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 lead 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 formulation; providing input param

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

$ov_{b,t}$ — 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

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

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

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.

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

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

$$inv_{s,b,0} = beg\_inv_{s,b} \qquad \forall s,b$$

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).

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

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

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

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

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

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

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 di9 ET /TT3 1 Tf 0 Tc 1 0.0049 1992 Tc 2M 12.007 0 0 12.007 191.0907 -0.0004 Td 0.1801 Tw 122 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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