

Optimizing Delta and Pine Land Company's Bag Seed Distribution

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Abstract

The paper describes a project conducted jointly by Delta and Pine Land Company and the National Center for Intermodal Transportation. The purpose of the project was to develop a tool that Delta and Pine Land Company could use to derive a more economical strategy for distributing cottonseed to its customers. Mathematical programming is used, and the model formulated is a relatively large linear programming problem that can be solved using commercial software. In this paper, the problem definition is stated, the model is formulated, the solution procedure is described, and the benefits to Delta and Pine Land Company (D&PL) during its

1999-2000 season are presented. This project demonstrates the potential for using linear programming in managing large-scale transportation and distribution problems. In the case of D&PL, the model resulted in the creation of new ratios for measuring their performance, the model helped D&PL understand conditions that result in inventory shortages, and the model led to the discovery of inaccuracies in D&PL distribution reports. D&PL's focus on their transportation and distribution processes during the 1999-2000 season resulted in significant financial savings and a 14% reduction in their finished goods move ratio.

1. Introduction

Delta and Pine Land Company (D&PL), headquartered in Scott, Mississippi, breeds, produces, conditions and markets many varieties of cottonseed in the United States and around the world. The National Center for Intermodal Transportation (NCIT) is a US Department of Transportation University Research Center, jointly operated by Mississippi State University and the University of Denver. D&PL contacted NCIT researchers at Mississippi State University about developing mathematical models in four areas (supply, forecasting, logistics, and operations) to be used in managing D&PL's cottonseed supply chain.

After preliminary discussions, it was decided that NCIT should initially assist D&PL by modeling their cotton bag seed transportation and distribution activities using mathematical programming. Mathematical programming has been applied frequently and successfully to a wide variety of distribution and transportation problems for a variety of industries. For example, Camm et al [1997] use integer programming and network optimization models to improve Procter & Gamble's distribution system; Arntzen et al [1995] use mixed-integer linear programming to determine Digital Equipment Corporation's distribution strategy; Martin et al

[1993] use linear programming to assist in distribution operations for Libbey-Owens-Ford; Robinson et al [1993] use optimization in designing a distribution decision-support system for DowBrands, Inc.; Mehring and Gutterman [1990] use linear programming to plan distribution at Amoco (U.K.) Limited. However, none of these models as well as other published models identified by the research team were directly applicable to the transportation and distribution system of D&PL. Thus, it is hoped that other companies with distribution systems similar to D&PL's system will benefit from this publication.

The purpose of formulating and optimizing the cottonseed distribution model is to provide D&PL with a means for comparing their strategy for moving bags of cottonseed through their distribution network with the optimized strategy derived from the formulated model. Such analyses usually lead to a more economical distribution strategy. Therefore, the first objective of the project was to establish the scope of the model by identifying the aspects of D&PL's distribution that would be studied. The second objective was to define the decision variables, parameters, constraints and performance measures necessary for formulating a model of D&PL's bag seed distribution operations. The third objective was to formulate a mathematical programming model of the distribution activities. The fourth objective of the project was to identify software for solving the defined mathematical programming model. The fifth objective was to develop and test the model using several realistic scenarios. And the sixth and final objective was to analyze the optimal distribution of bag seed determined for the model to identify improvements to the current distribution strategy used by D&PL.

D&PL staff worked closely with NCIT in achieving these objectives. Specifically, D&PL staff assisted in: establishing the problem definition (project scope); defining the model's decision variables, parameters, constraints, and performance measures; validating the model

formulation; providing input parameters for the model; and defining and analyzing test scenarios. The close involvement of D&PL proved to be beneficial for the company by quantifying the variables and relationships which drive bag seed distribution and identifying areas for additional data collection and study.

2. Problem Definition

D&PL staff met with NCIT for the purpose of identifying the scope of the distribution operations to be included in the study. Because the NCIT researchers were unfamiliar with the details of the cottonseed industry, D&PL staff explained the operations of their company over the course of several meetings. The headquarters for D&PL is located in Scott, Mississippi, but in addition to this site, several other locations throughout the United States are used to produce, store and distribute their product. In addition, D&PL does distribute cottonseed to international markets. For the purpose of this project, it was decided that 18 locations would be included in the model. These locations are referred to by D&PL staff as branch plants.

The company produces many proprietary varieties of cottonseed. Because each variety of cottonseed has separate demand and cost behavior, they must be treated as separate products in the model. D&PL staff supplied NCIT with the data for 67 varieties of cottonseed. Each of the 67 varieties can be treated in three different ways for a total of 201 SKU's (stock-keeping units). However, it was agreed by D&PL that distinguishing among the three types of treatments was unnecessary for this first study. Therefore, the model includes 67 SKU's.

The production and distribution of cottonseed is a dynamic activity. Therefore, the activities captured by the model must be indexed over time. The term *time bucket* was used to describe a two-week period. The model must take into consideration the planning horizon of interest to D&PL. The planting season (the product's peak selling season) is approximately 30

weeks, or 15 time buckets. However, for the purpose of this model, a planning horizon of eight weeks, or four time buckets, was chosen for an important reason. Demand and production quantities are based on forecasting methods that decrease in validity over extended planning horizons. In other words, the shorter planning horizon increases the accuracy of forecasted input data and as a result increases the usefulness of the model as a decision-support tool.

The unit *pallet* was established as the most effective way to count the movements of bag seed. D&PL generally collects and records data on a per bag basis, but finished cottonseed is almost always distributed in full pallets (50 bags per pallet). D&PL required that the model indicate appropriate decision's regarding moving pallets of cottonseed between branch plants. In addition, D&PL wanted the model to record ending inventory levels, sales and lost sales. Note that these quantities are also measured in pallets.

In order to facilitate model development, D&PL provided NCIT with several physical and cost parameters. The physical parameters include beginning inventory levels, production levels and demand levels for each SKU (indexed by time bucket where appropriate), as well as storage capacities for each branch plant. The cost parameters include selling price as well as shipping, handling, storage and overfill costs. All cost parameters are reported on a per pallet basis (or per pallet per time bucket where appropriate). The overfill cost captures the fact that D&PL can secure additional storage capacity at some branch plants.

Four key assumptions about the distribution operations were identified and discussed by NCIT and D&PL. First, it was assumed that demand and production forecasts were accurate. Second, it was assumed that shipping cost could be captured on a per pallet basis. Third, it was assumed that an adequate supply of trucks are always available. Fourth, fractional pallet values were permitted in the model. While none of these assumptions are perfectly valid, NCIT and

D&PL agreed that they were necessary for one of two reasons. First, it was agreed that a simpler model would be beneficial for this first study. Second, valid data sources necessary for relaxing these assumptions did not exist.

3. Linear Programming Formulation

The first step in formulating the mathematical programming model is to establish the indexes over which the variables and parameters of the model will be defined. The indexes are SKU, branch plant and time bucket.

SKU: $s = 1, 2, \dots, 67$

branch plant: $b = 1, 2, \dots, 18$

time bucket: $t = 1, 2, 3, 4.$

Having defined these indexes, the next step is to identify the variables included in the model. These variables include the decision variables and other output variables.

The decision variables in this model capture the movement of bag seed among D&PL's branch plants. Therefore, the decision variables are:

$pa_{s,b,b',t}$ the number of pallets of SKU s delivered to branch plant b from branch plant b' in time bucket t .

The output variables capture ending inventory, sales, lost sales and branch plant overflow quantities. Therefore, the output variables are:

$inv_{s,b,t}$ the number of pallets of SKU s remaining in inventory at branch plant b at the end of time bucket t

$sal_{s,b,t}$ the number of pallets of SKU s sold at branch plant b during time bucket t

$lostsal_{s,b,t}$ the number of pallets of SKU s that were not available for sale upon demand at branch plant b during time bucket t

$ov_{b,t}$ the number of pallets by which capacity was exceeded at branch plant b during time bucket t .

The input parameters for the model include the physical and cost parameters supplied to NCIT by D&PL. The physical parameters are:

$beg_inv_{s,b}$ the number of pallets of SKU s in inventory at branch plant b prior to the first time bucket

cap_b the storage capacity of branch plant b measured in pallets

$pr_{s,b,t}$ the number of pallets of SKU s at branch plant b that become available for shipment during time bucket t

$dem_{s,b,t}$ the demand for SKU s at branch plant b during time bucket t measured in pallets.

The cost parameters are:

rev_s the selling price of a pallet of SKU s

$csh_{b,b'}$ the cost to ship one pallet to branch plant b from branch plant b'

ch_b the cost for handling one pallet at branch plant b

cst_b the cost to store one pallet at branch plant b for one time bucket

co_b the cost per pallet to exceed storage capacity at branch plant b for one time bucket.

The objective of the model is to identify the most economical decisions regarding the distribution of pallets of cottonseed. Therefore, the objective function was defined to maximize the difference between revenue generated by sales and the costs associated with distribution and storage (shipping, handling, storage, overfill).

$$\max \sum_{s=1}^{67} \sum_{b=1}^{18} \sum_{t=1}^4 rev_s sal_{s,b,t} - \sum_{s=1}^{67} \sum_{b=1}^{18} \sum_{b'=1}^{18} \sum_{t=1}^4 (csh_{b,b'} + ch_b) pa_{s,b,b',t} -$$

$$\sum_{s=1}^{67} \sum_{b=1}^{18} \sum_{t=1}^4 cst_{s,b,t} inv_{s,b,t} - \sum_{b=1}^{18} \sum_{t=1}^4 co_b ov_{b,t}$$

There are several functional relationships which limit the values that can be taken on by the decision and output variables. The first of these relationships requires that balance be maintained between pallets input to a branch plant during a time bucket (initial inventory, shipments received, production), pallets sent out of a branch plant during a time bucket (shipments out, sales), and ending inventory.

$$inv_{s,b,t-1} + \sum_{b'=1}^{18} pa_{s,b,b',t} + pr_{s,b,t} - \sum_{b=1}^{18} pa_{s,b,b',t} - sal_{s,b,t} = inv_{s,b,t} \quad \forall s,b,t$$

Note that ending inventory for time bucket zero corresponds to beginning inventory.

$$inv_{s,b,0} = beg_inv_{s,b} \quad \forall s,b$$

The second functional relationship requires that the total inventory at a branch plant be at or below the capacity of that branch plant (including any purchased overfill).

$$\sum_{s=1}^{67} inv_{s,b,t} \leq cap_b + ov_{b,t} \quad \forall b,t.$$

The third functional relationship requires that all demand must be accounted for by either a sale or a lost sale.

$$sal_{s,b,t} + lostsal_{s,b,t} = dem_{s,b,t} \quad \forall s,b,t.$$

Adding non-negativity constraints for each of the decision and output variables yields the final formulation.

$$\max \sum_{s=1}^{67} \sum_{b=1}^{18} \sum_{t=1}^4 rev_s sal_{s,b,t} - \sum_{s=1}^{67} \sum_{b=1}^{18} \sum_{b'=1}^{18} \sum_{t=1}^4 (csh_{b,b'} + ch_b) pa_{s,b,b',t} -$$

$$\sum_{s=1}^{67} \sum_{b=1}^{18} \sum_{t=1}^4 cst_{s,b,t} inv_{s,b,t} - \sum_{b=1}^{18} \sum_{t=1}^4 co_b ov_{b,t} - \sum_s \sum_b \sum_{b'} \sum_t (csh_{b,b'} * pa_{b,b'})$$

s.t. $inv_{s,b,t-1} + \sum_{b'=1}^{18} pa_{s,b,b',t} + pr_{s,b,t} - \sum_{b=1}^{18} pa_{s,b,b',t} - sal_{s,b,t} = inv_{s,b,t} \quad \forall s,b,t$

$$\sum_{s=1}^{67} inv_{s,b,t} \leq cap_b + ov_{b,t} \quad \forall b,t$$

$$sal_{s,b,t} + lostsal_{s,b,t} = dem_{s,b,t} \quad \forall s,b,t$$

$$pa_{s,b,b',t} \geq 0 \quad \forall s,b,b',t$$

$$inv_{s,b,t} \geq 0 \quad \forall s,b,t$$

$$ov_{b,t} \geq 0 \quad \forall b,t$$

$$lostsal_{s,b,t} \geq 0 \quad \forall s,b,t$$

$$sal_{s,b,t} \geq 0 \quad \forall s,b,t$$

Note that this is a linear programming problem having 101,376 variables and 9,720 functional constraints. The density of the coefficient matrix for this problem is less than 0.02%.

4. Solution and Implementation

Having formulated the distribution problem as a linear programming problem, the next step in the project was to select a method of performing the optimization. A review of several vendors was performed and LINGO (developed by LINDO Systems, Inc.) was selected for use. LINGO permits the use of spreadsheets for reading the values of input parameters and output variables. NCIT and D&PL jointly designed the input and output spreadsheets for the model. For the purposes of debugging and testing the LINGO code, NCIT defined a test problem.

Once the LINGO code had been verified, D&PL provided NCIT with input data for implementation. The data provided consisted of actual data beginning in December, 1999.

NCIT implements the LINGO code and provides the output to D&PL. Note that a typical implementation requires 30 seconds to solve on a Pentium-II (400 MHz) computer having 384 MB RAM.

5. Implementation and Benefits

During the 1999-2000 season, D&PL implemented the model on a biweekly basis. The output of the model was compared to their actual decisions to identify weaknesses in their distribution strategy. The process of formulating the model, developing test scenarios, and making these comparisons has provided valuable benefit to D&PL. In fact, D&PL staff have identified six key benefits of the project.

1. The model input required that D&PL project availability for shipment (production) on a variety (SKU) basis. D&PL interpreted this requirement to be “released inventory” because they do not declare inventory “available” until it is released by the quality assurance group. D&PL had to analyze work order completions and add the 14-day target release cycle to determine projected production availability for shipping schedule creation. D&PL currently does not have such a report or tool in place in their business; however, they certainly recognized a need and the potential value for such data reporting.
2. The model calculated projected revenues from sales that were shipped to meet demand based upon the selling price on a variety basis. The model also calculated costs for freight, handling and storage. D&PL was able to create a ratio of shipping, handling and lease costs as a percentage of revenue. D&PL has not historically performed this comparison in their business; however, it is a valuable measure.

3. The model calculates “lost sales” – units of sales lost due to inventory unavailability in the desired time bucket or freight costs in excess of revenue from sale. In reality, D&PL calls a customer to work out later shipping dates when inventory is not available. D&PL never holds a truck or misses a sale because the revenue does not exceed the freight costs. However, this information is tremendously valuable as D&PL uses it to analyze why inventory was not available or available closer to the point of sale. The model does provide information to distinguish which situation (unavailable or prohibitive freight cost) created the lost sale situation.
4. The model assigns demand to a branch plant. For example, all shipping orders shipped from Eloy (one of the branch plants) are assigned as Eloy demand. This concept creates some issues as noted below; however, the concept of assigning demand for particular customers or SKU’s to specific branch plants has caused many new ideas and great discussion and consideration for D&PL. Although D&PL has not yet determined fully the benefits or issues related to such a philosophy, the new ideas that this situation has launched have been valuable to their business.
5. The decision to run “actuals” (real data) through the model proved to be a beneficial exercise for D&PL. They found that two additional shipping locations in Texas were actually used that were not on any master lists for warehouses. The potential to report inaccurate numbers has since been corrected due to their review of model output.

6. The cost information requested by NCIT reinforced two things: (1) validation for D&PL's freight account restructuring, and (2) necessity of cost-sensitive measures and goals.

Conclusions

The process of formulating the model, testing the model, and analyzing the model's results has provided valuable benefits to D&PL. The D&PL focus on their transportation and distribution processes during the 1999-2000 season resulted in significant financial savings and a 14% reduction in their finished goods move ratio. Note that the move ratio based on the model helps D&PL's measure the efficiency of their distribution activities by capturing their ability to have product in "the right place at the right time."

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