Building Decision Support Systems in Excel for Production and Distribution Planning: A Case Study

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We develop a decision support system in Microsoft Excel that integrates production and distribution for a manufacturer of natural fiber-based products in North America. The production and distribution of the company's products were optimized using a linear programming model, implemented in Excel. The spreadsheet dynamically adjusts the formulation to reflect the user's current requirements, solves the optimization model in the background, and generates detailed managerial reports. In addition, it allows users to conduct what-if analyses by varying the number of plants and warehouses. It demonstrates the ability of a Linear Programming Model run on an Excel platform to provide the firm with an optimized production plan resulting in significant, cost savings since implementation.

Keywords: decision support system, optimization, production and distribution planning, integer linear programming, case study

INTRODUCTION

Companies adopting optimization for different functions (e.g., purchasing, production, distribution, and storage) simultaneously have been rewarded with reduced costs, increased profits, and improved service levels (Ganeshan, Jack, Magazine, & Stephens, 1999; Mabert & Venkataramanan, 1998; Park, 2005; Shapiro, 1999). Integration of production and distribution functions accrue economic benefits by exploiting economies of scale resulting from cost reduction and improved service levels (Fumero & Vercellis, 1999; Martin, Dent, & Eckhart, 1993; Thomas & Griffen, 1996).

Extensive literature reviews can be found in Sarmiento and Nagi (1999), Erenguc, Simpson, and Vakharia (2001), Mula, Poler, Garcia-Sabater, and Lario (2006), Melo, Nickel, and Saldanha-da-Gama (2009), Mula, Peidro, Díaz-Madroñero, and Vicens (2010), and Fahimnia, Farahani, Marian, Luong (2013) and Adresai et. al (2017). The literature for integrated production and distribution models can be divided into seven categories. (1) Single product, (2) Multiple product, single plant, (3) Multiple product, multiple plant, single or no warehouse, (4) Multiple product, multiple plant, multiple warehouse, single or no end-user, (5) Multiple product, multiple plant, multiple warehouse, multiple end-user, single transportation path, (6) Multiple product, multiple plant, multiple warehouse, multiple end-user, multiple transportation path, single period, and (7) Multiple product, multiple plant, multiple warehouse, multiple end-user, multiple transportation path, multiple period. Table 1 summarizes the literature in this area.

Despite extensive literature, sophisticated models are rarely used in practice (Buxey, 2005; Buzacott, 2013). Gilgeous (1987) conducted a survey of manufacturing companies in the UK. The conclusions showed that plant managers do not use optimization models for production and distribution planning. This was further confirmed by DuBois and Oliff (1991) who surveyed manufacturing firms in southeast US and concluded that managers lack the expertise to use complex mathematical models.

TABLE 1
SUMMARY OF LITERATURE

Product	Plant	Warehouse	End-User	Transport Path	Period	Method	Papers
Single	Multiple	Multiple	Multiple	Single	Multiple	MIP	Haq, Vrat, and Kanda (1991)
Single	Multiple	N/A	Multiple	Single	Single	LP and GA+AHP	Chan, Chung, and Wadhwa (2005)
Single	Multiple	Multiple	Multiple	Single	Multiple	MIP with heuristics	Yilmaz and Catay (2006)
Single	Single	N/A	Multiple	Multiple	Multiple	Heuristic	Boudia, Louly, and Prins (2007)
Single	Multiple	Multiple	Multiple	Multiple	Multiple	Algorithm + MIP	Hamedi, et. al (2009)
Single	Single	N/A	Multiple	Single	Multiple	Tabu Search	Bard & Nananukul (2009)
Multiple	Single		Single	Single	Multiple	Algorithm for near optimal solutions	Pyke & Cohen (1993)
Multiple	Single	Multiple	Single		Multiple	Fuzzy Goal Programming	Torabi & Hassini (200,8)
Multiple	Single	Multiple	Multiple		Multiple	MIP + Lagrangian heuristic	Barbarosglu & Ozgur (1999)
Multiple	Single	Multiple	Multiple		Multiple	Fuzzy Goal Programming	Selim, et. al. (2008)
Multiple	Single	Multiple			Multiple	Hierarchical Planning	Ozdamar & Yazgac (1999)
Multiple	Single	Multiple	Multiple	Multiple	Multiple	LP + Simulation	Lee & Kim (2002)
Multiple	Single	Single			Multiple	MIP	Rizk et. al. (2006)
Multiple	Single				Multiple	MILP + Lagrangian heuristic	Nishi et. al. (2007)
Multiple	Single	Multiple	Multiple	Multiple	Multiple	MILP+GA	Elahipanah & Farhani (2008)
Multiple	Multiple	Single	Multiple		Multiple	Different Math models for different scenarios	Mohamed (1999)
Multiple	Multiple	Single	Multiple		Multiple	GA + Fuzzy Logic	Gen & Syarif (2005)
Multiple	Multiple	Single	Multiple		Multiple	LP	Chen & Wang (1997)
Multiple	Multiple	Single	Multiple	Multiple	Multiple	MILP	Kanyalkar & Adil (2005)
Multiple	Multiple	Single				MILP	Kanyalkar & Adil (2010)
Multiple	Multiple	Multiple	Single			Heuristic Algorithm	Cohen & Lee (1988)
Multiple	Multiple	Multiple	Single			Non-Linear Math Model	Tang, et. al. (2004)
Multiple	Multiple	Multiple	Single	Multiple	Multiple	MILP	Kanyalkar & Adil (2007)
Multiple	Multiple	Multiple	Single		Multiple	Fuzzy Mathematical Programming	Liang (2008)
Multiple	Multiple	Multiple	Single		Multiple	MILP	Bilgen (2010)
Multiple	Multiple	Multiple	Single		Multiple	Fuzzy Goal Programming	Torabi & Hassini (2009)
Multiple	Multiple	Multiple	Multiple	Single	Multiple	MILP	Dhaenens-Flipo & Finke (2001)
Multiple	Multiple	Multiple	Multiple	Single	Multiple	MINLP	Chen & Lee (2004)
Multiple	Multiple	Multiple	Multiple	Single	Multiple	Simulation Optimization	Lim et. al. (2006)
Multiple	Multiple	Multiple	Multiple	Single		GA and Lagrangian Heuristic	Jang et. al. (2002)
Multiple	Multiple	Multiple	Multiple	Single	Multiple	GA + Fuzzy Programming	Aliev et. al. (2007)
Multiple	Multiple	Multiple	Multiple	Single	Multiple	Multi Objective LP	Selim et al. (2008)
Multiple	Multiple	Multiple	Multiple	Single	Multiple	Multi Agent (GA) with Lagrangian Relaxation	Kazemi et. al. (2009)
Multiple	Multiple	Multiple	Multiple	Single	Multiple	GA	Yimer & Demirili (2010)
Multiple	Multiple	Multiple	Multiple	Multiple	Single	MIP	Gunnarsson, H. et. al. (2007)
Multiple	Multiple	Multiple	Multiple	Multiple	Single	MILP	Kim et. al. (2008)
Multiple	Multiple	Multiple	Multiple	Multiple	Multiple	GA	Fahimnia, et. al. (2012)
Multiple	**Multiple**	**Multiple**	**Multiple**	**Multiple**	**Multiple**	**LP**	**This Case Study**

Table 1: Summary of Literature

In this paper, we demonstrate a decision support system built in Microsoft Excel which incorporates multiple products, multiple plants, multiple warehouses, multiple end-users, multiple transportation path, multiple period production and distribution models. This linear programming model was developed for, and subsequentially adopted by, a largest manufacturer of natural fibre products in North America. It fills the need for a complex real-world model of production and distribution planning. The main contribution of this case study is the demonstration of an industry application in operations research. We show how the application of linear programming implemented via a user-friendly Excel platform can provide the firm with an optimized production planning system.

The company is headquartered in the Southeastern United States. The company makes cellulose insulation products with recycled paper fiber which is used in housing construction for attic, side walls, and floor insulation and for agriculture structures. The cellulose insulation is cheaper than spray foam or fiber glass insulation and is easier to install. Furthermore, 85% of its raw material comes from recycled paper and then additional fire-resistant materials are added to the product to give it Class 1A fire rating which is makes it 57% better at resisting fire than the other kinds of insulation made form foam or fiber glass. The cellulose insulation material is also superior to fiber glass insulation when it comes to sound proofing. When the project began, the company had 10 plants scattered across the country. Two of the 10 plants had sizable warehouses for inventory, while the remaining plants had the option of leasing warehouses. These products are shipped to independent distributors grouped into 51 freight zones. In each freight zone there are two types of distributors: (1) distributors specializing in retail demand, and (2) distributors specializing in contractor demand.

Distributors ship products to customers only within their region. The demand for each product is known (forecasted) for planning horizons of 2 to 12 months. Variable production and inventory carrying costs by product and by plant are incorporated. Raw material, processing, and labor costs are included in the production variable cost. If the primary raw material, which is recycled fiber, requirements exceed a specified amount for a given plant, the company must acquire and transport the raw material from locations outside the plant's region. Therefore, the incremental cost of raw material usage is tracked in the model and recorded when a plant's requirements exceed the local threshold for available recycled fiber. Given that 85% of the raw material is recycled paper, all the company's plants are located right next to the major recycling centers in the city. According to the firm the cost of shipping the product over large distances is relatively higher than its cost. Therefore, transportation costs associated with the three to five closest plants identified by the firm to each distributor used in the model. The model also incorporates each plant's capacity and minimum monthly production requirements where applicable. The company's goal is to minimize enterprise-wide total cost of production, storage, and distribution of their products to distributors (retail and contractor), located around the country for a planning horizon of 2 to 12 months.

The remainder of this paper is organized as follows. The next section is the linear programming model developed for this case. We than discuss the implementation of the model in an Excel spreadsheet followed by an example of how it is used. Finally, we present our conclusions and next steps.

THE MODEL

Assumptions and User Specifications

The following are assumptions and some user specifications given by the client. Some of these user specifications are handled as an input and do not restrict the model. These are (1) No loss and damage during delivery, (2) No shortage or backorders, (3) No change in Production and delivery cost with the quantity to be delivered, (4) The company has 10 plants and wants to be able to increase them to 15 (there is no such restriction in the model), (5) There are two different products (the model allows for more than two products), (6) There are 51 demand or freight zones (the model allows for any number of demand zones, (7) There are warehouses in 2 plants, and the other plants can lease warehouses, (8) Fixed cost of building new plants is not considered, and (9) User specifies up to five closest plants to supply each distributor (freight zone) (The model does not place any such restriction and handles it by using transportation costs for the five closest plants and uses very large values for other plants).

We developed a linear programming formulation to solve an integrated multiple period production planning and distribution problem with fixed capacity.

Input Variables

We use the following notations are inputs to our model:

t	index of periods (2-12 months)
p	index of products (2)
i	index of plants (10-15)
j_p	index of demand (freight) zones per product *p*
$c_{p,i,t}$	unit production cost of product p at plant i in period t
$r_{p,i,j}$	unit transportation cost of product p from plant i to demand zone $j \in j_p$
h	inventory carrying cost per unit per period
$Inv_{p,i}$	initial inventory of product p per plant i
a_p	raw material usage per product *p*
$cm_{i,t}$	incremental cost of raw material for plant i in period t
$D_{p,j,t}$	demand for product p in zone j_p in period t
$Cap_{i,t}$	maximum capacity of plant i in period t
$Min_{i,t}$	minimum production requirement for plant i in period t
$WC_{i,t}$	warehouse capacity of plant i in period t
$Mat_{i,t}$	maximum amount of raw material locally available per plant i in period t

Decision Variables

The following decision variables are used in the model:

$x_{p,i,j,t}$	number of products p made in plant i shipped to demand zone $j \in j_p$ in period t
$w_{p,i,j,t}$	ending inventory of product p made in plant *i*, shipped to demand zone $j \in j_p$ in period t
$y^+_{i,t}$	amount of excess raw material usage for plant i in period t

The Model

Minimize

$$\sum_p \sum_i \sum_{j\in j_p} r_{p,i,j}\, w_{p,i,j,0} + \sum_p \sum_i \sum_{j\in j_p} \sum_t \left(r_{p,i,j} + c_{p,i,j,t}\right)\left(x_{p,i,j,t} + hw_{p,i,j,t}\right) + \sum_i \sum_t cm_{i,t} y^+_{i,t} \qquad (1)$$

The objective function minimizes total costs over the planning horizon. These include the costs of shipping the inventory on hand at the beginning of month 1, costs for storage, production and transportation of products during the planning horizon (2-12 months), and the cost of excess material required for production.

Subject to

$$\sum_{j\in j_p} w_{p,i,j,o} = Inv_{p,i} \;\; \forall\, p, i \qquad (2)$$

Constraint (2) limits the shipments of initial inventory at the beginning of month 1 to the inventory on hand (carried over from the prior month’s excess production)

$$\sum_p \sum_{j\in j_p} w_{p,i,j,t} \le WC_{i,t} \;\; \forall\, i, t \qquad (3)$$

Warehouse capacity limitations are enforced with this constraint.

$$\sum_i \left(w_{p,i,j,t-1} + x_{p,i,j,t} - w_{p,i,j,t}\right) = D_{p,j,t} \ \forall p, j \in j_p, t \quad (4)$$

Constraint (4) ensures that once demand for each product at each freight zone is fulfilled (by beginning inventories and the production in the current month), any excess production is stored and carried over to the next month.

$$\sum_p \sum_{j \in j_p} x_{p,i,j,t} \leq Cap_{i,t} \ \ \forall\, i, t \quad (5)$$

Constraint (5) enforces maximum production quotas per plant in each month

$$\sum_p \sum_{j \in j_p} x_{p,i,j,t} \geq Min_{i,t} \ \ \forall\, i, t \quad (6)$$

Constraint (6) enforces minimum production quotas per plant in each month

$$\sum_p \sum_{j \in j_p} a_p x_{p,i,j,t} \leq Mat_{i,t} + y_{i,t}^{+} \ \ \forall\, i, t \quad (7)$$

Constraint (7) limits the raw material consumption per plant in each month to the current availability plus excess usage. Excess usage incurs an additional material usage cost ($cm_{i,t} y_{i,t}^{+}$).

$$w_{p,i,j,t}\ , x_{p,i,j,t}\ , y_{i,t}^{+} \ \ \geq 0 \quad (8)$$

Finally, constraint (8) imposes the non-negativity restriction on the decision variables $w_{p,i,j,t}, x_{p,i,j,t}$ and $y_{i,t}^{+}$.

IMPLEMENTATION AND EXAMPLE

The project was completed in three stages: (1) problem definition and deliverable requirements, (2) model development and validation, and (3) implementation of the model in Excel. The project deliverables included a user friendly and automated data input interface to permit management at the company's headquarters to use the model for what-if analyses. The implementation requirements included instantaneous detailed production and transportation plan reports per plant for the markets they serve as well as an enterprise-wide summary report. The project took approximately six months to complete.

Some Implementation Details

We described the main problem statement in the introduction and presented the model in the previous section. Data requirements for the model were in three categories: (1) costs (production, transportation, storage and acquisition of excess raw fiber material), (2) plant requirements (minimum, maximum, inventory space, and estimated fibre availability), and (3) forecasted demand.

We first developed a prototype model for the smallest problem instance using only two months of the most recent real data. We solved it using CPLEX (2009) and manually created basic production and transportation reports based on the optimal solution. The company's management participated in solving various scenarios using historical data and compared their plans versus the optimal solutions found by the model, thus validating the model.

For the final Excel implementation we chose LINDO (2010) for the solver largely based on our experience with its application programming interface (API). Since the model does not require integer variables, both CPLEX and LINDO solve the largest problem instances in only a few seconds.

Per project requirements, we created a user-friendly interface in Excel for data entry and running the model. The interface allows the planner to enter, or review, the input data and then run the model. The user is prompted for the number of plants (10-15) and the number of months (2-12). Our Excel VBA code reads the problem data, invokes LINDO to solve the problem, reads the optimal solution, writes the reports in a new Excel file, and then prompts the user to name the file. It is important to note that all costs are recalculated using the identified optimal decision variable values. That is, we compute each of the cost components for all plants and months, as well as the grand total cost for the company. We compare the grand total cost from LINDO with our recalculated grand total cost using a bottom-up approach. If the difference is less than one dollar, we conclude that the identified optimal solution has been found, and the resulting reports are accurate.

At the time of the study the company had 10 plants but wanted to have the flexibility to consider opening new plants or shutting down existing plants, hence we designed the system to handle up to 15 plants. As mentioned above the planning horizon is 2 to 12 months. Regarding the distribution options, for each demand zone and product, the company determines the closest three to five plants and the corresponding transportation costs. However, the formulation generator is built to handle the possibility of distribution from any plant to any demand zone. Similarly, the formulation generator determines the availability of a warehouse for a given plant from the input data. If the warehouse capacity is zero for a plant, then the corresponding decision variables and constraints are omitted. When a plant's maximum capacity is set to zero, the formulation generator treats as plant as if it were closed and, hence, omits all affected decision variables and constraints. In general, the user can conduct what-if analyses by varying capacities, quota, distribution costs.

Regarding the problem sizes, keeping the number of plants fixed at ten, a typical two period problem, would have require 1,000 variables and 300 constraints. For a twelve month plan the problem instance would have nearly 7,000 variables and 1,800 constraints. The time to solve large problem instances is negligible. For our model, the total time to run an analysis (excluding the data entry for production and transportation costs, and demand forecasts) is under one minute on a basic laptop (e.g., Dell Pentium IV 2.4 GHz with 4 GB RAM). This time includes the time to generate the output reports.

RESULTS FROM A SAMPLE RUN

Here we will illustrate the ease of using the model with an example. To maintain the anonymity of the company we use simulated data generated from actual data. For space considerations we will share only select partial input and output data. We first ran the model for a two month, 10-plant scenario where all plants are assumed to have a 100,000-unit (i.e., bag) warehouse capacities and have 1,000 bags of each product as their initial (beginning) inventory level. Figure 1 shows a portion of the plant-based input data such as direct (variable) cost per plant per month, the maximum amount of fiber that can be sourced locally (base volume) per plant, and the cost per pound for additional fiber usage. The company produces two sizes of bags that require, on average, 20 and 26 pounds of raw fibre per bag, respectively. We do not show the plant production quota (minimum and maximum), or the beginning inventory levels which are also located on the plant inputs worksheet.

FIGURE 1
A PARTIAL VIEW OF THE PLANT INPUT WORKSHEET

DIRECT COSTS				Recycled Fiber Availability	
P1 cost/bag by month				Base Volume	Extra usage
Month	May	Jun	Jul	Lbs/mo.	Cost/LB
Phoenix	2.31	2.31	2.31	10,000,000	0.0109
Sacramento	2.37	2.37	2.37	6,000,000	0.0125
Waco	2.36	2.36	2.36	5,000,000	0.0118
Denver	2.36	2.36	2.36	1,500,000	0.0108
Norfolk	2.26	2.26	2.26	6,000,000	0.0080
Delphos	2.21	2.21	2.21	6,000,000	0.0054

Figure 2 displays a partial view of the input sheet for product one (P1). The design of the data input sheets was based on the company's existing spreadsheets. As shown in Figure 2 the shipping destinations are in rows with demand forecast for twelve months to the right of each destination (to fit in the paper only three months are shown, the remaining columns are hidden). Further to the right of each destination are the shipping costs from three to five of the closest plants (to fit in the paper only a few of the destination shipping costs are shown). For example, the New England market is best served from three plants which are in "Del", "Cha", and "Elk".

FIGURE 2
A PARTIAL VIEW OF THE INPUTS WORKSHEET FOR PRODUCT ONE

Optimize	Demand			Shipping costs									
P1 Destinations	May	Jun	Jul	Phx	Sac	Wac	Den	Nor	Del	Atl	Tam	Cha	Elk
New England	9,276	4,401	2,647						1.61			1.50	0.96
E. NY	12,411	10,616	7,226						1.19			1.62	0.94
W. NY	6,886	6,056	4,368						0.83			1.46	0.83
S. NY	922	1,602	1,672						0.91			1.40	0.72
W. PA	3,553	5,155	2,578						0.58			0.89	0.40
C. PA	2,438	975	1,007						0.50			1.03	0.56
E. PA	23,809	20,634	15,536						0.91			1.07	0.42

Prior to the actual running of the optimization routine, we further perform various data validation procedures. After the input data are checked for errors and missing values, and corrected as needed, the user invokes the optimization procedure by clicking on the "Optimize" button. The problem instance is then generated, the solver is invoked, the results are parsed, and the reports are generated. The complete optimization and report generation process for a two-month, 10-plant problem takes less than 30 seconds. The summary sheet of the report shows the total cost by plant (Figure 3), as well as the projected grand total cost of $12,294,541 for the company.

FIGURE 3
SUMMARY WORKSHEET SHOWING TOTAL COSTS

Plant	Total Cost
Phx	$2,502,407
Sac	$1,227,851
Wac	$1,397,728
Den	$267,898
Nor	$1,358,999
Del	$1,783,798
Atl	$839,220
Tam	$1,030,634
Cha	$998,494
Elk	$887,512
Grand Total =	$12,294,541

The report generator creates an Excel file that contains two summary sheets plus one sheet per plant with complete details. The overall (cost) summary sheet is shown in Figure 3 above, a detailed summary sheet showing planned production, inventory, transportation, and corresponding costs by month for all plants. A summary sheet is not shown due its size, even for the smallest problem instances. Individual detailed plans for each of the plants (i.e., 10 more sheets in this example) would be generated for our example two-month planning horizon. Figure 4 displays the complete production and transportation plan outputted to an Excel worksheet labeled "Phx." Figure 4 shows, that the Phoenix plant's total cost is projected to be $2,502,407.

FIGURE 4
DETAILED PLANNED PRODUCTION AND COSTS FOR THE PHOENIX PLANT

Totals	Beg. Inv.	May	May Inv	Jun	Jun Inv
P1 Bags	1,000	24,176	17,054	1,149	0
P2 Bags	1,000	371,765	19,005	430,852	0
Total Bags	2,000	395,941	36,059	432,000	0
Total lbs		10,984,620	--	11,225,109	--
Base lbs		10,000,000	--	10,000,000	--
Extra lbs		984,620	--	1,225,109	--
Total Cost	$817	$1,232,990	--	$1,268,601	--
Cost/Bag		$2.85	--	$2.94	--
Total Cost	$2,502,407				
P1 Shipping Plan					
El Paso	848	0	0	0	0
N. UT	152	5,589	0	0	4,665
S. UT	0	816	0	0	0
AZ	0	6,947	0	0	6,368
NV	0	3,719	0	1,149	2,146
S. CA	0	7,105	0	0	3,875
P2 Shipping Plan					
W. MO	0	3,307	0	0	10,667
KS	0	5,082	0	0	8,338
E. NE	1,000	223,453	0	255,097	0
LA	0	1,176	0	3,553	0
AR	0	67,432	0	103,636	0
OK	0	71,315	0	68,565	0

To demonstrate various ways of utilizing the decision support system, we ran the model with the same input settings as above, but this second run removed the warehouse option for all plants. In the first run only two plants, "Sac" and "Phx", have ending inventories of 3,542 and 36,059 bags for May, respectively. In the second run, all plants had zero ending inventories for May. Not surprisingly, the total cost across all plants increased by $36,994 to $12,331,535. This increase was (1) inevitable, and (2) the optimal (i.e., minimal) increase for the entire system.

The optimal solution from the second run, for a ten-plant problem instance, three plants had no changes in their total costs, four had increases in their total costs, and three had decreases in their total costs (Figure 5). For example, the Phoenix plant saw the most gains from the system wide no warehouse restriction. Although these findings are well understood and accepted by operations research professionals, sometimes they appear to be counter intuitive or surprising to plant managers and senior management. For example, the Phoenix plant's total costs with warehouse availability was $2,505,407. When the system warehouse restriction (i.e., no warehouses) was imposed their production and distribution plan changed noticeably, and their total costs dropped by $88,263.

FIGURE 5
TOTAL COSTS FROM RUN 2 AND CHANGES FROM RUN 1

Plant	Total Cost	Change
Phx	$2,414,144	($88,263)
Sac	$1,225,249	($2,602)
Wac	$1,371,961	($25,766)
Den	$282,147	$14,249
Nor	$1,366,250	$7,251
Del	$1,819,375	$35,576
Atl	$935,769	$96,549
Tam	$1,030,634	$0
Cha	$998,494	$0
Elk	$887,512	$0
Grand Total =	$12,331,535	$36,994

FIGURE 6
DETAILED PLANNED PRODUCTION AND COSTS FOR THE PHOENIX PLANT FROM THE SECOND RUN

Totals	Beg. Inv.	May	May Inv	Jun	Jun Inv
P1 Bags	1,000	30,210	0	18,202	0
P2 Bags	1,000	376,056	0	413,798	0
Total Bags	2,000	406,266	0	432,000	0
Total lbs		10,381,651	--	11,122,787	--
Base lbs		10,000,000	--	10,000,000	--
Extra lbs		381,651	--	1,122,787	--
Total Cost	$1,554	$1,168,331	--	$1,244,259	--
Cost/Bag		$2.88	--	$2.88	--
Total Cost	$2,414,144				
P1 Shipping Plan					
El Paso	0	848	0	0	0
W. CO	0	3,523	0	0	0
N. UT	185	5,557	0	4,665	0
S. UT	816	0	0	0	0
AZ	0	6,947	0	6,368	0
NM	0	2,511	0	0	0
NV	0	3,719	0	3,295	0
S. CA	0	7,105	0	3,875	0
P2 Shipping Plan					
W. MO	0	2,469	0	0	0
KS	0	5,082	0	5,876	0
E. NE	0	224,453	0	235,720	0
W. NE	0	5,128	0	0	0
LA	1,000	176	0	0	0
AR	0	67,432	0	103,636	0
OK	0	71,315	0	68,565	0

CONCLUSIONS

The entire project took six months to complete. The first two months were spent in gathering project requirements and how the deliverables should look like. There were weekly meetings with the managers and multiple conference calls. Data requirements were straight forward with very little data cleaning required. The next month was spent on model development and validation of the results by the managers with their own solutions. Finally, the last three months was spent in building the reporting and the decision support system in Excel to generate optimal production and transportation plans for the large U.S. manufacturer.

The final system was implemented on Excel and utilizes VBA in Excel for problem generation, interface with the solver, reading the optimal solution, and writing the requisite reports. The interface is user friendly, and the user does not have to interact with the model or the solver output directly and requires a basic familiarity with the Excel. We also incorporated a feature for management to conduct what-if analysis by allowing the user to vary the number of plants (i.e., simulating plant closures or adding plants) and leasing warehouses. Since its implementation, the company has been using this system which has generated significant cost savings for the company.

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