportation Network for Williams Technologies, Inc."

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CSE 4395: SENIOR DESIGN

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1. PROJECT SUMMARY

This section includes an overview of the transportation project we completed for Williams Technologies Incorporated. It provides brief descriptions of the problem, method of analysis, and results of the analysis.

1.1. Description of the Problem

Williams Technologies Incorporated (WTI), intends to increase customer satisfaction by decreasing time-to-market of its products, namely re-manufactured transmissions. WTI believes this goal can be accomplished by developing a more efficient shipping system, while minimizing the cost-to-market . This new system may be developed in-house or out-sourced. Therefore, WTI needs an in-house solution that can be compared to those submitted by outside sources.

1.2. Method of Analysis

A transportation model that includes all primary markets, secondary markets, distribution centers, the production plant, and all combinations of connecting routes provides the basic tool used in the analysis. The demands and costs used in the construction of the model are based on projections from the prior year. More constraints and/or assumptions may be added as needed to fine tune the model. This model provides the shipping route and distribution center combination that yields the lowest total cost, while achieving WTI's objective. The model can be modified to reflect changes in market demands, warehouse costs, and shipping costs.

1.3. Results of the Analysis

The model indicates that a single distribution center that serves all markets should be located in Charlotte, NC. This is a surprising result, which reflects the high fixed cost associated with establishing a distribution center. The fixed cost were determined through a subjective method, which might not accurately reflect actual fixed cost. If better information about fixed cost is entered into the model, the outcome might be substantially different.

2. PROBLEM BACKGROUND AND DESCRIPTION

This section includes a further development of the problem. It provides a description of the problem recognition, problem status, and the project objectives.

2.1. Problem Recognition

The present shipping system at WTI, a re-manufacturer of automobile transmissions, routes transmissions from WTI to the automobile manufacturers, which ship the transmissions to the automobile dealerships. WTI recognizes an opportunity to decrease product-to-market time by shipping its products directly to the automobile dealerships. An efficient shipping system also represents an opportunity to lower consumer prices based on a reduction of shipping cost.

2.2. Problem Status

WTI is accepting bids on a project that meets certain time-to-market requirements it has made available to interested parties. WTI has also provided these parties with product demand, weight, size, package, and other information relevant to the project. The bidding parties use this information to develop solutions that will fulfill WTI's needs, while enabling the bidding parties to make a profit on the service . In an effort to reach an optimal solution, WTI has elected to develop their own model in conjunction with our team from Southern Methodist University.

2.3. Project Objectives

The main objective is to provide maximum customer service while minimizing cost. In doing this, the model answers several logistic and cost questions. It decides in which cities to locate distribution centers. It establishes which distribution center(s) serve each market. The distance between the distribution center and market pairs determines shipment by air or truck. The model determines the cost of all active routes, distribution centers, and entire project. The model remains flexible, so changes can be made as conditions dictate.

3. Analysis of the Situation.

In this section we will describe our general approach to the problem. This includes discussion of: (1) modeling considerations, (2) assumptions, (3) cost determination, (4) model description, and (5) an illustrative example.

3.1. Modeling Considerations.

After completing initial discussions with WTI, we felt that what needed to be determined was the optimal number of distribution centers, where they should be positioned, and what markets would be served by each distribution center. The way that we chose to solve this problem was to model it using a mixed integer network. Because of the problem's network characteristics, it's solution is more easily obtained than from other modeling techniques. Binary variables were necessary in order to account for the fixed costs of setting up distribution centers, while regular network flow arcs were used to account for the flow of transmissions and the transportation costs incurred.

The first thing that we did in modeling the problem was to number all of the markets that are served by WTI. This was done by sorting the markets alphabetically and then assigning each market its own number in order. This was done to reduce the amount of data entry and to aid in spreadsheet manipulation. The markets were divided by WTI into 54 primary markets and 153 secondary markets. Primary markets represent markets with a large demand, and must be served within one day of a request for product. Secondary markets represent markets with smaller demand and must be served within two days of a request for product.

3.2. Assumptions Made

Some assumptions were made as to what markets were to be considered for distribution center sites. First, all secondary markets were eliminated because of the very small demand at each market and the relaxed time constraint of these cities. The next step was to eliminate some of the primary markets as candidates to reduce the number of variables in the problem. In the case that there were primary markets within 20 miles of each other, one of the markets was chosen at random to represent that position. If a market of this type was to make it into the optimal solution, the market with the smallest cost (real estate, utilities, etc.) of the two would be chosen. The smallest of the primary markets were eliminated due to the need for access to a major airport for facilitating air transport. After these assumptions, the set of candidates for distribution center locations was reduced to 28 sites.

3.3. Cost Determination

Once we determined the set of candidates, our next step was to ascertain the costs involved in the proposed distribution system. Transportation costs for the transmissions are a function of distance, mode of transport and weight, so these data were needed. Market demands were provided by WTI, based on projections from historical data. Because of the extremely large number of possible routes(28*207=5796), we decided on using straight line distance rather than road miles. These distances were calculated by obtaining the latitude and longitude of each city, then using geometry to determine distance (see calculations in next section.) Whether a city was to be served by truck or air freight was computed by using its distance from the distribution center and whether it required one-day service or two (see calc.) The cost of transportation over each route was derived from the cost of shipping one unit one mile and then multiplying by the length of the route (see calc.)

The cost of shipping transmissions from the plant in Charleston, SC to each of the distribution centers was calculated in the same manner as the other route costs. An assumption was made that the demand in Charleston would be supplied directly from the plant. For this reason Charleston's demand was set to zero in the model, effectively eliminating this demand from consideration.

Fixed and variable costs of placing a distribution center in a candidate market were difficult to obtain because of the lack of historical data. These costs were ascertained by computing total costs for setting up a central distribution center that could handle all 24,000 units and the total costs for opening a minimal distribution center. The cost for a minimal distribution center was used as the fixed cost and then the difference between that cost and the central distribution center's cost was spread out over the 24,000 units to obtain the unit variable cost (see calc.) These fixed and variable costs were determined using costs in Dallas, TX. The costs were then adjusted using a cost of living index published by the Chamber of Commerce Association.

3.4. Model Description

The model includes three sets of variables, X(*DC,M*), S(*DC*), and Y(*DC*). X(*DC,M*) represents the amount of flow from distribution center candidate *DC* to market *M*. Variable S(*DC*) represents the flow from the plant in Charleston, SC to distribution center candidate *DC*. The variables Y(*DC*) are binary (0,1) variables that are equal to 1 if a distribution center is to be placed in candidate *DC* and equal to 0 otherwise.

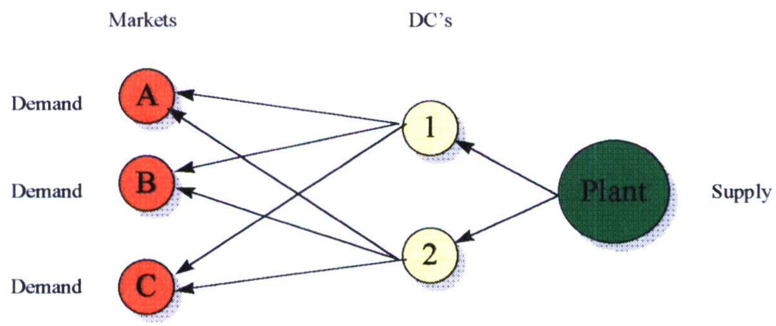
The costs that are included in the model are accounted for by the parameters COST(*DC,M*), F(*DC*), and DCCOST(*DC*). COST(*DC,M*) are the costs associated with moving one transmission from distribution center *DC* to market *M*. The parameters F(*DC*) are the fixed costs of placing a distribution center in candidate *DC*, and the parameters DCCOST(*DC*) include both the transportation cost to and the variable cost at distribution center *DC*.

The focus of the model was to minimize the total costs. These were determined to be the sum of: the fixed costs, the variable costs at each distribution center, and the transportation costs. Our constraints were that: the demand at each market is met and is met within the prescribed time frame, the supply at each distribution center is equal to the demand that it is serving, and a distribution center cannot serve any demand unless a fixed cost is incurred. The formulation for the model is included in the next section.

3.5. Illustrative Example of the Model

Following is an example of a comparable model on a smaller scale:

NETWORK FLOW DIAGRAM



In this example there are two possible distribution center sites serving three markets. The fixed cost of establishing a distribution center at each location is $1,000. The costs associated with transportation and the demands of each of the markets are included in the following tables:

Table 3.5.a Transportation Costs Per Unit

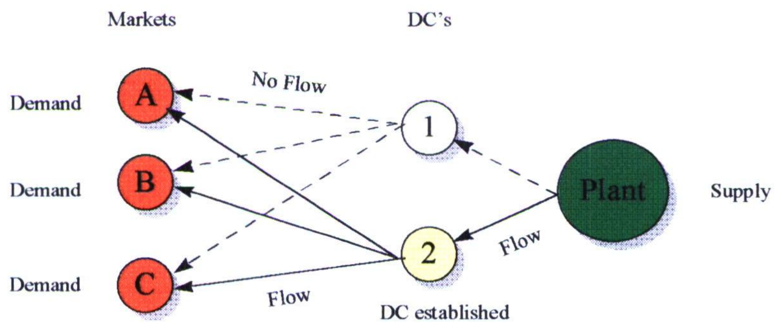
		DC's	
		1	2
Markets	A	$ 4.50	$ 9.00
	B	$ 7.50	$ 4.00
	C	$ 9.50	$ 2.50

Table 3.5.b Demand

Market	Demand
A	50
B	30
C	60

When this model is solved, the optimal solution establishes only one distribution center at site two, which serves all three markets. The solution network is shown below:

NETWORK FLOW DIAGRAM



4. Technical Description of the Model

This section includes the technical information regarding the model formulation and calculations that we made. This information is divided into: (1) a breakdown of cost calculations, and (2) a model description.

4.1. Cost Calculations

4.1.1. Distance Computations

To calculate the large number of route distances, we went online to find the latitude and longitude of each market city. These figures were available at *http://www.mit.edu:8001/geo*. We placed the latitude and longitude figures into a

Microsoft Excel spreadsheet and derived the following geometric formulae to convert them to Cartesian coordinates:

$$X = \cos(Lat)*\cos(Long)$$

$$Y = \sin(Lat)$$

$$Z = \cos(Lat)*\sin(Long)$$

From the Cartesian coordinates the straight-line distances between the cities were computed by the distance formula:

$$d = ((X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2)^{1/2}$$

Once this distance was obtained it was converted to the distance along the surface of the earth by the conversion shown below:

Mean Earth Radius = 3958.832412

$$D = 2 * \tan^{-1}(d / 2 / (1 - (d / 2)^2)^{1/2}) * 3958.832412$$

These distances were verified by checking the computed values against values obtained from an air mileage table for several of the routes. The computed values were within 2-3 miles of the tabulated values, which confirms our confidence in the use of these numbers.

4.1.2. Determination of Air and Trucking Costs

The unit costs per mile for shipment by air and by truck were calculated from a random sample of historical data as is shown in the table below:

Table 4.1.2.a Air and Truck Transportation Costs/Unit/Mile

AIR	Units	Miles	Unit Cost	unit*Miles	unit cost/mile
	214	470	232.05	100580	0.002307119
	93	512	192.78	47616	0.004048639
	218	566	192.78	123388	0.001562389
	628	603	84.81	378684	0.00022396
	861	644	192.78	554484	0.000347675
	464	781	278.46	362384	0.000768411
	501	783	278.46	392283	0.000709845
	39	820	239.19	31980	0.007479362
	130	905	278.46	117650	0.002366851
	6	905	239.19	5430	0.044049724
	18	913	239.19	16434	0.014554582
	16	961	239.19	15376	0.015556061
	115	971	278.46	111665	0.002493709
	31	990	239.19	30690	0.007793744

	14	998	239.19	13972	0.017119238	
	11	1085	239.19	11935	0.020041056	
	25	1086	239.19	27150	0.008809945	
	14	1099	239.19	15386	0.015545951	
	17	1125	239.19	19125	0.012506667	
	21	1163	239.19	24423	0.009793637	AVG Cost/unit/mile
	78	1289	239.19	100542	0.002379006	0.009069408
TRUCK	Units	Miles	Unit Cost	unit*Miles	unit cost/mile	
	19	77	76.53	1463	0.052310321	
	33	111	77.87	3663	0.021258531	
	47	115	78.18	5405	0.014464385	
	70	120	76.2	8400	0.009071429	
	154	145	78.53	22330	0.003516794	
	9	166	76.88	1494	0.05145917	
	52	176	79.89	9152	0.00872924	
	65	194	78.18	12610	0.006199841	
	46	200	77.87	9200	0.00846413	
	10	201	79.89	2010	0.039746269	
	52	211	74.55	10972	0.006794568	
	47	230	79.22	10810	0.0073284	
	17	232	85.64	3944	0.021713996	
	100	237	75.54	23700	0.003187342	
	154	243	192.78	37422	0.005151515	
	29	243	74.55	7047	0.01057897	
	39	254	85.34	9906	0.008614981	
	18	256	78.12	4608	0.016953125	
	51	278	74.55	14178	0.005258146	
	16	635	207.06	10160	0.020379921	
	5	664	70.43	3320	0.021213855	
	197	691	207.06	136127	0.00152108	AVG Cost/unit/mile
	4	697	207.06	2788	0.074268293	0.018181926

4.1.3. Determination of Mode of Shipment and Route Unit Cost

Per the requirements of WTI, primary markets within 400 miles and secondary markets within 750 miles of a distribution center are to be serviced by truck. All markets beyond these respective ranges are to be serviced by air. These requirements ensure that market demand is met within an acceptable time frame. We used a nested IF statement to evaluate whether a market was primary or secondary and then to assign the proper mode of shipment based upon the route distance. The route distance was then multiplied by the appropriate unit cost/mile to determine the route cost per unit. A section of the Excel spreadsheet is included.

Table 4.1.3.a Mode Shipment Determination and Route Unit Cost

Origin City	St	Market #	Dest. City	St	distance	Day Requirement	Truck	Air	Route Unit Cost
Albany	NY	1	Abilene	TX	1572.9	2	0	1	28.59846085
Albany	NY	2	Albany	NY	0	1	1	0	0
Albany	NY	3	Albany	GA	954.8496	2	0	1	17.3610758
Albany	NY	4	Albuquerque	NM	1832.527	1	0	1	33.3190001
Albany	NY	5	Alexandria	LA	1290.645	2	0	1	23.46650081
Albany	NY	6	Alpena	MI	509.0317	2	1	0	4.616408647
Albany	NY	7	Amarillo	TX	1584.847	2	0	1	28.81569607
Albany	NY	8	Anchorage	AK	3265.89	2	0	1	59.38041797
Albany	NY	9	Ardmore	OK	1388.995	2	0	1	25.25470033

4.1.4. Determination of Fixed and Variable Cost of DC

Table 4.1.4.a Fixed and Variable Costs of DC

COST/SQ FT	3
COST PERSON	25000

MINIMAL WAREHOUSE INFO

Fixed Costs	QTY	COST
OFFICE SPACE	1000	3000
WAREHOUSE SPACE	5000	15000
PERSONNEL	5	125000
INSURANCE	12 mos.	6000
EQUIPT (forklift, computers, etc.)	12 mos.	15000
UTILITIES	12 mos.	6000
		170000

MAXIMUM WAREHOUSE INFO

OFFICE SPACE	5000	15000
WAREHOUSE SPACE	20000	60000
PERSONNEL	15	375000
INSURANCE	12 mos.	27500
EQUIPT (forklift, computers, etc.)	12 mos.	30000
UTILITIES	12 mos.	12000
		519500

Variable Costs

OFFICE SPACE	0.17	0.51
WAREHOUSE SPACE	0.625	1.875
PERSONNEL	0.00042	10.5
INSURANCE	12 mos.	0.899
EQUIPT (forklift, computers, etc.)	12 mos.	0.625
UTILITIES	12 mos.	0.25
		14.659

4.2. Model Description

4.2.1. Model Formulation

The model formulation is as follows:

Parameters

COST(DC,M)	:	cost of transporting one unit from distribution center DC to market m
DCCOST(DC)	:	unit cost at distribution center DC including transportation to distribution center DC
D(M)	:	demand at market M
F(DC)	:	fixed cost of placing a distribution center at site DC
TD = 24007	:	total demand

Variables

X(DC,M)	:	flow from distribution center DC to market M
S(DC)	:	flow from plant in Charleston to distribution center DC

Binary Variables

Y(DC)	:	0,1 variable; 1 if a distribution center is placed at site DC

Equations

```
minimize    SUM((DC,M),COST(DC,M)*X(DC,M)) + SUM(DC,DCCOST(DC)*S(DC))
                 + SUM(DC,F(DC)*Y(DC))                  [objective function]

subject to

            SUM(DC,X(DC,M)) = D(M)      for all M       [demand constraint]
            S(DC) = SUM(M,X(DC,M))      for all DC      [supply constraint]
            S(DC) <= TD*Y(DC)           for all DC      [fixed costs turned on/off]
            X(DC,M), S(DC) >= 0         for DC, M       [non-negativity]
```

4.2.2 Design of the Network Model

The problem can be represented by a mixed integer network, with 5,824 flow arcs, 28 binary (1,0) arcs, and 236 nodes. See appendix B for illustration of the network.

4.2.3 GAMS I/O and Execution

The model that is described above was loaded onto titan.cis.smu.edu and run using GAMS, a high level language for formulating models with algebraic statements. GAMS is an interface for a variety of algorithmic solvers. For this mixed integer program, GAMS used CPLEX to solve for an optimal solution. The input files and GAMS formulation can be found in appendix C.

5. Analysis and Managerial Interpretation

The model's solution indicates that a single distribution center should be established in Charlotte, North Carolina. This distribution center will serve all markets in the model. Output from GAMS shows all flow going from the plant to a distribution center in Charlotte, and from there out to all markets. The only binary variable with a value of one is Y(36), the fixed cost variable associated with Charlotte. Refer to Appendix D for GAMS output.

6. Conclusions and Critique

After close examination of the results of the model output, we feel that the fixed cost data that was used might not accurately reflect true costs. While most of the other data that was used could be verified, our fixed cost data was quite subjective. Another possible source for error in the model is that transportation cost from the plant to the distribution centers did not account for the fact that bulk shipments would have a lower unit transportation cost. We feel that if more accurate data were available, an alternate solution would probably be found to be optimal. We therefore recommend that management pursue accurate, verifiable cost data. This data could easily be entered into the model and the model resolved.

We would like to thank the following people for their help throughout the duration of this project:
Dr. Richard S. Barr, Southern Methodist University
Chris Emery, Director of Marketing, Williams Technologies, INC.
Mike Champion, Return Products Management
David Welch, Systems Support, Southern Methodist University
Mike McWhorter, Bolanz & Miller Realtors, INC.
John Fargo, Lone Star Fork Lift

APPENDICES

APPENDIX A: *Coordinate Conversion Data*

Erik Wikstrom

From: Erik Scott Wikstrom
Sent: Friday, May 03, 1996 4:59 AM
To: Erik Wikstrom
Subject: Lat-longs (fwd)

x = (mean radius of the earth)(longitude in radians)
y = (mean radius of the earth)(latitude in radians)
MEAN_EARTH_RADIUS = 6370949.0 /* Mean earth radius meters */
MI_TO_M(m) ((m) * 1609.3) /* statute miles to meters */

```
/*---------------------------------------------------------------------                    ANGULAR CONSTANTS AND
CONVERSIONS
----------------------------------------------------------------------*/


#define PI                   3.14159265358979323846
#define TWOPI                6.28318530717958647692
#define FOURPI                  12.56637061435917295384
#define PIOVER2                  1.57079632679489661923
#define PIOVER4                  0.78539816339744830962

/*---------------------------------------------------------------------

LINEAR DISTANCE CONSTANTS AND CONVERSIONS

        MI  -- STATUTE MILES    NMI -- NAUTICAL MILES
        M   -- METERS           FT  -- FEET
        KM  -- KILOMETERS
----------------------------------------------------------------------*/


#define MI_TO_NMI(m)   ((m) * 0.8683973) /* statute miles to nautical miles */
#define NMI_TO_MI(n)   ((n) * 1.1515466) /* nautical miles to statute miles */

#define FT_TO_M(f)     ((f) * 0.304800) /* feet to meters              */
#define M_TO_FT(m)     ((m) * 3.280839) /* meters to feet                 */

#define MI_TO_KM(m)    ((m) * 1.6093)   /* statute miles to kilomters     */
#define MI_TO_M(m)     ((m) * 1609.3)   /* statute miles to meters        */

#define KM_TO_MI(k)    ((k) * 0.6214)   /* kilomters to status miles      */
#define M_TO_MI(m)     ((m) * 0.0006214) /* meters to nautical miles      */

#define NMI_TO_KM(n)   ((n) * 1.853184)  /* nautical miles to kilometers  */
#define NMI_TO_M(n)    ((n) * 1853.184)  /* nautical miles to meters      */

#define KM_TO_NMI(k)   ((k) * 0.539622)  /* kilometers to nautical miles  */
#define M_TO_NMI(m)    ((m) * 0.000539622) /* meters to nautical miles       */
```

```
/*-----------------------------------------------------------------------

ANGULAR CONSTANTS AND CONVERSIONS
-----------------------------------------------------------------------*/


#define RAD_TO_DEG(r)     ((r) * 57.29577951308232300 ) /*radians to degrees*/
#define DEG_TO_RAD(d)     ((d) * 0.017453292519943295 ) /*degrees to radians*/

/* Degrees CW from north to deg. CCW from east */
#define COMP_TO_GRAPH_DEG(d) (((d)<90.0) ? (-(d) + 90.0):(360.0 - (d) + 90.0))

/* Degrees CCW from east to deg. CW from north*/
#define GRAPHTOCOMPDEG(d) COMPTOGRAPHDEG(d)

/*-----------------------------------------------------------------------

PLANETARY CONSTANTS AND CONVERSIONS
-----------------------------------------------------------------------*/


#define POLAR_RADIUS      6356912.0 /* pole to pole distance meters */
#define EARTH_RADIUS          6371220.0 /* equatorial distance meters   */
#define MEAN_EARTH_RADIUS  6370949.0 /* Mean earth radius meters */

/*
 Latitude degrees to arc seconds
*/
#define DEG_TO_ARCS(l) ((l) * 3600)

/*
 Meters to latitude degrees
*/
#define M_TO_LAT(m) ((m) * 360.0/(MEAN_EARTH_RADIUS*TWOPI))

/*
 Latitude degrees to meters
*/
#define LAT_TO_M(l) ((l) * (MEAN_EARTH_RADIUS*TWOPI)/360.0)

/*
 Meters to longitude degrees at a given latitude
*/
#define M_TO_LNG(m,lat) \
 ((m) * (360.0/(MEAN_EARTH_RADIUS*cos(DEG_TO_RAD(lat))*TWOPI)))

/*
 Longitude deg. to meters at a given latitude
*/
#define LNG_TO_M(lng,lat) \
 (((lng) * MEAN_EARTH_RADIUS*cos(DEG_TO_RAD(lat))*TWOPI)/360.0)

/*
 Approximation for earth curvature
```

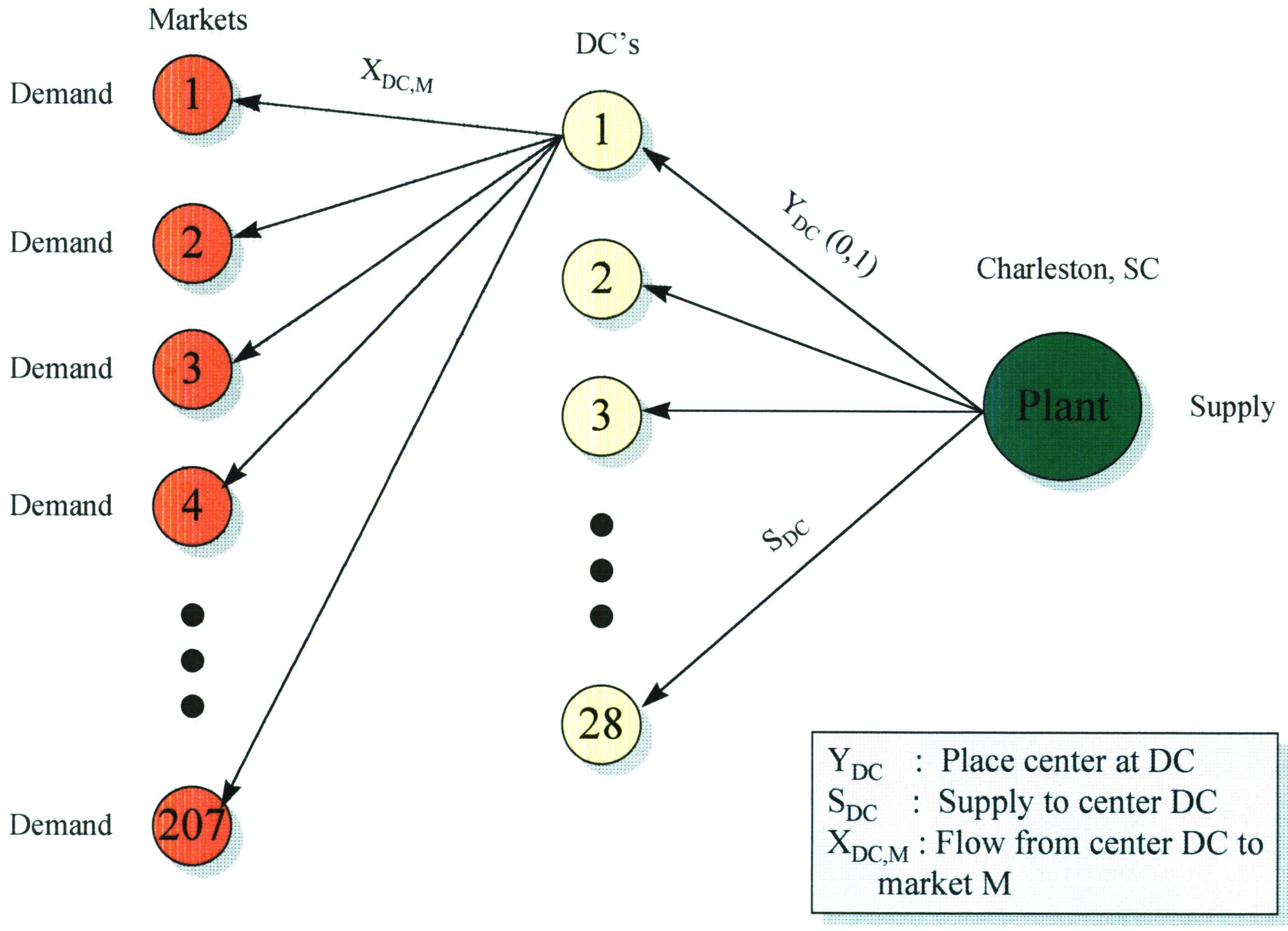
Sample From Coordinate Conversion Spreadsheet

Market #	Dest. City	ST	LAT	SEC	LONG	SEC	DEC. LAT	DEC. LON	RAD LAT.	RAD LON(	X	Y
1	Abiline	TX	32	36	99	43	32.600	99.71667	0.568977	1.740384	-0.14219	0.538771
2	Albany	NY	42	39	73	45	42.650	73.75	0.744383	1.28718	0.205816	0.677518
3	Albany	GA	31	34	84	9	31.567	84.15	0.550942	1.468695	0.086843	0.52349
4	Albuquerq	NM	35	5	106	39	35.083	106.65	0.61232	1.861394	-0.23447	0.574767
5	Alexandria	LA	31	18	92	26	31.300	92.43333	0.546288	1.613266	-0.03628	0.519519
6	Alpena	MI	45	3	83	25	45.050	83.41667	0.786271	1.455895	0.080998	0.707724
7	Amarillo	TX	35	13	101	49	35.217	101.8167	0.614647	1.777036	-0.1673	0.57667
8	Anchorage	AK	61	13	149	54	61.217	149.9	1.068432	2.616249	-0.41657	0.876447
9	Ardmore	OK	34	10	97	8	34.167	97.13333	0.596321	1.695296	-0.10275	0.561602
10	Atlanta	GA	33	44	84	23	33.733	84.38333	0.588758	1.472767	0.081394	0.555328
11	Augusta	ME	44	18	69	46	44.300	69.76667	0.773181	1.217658	0.247518	0.698415
12	Austin	TX	30	16	97	44	30.267	97.73333	0.528253	1.705768	-0.11622	0.504025
13	Bakersfielc	CA	35	22	119	1	35.367	119.0167	0.617265	2.077233	-0.39555	0.578807
14	Baltimore	MD	39	17	76	36	39.283	76.6	0.685624	1.336922	0.179379	0.633156
15	Bangor	ME	44	48	68	46	44.800	68.76667	0.781908	1.200205	0.256983	0.704634
16	Baton Rou	LA	30	27	91	9	30.450	91.15	0.531453	1.590868	-0.0173	0.506786
17	Beaumont	TX	30	5	94	6	30.083	94.1	0.525053	1.642355	-0.06187	0.501259
18	Bend	OR	44	3	121	18	44.050	121.3	0.768818	2.117084	-0.3734	0.695286
19	Billings	MT	45	47	108	30	45.783	108.5	0.79907	1.893682	-0.22128	0.716708

Z
0.830367
0.706123
0.847594
0.784007
0.853688
0.701831
0.799664
0.241477
0.821003
0.827639
0.671529
0.855834
0.713106
0.752952
0.6614
0.861898
0.863083
0.614128
0.661336

APPENDIX B: *Network Diagram*

NETWORK FLOW DIAGRAM



APPENDIX C: *GAMS Data*

```
SET M       Markets /1*207/
    DC(m)   Distribution Centers /2, 10, 22, 26, 36, 40, 47, 51, 55, 57, 86, 99

$INCLUDE "demand.inc"
$INCLUDE "dccost.inc"
$INCLUDE "fixed.inc"
$INCLUDE "cost.inc"


POSITIVE VARIABLES X(DC,M)    Flow from DC dc to market m
                   S(DC)      Flow from Charleston to DC dc;
VARIABLE           Z          Total cost;

BINARY VARIABLE    Y(DC)      Place a distribution center in DC dc;

EQUATIONS
     TCOST            Total cost for project
     DEMAND(M)        Demand for each market is met
     DISTCON(DC) Supply at each distribution center
     FIX(DC)     Fixed costs at each distribution center;

TCOST .. Z =E= SUM((DC,M),COST(DC,M)*X(DC,M)) + SUM(DC,F(DC)*Y(DC))
           + SUM(DC,S(DC)*DCCOST(DC));
DEMAND(M) .. SUM(DC,X(DC,M)) =E= D(M);
DISTCON(DC) .. S(DC) =E= SUM(M,X(DC,M));
FIX(DC) .. S(DC) =L= 1000000*Y(DC);

MODEL TRANSPORT      A transportation network  /ALL/;
SOLVE TRANSPORT USING MIP MINIMIZING Z;
```

```
Parameters  d(m)  demand at market m
      / 1       16
        2       140
        3       9
        4       112
        5       3
        6       1
        7       25
        8       73
        9       8
        10      384
        11      24
        12      130
        13      16
        14      106
        15      23
        16      32
        17      18
        18      4
        19      11
        20      16
        21      14
        22      154
        23      6
        24      13
        25      42
        26      844
        27      4
        28      18
        29      17
        30      132
        31      68
        32      9
```

PARAMETERS COST(DC,M) Cost of shipping from dc DC to market m
/

2	.	1	28.59846085
2	.	2	0
2	.	3	17.3610758
2	.	4	33.3190001
2	.	5	23.46650081
2	.	6	4.616408647
2	.	7	28.81569607
2	.	8	59.38041797
2	.	9	25.25470033
2	.	10	15.32816083
2	.	11	2.085274687
2	.	12	28.63822869
2	.	13	44.57731674
2	.	14	2.503408142
2	.	15	2.627481911
2	.	16	23.22348445
2	.	17	25.82577363
2	.	18	42.8638575
2	.	19	31.28481743
2	.	20	21.63540006
2	.	21	1.064068533
2	.	22	17.2306553
2	.	23	24.6588609
2	.	24	4.919751849
2	.	25	38.51282956
2	.	26	1.261407892
2	.	27	14.13636379
2	.	28	5.564454299
2	.	29	32.19673669
2	.	30	2.357924809
2	.	31	1.165425639
2	.	32	29.83596044
2	.	33	16.59936295
2	.	34	13.83664032
2	.	35	4.619484059
2	.	36	11.61448926
2	.	37	3.673608814
2	.	38	14.78378261
2	.	39	28.95191283
2	.	40	12.95021632
2	.	41	11.14677518
2	.	42	3.766451065
2	.	43	7.539510051
2	.	44	29.78431398
2	.	45	6.490119931

etc...

```
Parameters  dccost(dc)  unit cost of throughput at dc as well as trans to dc

/ 2       22.77848566
  10      16.95804185
  22      18.26103001
  26      24.7655862
  36      16.22223752
  40      22.845774
  47      19.45057544
  51      25.14771809
  55      28.59272362
  57      21.63275805
  86      22.84521222
  99      22.66225987
  112     38.52991377
  125     24.69901063
  129     20.18298223
  130     19.96948686
  131     26.0079526
  136     17.32132465
  142     21.14096315
  143     31.11037199
  144     19.99541739
  146     23.44270125
  160     39.70245357
  163     30.62585201
  167     45.55771024
  171     40.453325
  181     20.79733797
  197     18.88223526/;
```

```
Parameters  f(dc) fixed cost of building a distribution center
/2        199999.56
 10       161666.311
 22       168166.2967
 26       230999.4918
 36       165332.9696
 40       202666.2208
 47       171166.2901
 51       169999.626
 55       177499.6095
 57       191832.9113
 86       208332.875
 99       161832.9773
 112      203499.5523
 125      170499.6249
 129      152332.9982
 130      158166.3187
 131      333332.6
 136      163666.3066
 142      215999.5248
 143      166332.9674
 144      188832.9179
 146      179832.9377
 160      199999.56
 163      162499.6425
 167      241166.1361
 171      199499.5611
 181      163666.3066
 197      174999.615/;
```

APPENDIX D: *GAMS Model.lst Output*

MODEL STATISTICS

BLOCKS OF EQUATIONS	4	SINGLE EQUATIONS	264
BLOCKS OF VARIABLES	4	SINGLE VARIABLES	5853
NON ZERO ELEMENTS	17501	DISCRETE VARIABLES	28

Cplex 4.0, GAMS Link 8-6, DEC AXP/OSF
Solution satisfies tolerances.

MIP Solution : 956498.369383 (6067 iterations, 158 nodes)
Final LP : 956498.369383 (0 iterations)

Best integer solution possible : 934461.123924
Relative gap : 0.0235828

---- EQU FIX Fixed costs at each distribution center

	LOWER	LEVEL	UPPER	MARGINAL
2	-INF	.	.	-8.651
10	-INF	.	.	-9.899
22	-INF	.	.	-11.218
26	-INF	.	.	-7.226
36	-INF	-9.760E+5	.	.
40	-INF	.	.	-10.408
47	-INF	.	.	-8.810
51	-INF	.	.	-13.054
55	-INF	.	.	-17.458
57	-INF	.	.	-8.798
86	-INF	.	.	-8.446
99	-INF	.	.	-14.825
112	-INF	.	.	-16.739
125	-INF	.	.	-14.172
129	-INF	.	.	-8.188
130	-INF	.	.	-13.046
131	-INF	.	.	-4.392
136	-INF	.	.	-8.939
142	-INF	.	.	-8.560
136	-INF	.	.	-8.939
142	-INF	.	.	-8.560
143	-INF	.	.	-21.038
144	-INF	.	.	-8.337
146	-INF	.	.	-34.331
160	-INF	.	.	-17.623
163	-INF	.	.	-22.784

167	-INF	.	.	-12.440
171	-INF	.	.	-17.243
181	-INF	.	.	-10.721
197	-INF	.	.	-9.739

FLOW FROM DC TO MARKET

36 .1	.	16.000	+INF	.
36 .2	.	140.000	+INF	.
36 .3	.	9.000	+INF	.
36 .4	.	112.000	+INF	.
36 .5	.	3.000	+INF	.
36 .6	.	1.000	+INF	.
36 .7	.	25.000	+INF	.
36 .8	.	73.000	+INF	.
36 .9	.	8.000	+INF	.
36 .10	.	384.000	+INF	.
36 .11	.	24.000	+INF	.
36 .12	.	130.000	+INF	.
36 .13	.	16.000	+INF	.
36 .14	.	106.000	+INF	.
36 .13	.	16.000	+INF	.
36 .14	.	106.000	+INF	.
36 .15	.	23.000	+INF	.
36 .16	.	32.000	+INF	.
36 .17	.	18.000	+INF	.
36 .18	.	4.000	+INF	.
36 .19	.	11.000	+INF	.
36 .20	.	16.000	+INF	.
36 .21	.	14.000	+INF	.
36 .22	.	154.000	+INF	.
36 .23	.	6.000	+INF	.
36 .24	.	13.000	+INF	.
36 .25	.	42.000	+INF	.
36 .26	.	844.000	+INF	.
36 .27	.	4.000	+INF	.
36 .28	.	18.000	+INF	.
36 .29	.	17.000	+INF	.
36 .30	.	132.000	+INF	.
36 .31	.	68.000	+INF	.
36 .30	.	132.000	+INF	.
36 .31	.	68.000	+INF	.
36 .32	.	9.000	+INF	.
36 .33	.	30.000	+INF	.
36 .34	.	.	+INF	17.830
36 .35	.	26.000	+INF	.
36 .36	.	100.000	+INF	.
36 .37	.	9.000	+INF	.
36 .38	.	47.000	+INF	.
36 .39	.	9.000	+INF	.
36 .40	.	659.000	+INF	.

36 .41	.	100.000	+INF	.
36 .42	.	7.000	+INF	.
36 .43	.	270.000	+INF	.
36 .44	.	107.000	+INF	.
36 .45	.	52.000	+INF	.
36 .46	.	17.000	+INF	.
36 .47	.	167.000	+INF	.
36 .48	.	33.000	+INF	.
36 .47	.	167.000	+INF	.
36 .48	.	33.000	+INF	.
36 .49	.	16.000	+INF	.
36 .50	.	31.000	+INF	.
36 .51	.	464.000	+INF	.
36 .52	.	12.000	+INF	.
36 .53	.	29.000	+INF	.
36 .54	.	22.000	+INF	.
36 .55	.	644.000	+INF	.
36 .56	.	22.000	+INF	.
36 .57	.	174.000	+INF	.
36 .58	.	46.000	+INF	.
36 .59	.	8.000	+INF	.
36 .60	.	18.000	+INF	.
36 .61	.	78.000	+INF	.
36 .62	.	17.000	+INF	.
36 .63	.	18.000	+INF	.
36 .64	.	88.000	+INF	.
36 .65	.	12.000	+INF	.
36 .66	.	7.000	+INF	.
36 .67	.	13.000	+INF	.
36 .68	.	25.000	+INF	.
36 .69	.	10.000	+INF	.
36 .70	.	5.000	+INF	.
36 .71	.	22.000	+INF	.
36 .72	.	56.000	+INF	.
36 .73	.	20.000	+INF	.
36 .72	.	56.000	+INF	.
36 .73	.	20.000	+INF	.
36 .74	.	10.000	+INF	.
36 .75	.	36.000	+INF	.
36 .76	.	30.000	+INF	.
36 .77	.	52.000	+INF	.
36 .78	.	8.000	+INF	.
36 .79	.	23.000	+INF	.
36 .80	.	66.000	+INF	.
36 .81	.	70.000	+INF	.
36 .82	.	47.000	+INF	.
36 .83	.	12.000	+INF	.
36 .84	.	84.000	+INF	.
36 .85	.	13.000	+INF	.
36 .86	.	457.000	+INF	.
36 .87	.	11.000	+INF	.
36 .88	.	16.000	+INF	.
36 .89	.	501.000	+INF	.
36 .90	.	52.000	+INF	.

36 .89	.	501.000	+INF	.
36 .90	.	52.000	+INF	.
36 .91	.	27.000	+INF	.
36 .92	.	91.000	+INF	.
36 .93	.	6.000	+INF	.
36 .94	.	50.000	+INF	.
36 .95	.	197.000	+INF	.
36 .96	.	76.000	+INF	.
36 .97	.	2.000	+INF	.
36 .98	.	17.000	+INF	.
36 .99	.	147.000	+INF	.
36 .100	.	65.000	+INF	.
36 .101	.	14.000	+INF	.
36 .102	.	38.000	+INF	.
36 .103	.	2.000	+INF	.
36 .104	.	21.000	+INF	.
36 .105	.	16.000	+INF	.
36 .106	.	14.000	+INF	.
36 .107	.	83.000	+INF	.
36 .106	.	14.000	+INF	.
36 .107	.	83.000	+INF	.
36 .108	.	63.000	+INF	.
36 .109	.	2.000	+INF	.
36 .110	.	26.000	+INF	.
36 .111	.	26.000	+INF	.
36 .112	.	1880.000	+INF	.
36 .113	.	53.000	+INF	.
36 .114	.	14.000	+INF	.
36 .115	.	19.000	+INF	.
36 .116	.	41.000	+INF	.
36 .117	.	5.000	+INF	.
36 .118	.	5.000	+INF	.
36 .119	.	25.000	+INF	.
36 .120	.	173.000	+INF	.
36 .121	.	5.000	+INF	.
36 .122	.	861.000	+INF	.
36 .123	.	21.000	+INF	.
36 .124	.	95.000	+INF	.
36 .125	.	279.000	+INF	.
36 .126	.	14.000	+INF	.
36 .127	.	114.000	+INF	.
36 .128	.	10.000	+INF	.
36 .129	.	154.000	+INF	.
36 .130	.	214.000	+INF	.
36 .131	.	3387.000	+INF	.
36 .132	.	65.000	+INF	.
36 .131	.	3387.000	+INF	.
36 .132	.	65.000	+INF	.
36 .133	.	.	+INF	37.185
36 .134	.	93.000	+INF	.
36 .135	.	62.000	+INF	.
36 .136	.	249.000	+INF	.
36 .137	.	11.000	+INF	.
36 .138	.	9.000	+INF	.

36 .139	.	17.000	+INF	.
36 .140	.	4.000	+INF	.
36 .141	.	11.000	+INF	.
36 .142	.	1207.000	+INF	.
36 .143	.	409.000	+INF	.
36 .144	.	200.000	+INF	.
36 .145	.	315.000	+INF	.
36 .146	.	121.000	+INF	.
36 .147	.	1.000	+INF	.
36 .148	.	249.000	+INF	.
36 .149	.	.	+INF	22.239
36 .150	.	139.000	+INF	.
36 .151	.	9.000	+INF	.
36 .152	.	12.000	+INF	.
36 .153	.	54.000	+INF	.
36 .154	.	93.000	+INF	.
36 .155	.	40.000	+INF	.
36 .156	.	89.000	+INF	.
36 .157	.	15.000	+INF	.
36 .158	.	8.000	+INF	.
36 .159	.	4.000	+INF	.
36 .160	.	174.000	+INF	.
36 .161	.	58.000	+INF	.
36 .162	.	2.000	+INF	.
36 .163	.	253.000	+INF	.
36 .164	.	11.000	+INF	.
36 .165	.	115.000	+INF	.
36 .166	.	358.000	+INF	.
36 .165	.	115.000	+INF	.
36 .166	.	358.000	+INF	.
36 .167	.	652.000	+INF	.
36 .168	.	28.000	+INF	.
36 .169	.	29.000	+INF	.
36 .170	.	53.000	+INF	.
36 .171	.	624.000	+INF	.
36 .172	.	47.000	+INF	.
36 .173	.	37.000	+INF	.
36 .174	.	1.000	+INF	.
36 .173	.	37.000	+INF	.
36 .174	.	1.000	+INF	.
36 .175	.	25.000	+INF	.
36 .176	.	15.000	+INF	.
36 .177	.	69.000	+INF	.
36 .178	.	106.000	+INF	.
36 .179	.	28.000	+INF	.
36 .180	.	3.000	+INF	.
36 .181	.	103.000	+INF	.
36 .182	.	118.000	+INF	.
36 .183	.	39.000	+INF	.
36 .184	.	389.000	+INF	.
36 .185	.	4.000	+INF	.
36 .186	.	28.000	+INF	.
36 .187	.	13.000	+INF	.
36 .188	.	2.000	+INF	.

36 .189	.	93.000	+INF	.
36 .190	.	54.000	+INF	.
36 .191	.	10.000	+INF	.
36 .190	.	54.000	+INF	.
36 .191	.	10.000	+INF	.
36 .192	.	23.000	+INF	.
36 .193	.	41.000	+INF	.
36 .194	.	25.000	+INF	.
36 .195	.	6.000	+INF	.
36 .196	.	39.000	+INF	.
36 .197	.	628.000	+INF	.
36 .198	.	14.000	+INF	.
36 .199	.	20.000	+INF	.
36 .200	.	218.000	+INF	.
36 .201	.	6.000	+INF	.
36 .202	.	29.000	+INF	.
36 .203	.	18.000	+INF	.
36 .204	.	28.000	+INF	.
36 .205	.	16.000	+INF	.
36 .206	.	16.000	+INF	.
36 .207	.	.	+INF	19.234

Flow from plant to Distribution Center

DC	L.	Level	U.	
2	.	.	+INF	.
10	.	.	+INF	.
22	.	.	+INF	.
26	.	.	+INF	.
36	.	23956.000	+INF	.
40	.	.	+INF	.
47	.	.	+INF	.
51	.	.	+INF	.
55	.	.	+INF	.
57	.	.	+INF	.
86	.	.	+INF	.
99	.	.	+INF	.
112	.	.	+INF	.
125	.	.	+INF	.
129	.	.	+INF	.
130	.	.	+INF	.
131	.	.	+INF	.
136	.	.	+INF	.
142	.	.	+INF	.
143	.	.	+INF	.
144	.	.	+INF	.
146	.	.	+INF	.
160	.	.	+INF	.
163	.	.	+INF	.
167	.	.	+INF	.
171	.	.	+INF	.
181	.	.	+INF	.
197	.	.	+INF	.