SELECTED MATERIALS MANAGEMENT ISSUES FOR A PLANT IN PICKERT, NORTH DAKOTA: A CASE STUDY

Matthew Titus
Julene Rodriguez
Douglas Benson

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BY

MATTHEW TITUS
JULENE RODRIGUEZ
DOUGLAS BENSON

UPPER GREAT PLAINS TRANSPORTATION INSTITUTE
NORTH DAKOTA STATE UNIVERSITY
P. O. BOX 5074
FARGO, NORTH DAKOTA 58105

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Particle board is a major input to the industrial furniture manufacturing industry. Firms manufacturing furniture with particle board currently face a critical shortage in the available supply of this vital input. These firms are being forced to operate with restricted allocations of particle board from their suppliers. As a result, available manufacturing capacity is underutilized, ultimately hurting the manufacturing firm's profitability. Additionally, furniture sales are constrained by a shortage of input rather than plant capacity; this negatively impacts current and future profitability.

The current situation has increased demand for substitutes to the traditional wood-chip particle board. One such substitute product is derived from wheat straw. This product meets all pertinent strength and useability standards established by the furniture manufacturing industry. For all practical purposes, boards derived from straw are identical to boards derived from traditional wood products.

A plant to produce this substitute board from wheat straw has been proposed for Pickert, North Dakota. Pickert is located approximately 5 miles south of Finley, North Dakota in Steele County. The proposed manufacturing facility would employ approximately 140 people. Wheat straw for the facility would be procured from the region surrounding Pickert in eastern North Dakota. Several furniture manufacturers have committed themselves to purchasing all of the board production from the plant.

Any manufacturing facility is faced with a complex logistical system. Logistics is the integration of two or more activities for the purpose of planning, implementing, and controlling the efficient flow of raw material, in-process inventory, and finished goods from point of origin to point of consumption. Locating a plant in rural North Dakota and securing agricultural by-products for inputs compounds the complexity of the logistics system. Proper management of this complex logistical system will be necessary for plant success.

This analysis will be limited to materials management issues pertaining to the procurement of wheat straw. Due to the preliminary nature of the situation and the time constraints in which to conduct the analysis, this analysis is further limited to determining the area required to supply the plant with wheat straw, the number of remote warehouse locations for storage of wheat straw and their distance from the plant, and finally an estimate of the transportation costs this logistical system will incur. These three aspects of the analysis will be discussed in further detail.

SUPPLY AREA

Several factors influence the area required to supply the plant with wheat straw. These primarily include plant requirements, distribution of wheat acres in the nearby area, constraints on the annual removal of straw from one wheat field, and the location of participating wheat fields. Not knowing the location of participating wheat fields, simplifying assumptions must be made in order to complete the analysis. The necessary assumption at this time is that farmer participation and wheat production are uniformly distributed throughout the region. The validity of this assumption is improved by the region's seemingly contiguous crop land and seemingly similar crop rotations among producers.

Wheat Acreage Required

The proposed manufacturing facility has been designed to process 150,000 tons of dry wheat straw per year. This will require approximately 3.8 million acres of farmland. On average, 27.8 percent of all acres in the region surrounding Pickert are harvested spring wheat acres. Table 1 indicates the density of spring wheat production for several counties in this area. Additionally, it was assumed that each acre of spring wheat yields 0.5 tons of wheat straw, the wheat straw would be harvested at 14 percent moisture, and straw can only be removed from a particular wheat field every three years.

Table 1. Percent of All Acres Harvested as Spring Wheat for a 10 County Region Surrounding Pickert, North Dakota, Average for 1988-1992.

County	Spring Wheat Density as a Percent of All Acres (5-Year Average)
Barnes	33.5
Cass	29.7
Eddy	18.6
Foster	32.4
Grand Forks	27.9
Griggs	26.7
Nelson	23.0
Steele	33.7
Stutsman	21.8
Traill	30.4
Average for Selected Counties	27.8

SOURCE: North Dakota Agricultural Statistics

Area Required

The area required to provide 150,000 tons of dry straw per year to the plant is impacted by production constraints and participation levels. It has been determined that almost 3.8 million acres will be required to produce the dry straw demanded with the given crop density, wheat straw yields, and removal constraints. Converting the required acres into a circular region surrounding Pickert results in a radius of just over 43 miles. However, this assumes that within this area, 100 percent of the eligible acres participate as suppliers for the plant. Although optimal, this is an unrealistic assumption and expectation. At 50 percent participation, the supply area expands to a radius of over 61 miles. Figure 1 shows how participation rates impact the radius of the area required by the plant.

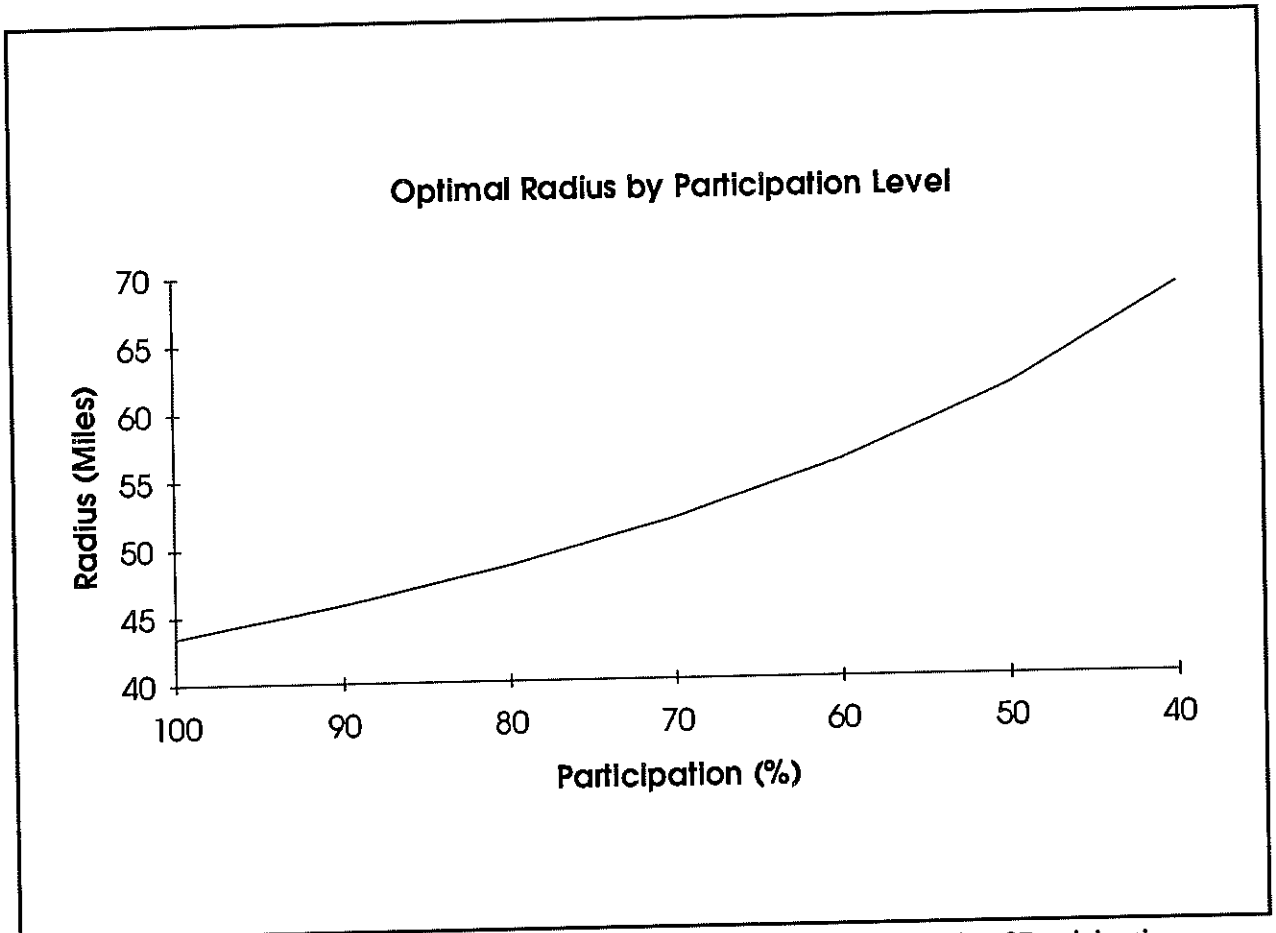

Figure 1. Optimal Radius of Wheat Straw Supply Area for Different Levels of Participation.

NUMBER OF REMOTE STORAGE FACILITIES

Storage considerations for 150,000 tons of dry straw present additional challenges to the plant's logistical system. One of these challenges is the high risk of total inventory loss. Fire, whether caused by accident, nature, or arson, is one such risk involved in straw storage. A sophisticated analysis of the value of reducing this risk, considering the added costs of risk reduction, is beyond the scope of this project. However, intuitively the implication of this is either multiple storage locations or a high-technology storage facility (or some combination of both). It is assumed that high-technology storage facilities are cost prohibitive at this time. Therefore, the alternative, multiple storage locations, will be analyzed.

The central question addressed by this analysis is how many storage facilities would be required. At this time, it must be assumed that all remote storage facilities will be of equal size. Insufficient information regarding the cost, economies, and value of risk reduction associated with additional storage locations make this assumption necessary. Intuitively it would be most economical to store all inventory at the plant. This would eliminate the non-value adding costs of interim storage and double handling. However, to reduce the risk of inventory loss as previously discussed, this is not acceptable. It is also impossible to determine from the given information, using a cost-benefit approach, whether there should be two, three, four, or more storage locations. Therefore, a different approach is required.

A movement minimization model was used to determine the optimal number of remote storage locations. This model does not take into account the added cost incurred by handling inventory multiple times or the additional cost of operating smaller facilities. The equation used by the model is shown in Figure 2.

Figure 2. The Movement Minimization Formula Equation Determines Ton-Mile Requirements for a Circular Region Where Some Demand is Delivered Directly to the Center and the Remaining Demand is Delivered First to a Remote Location and then Ultimately Delivered to the Plant.[1]

$$TM = C_c + n\left[\frac{(D-d)R_s}{n} + 2e\left(\int_0^{\delta}\int_{R_s}^{R} r\sqrt{r^2 - 2r\,(R_s \cdot \cos(\theta)) + R_s^2}\;dr\,d\theta\right)\right]$$

when:

	TM	= System Ton-Miles
	n	= Number of Remote Storage Facilities
	D	= Total Demand for Plant (tons)
	d	= Demand Delivered and Stored at Plant (tons)
	R	= Radius of Entire Region
	R_s	= Distance between Plant and Satellites

where:

$$C_c = \frac{2}{3} \cdot R \cdot d^{\frac{3}{2}} \cdot D^{-\frac{1}{2}}$$ (Ton-Miles for Demand Stored at the Plant)

(Radius of Plant Demand, Independent of R_s) $$R_c = R \cdot d^{\frac{1}{2}} \cdot D^{-\frac{1}{2}}$$

$$e = \frac{D}{\pi \cdot R^2}$$ (Demand Density - Tons/Mile^2)

(Half Angle of a Sector in Radians) $$\delta = \frac{\pi}{n}$$

The previous model was used in the analysis to determine total ton-miles involved in procuring wheat straw necessary for the plant. To solve the equation, *n* (the number of remote storage locations) was allowed to range from 1 to 15 and R_s (the distance between

[1]The authors wish to acknowledge the assistance of Mike Hennebry, Graduate Research Assistant, Department of Computer Science, North Dakota State University in the formulization of the movement minimization model.

storage facilities and the plant) to equal 13 miles, 23 miles, or 33 miles. The output of the model is graphically displayed in Figure 3. As can be seen from the graph in Figure 3, system ton-miles decrease as the number of remote locations increases. This trend continues indefinitely. However, the marginal benefit from additional storage locations decreases substantially (i.e., ton-miles decline over 21 percent when the number of locations is increased from 1 to 2, but decline less than 1 percent when the number of locations increases from 9 to 10 for the 23 mile scenario). Figure 3 also indicates that as distance between plant and storage locations increase so does the optimal number of remote storage locations. The analysts felt that 10 remote storage locations would maximize the benefits of decreased ton-mileage given an unknown marginal cost of adding one more location and the high likelihood that the supply area will be larger than 43 miles (100 percent participation).

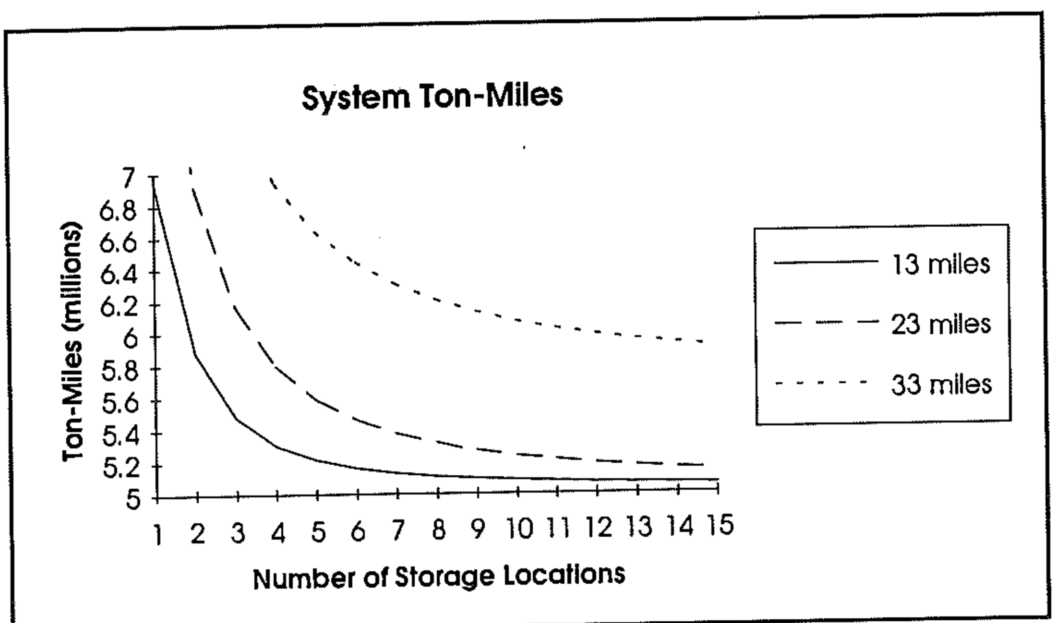

Figure 3 System Ton-Miles for Storage Facilities Located 13, 23, and 33 miles from the Plant for 1 to 15 Remote Storage Locations.

TRANSPORTATION ISSUES

The transportation problem in this analysis is constrained by the nature of wheat production. Wheat, like most agricultural crops, grows in a season. The entire crop is planted in the spring and harvested in late summer. For the region surrounding Pickert, it is reasonable to assume that the entire wheat harvest will last four weeks, usually in August. All of the straw supplied to the plant will need to be baled immediately after the wheat is harvested. As a result, all 150,000 tons of dry wheat straw (approximately 175,000 tons at 14 percent moisture) will be produced in a four week period coinciding with wheat harvest. This results in all of the wheat straw being transported to either the plant or a remote storage location within the four week production season. This process will be labor, equipment, and management intensive.

Transportation Capacity

Transportation capacity is a critical managerial problem for this plant. During the month-long harvest, over 11,600 truckloads of wheat straw will enter the logistical pipeline at either the plant or a remote storage facility. During the remainder of the year, however, only 850 truckloads per month will move through the logistical pipeline. It is obvious that a tremendous amount of transportation capacity will be required during harvest, especially compared to the transportation capacity for the remainder of the year.

The plant must secure transportation capacity on a contractual basis for the peak harvest period. Internalizing this peak period transportation capacity would not only be inefficient, it would be cost prohibitive. However, the availability of for-hire capacity during harvest is limited by the demand for transportation by the region's agricultural production.

A potential strategy for securing transportation capacity during the harvest season, as well as for the entire year, is through a strategic alliance with another firm that requires compatible seasonal transportation capacity. This would improve the transportation service provider's profitability by substantially improving capacity utilization without acquiring substantial additional capacity. A strategic alliance would coordinate the firms' contractual efforts and, therefore, ensure that all parties benefit from improvements in the service provider's profitability. Additionally, a larger, less seasonal contract may attract additional bidders thereby increasing the competition among bidders. Such an arrangement may be possible with the sugar processing cooperative in the region. October to May represents the primary transportation capacity demand season for the sugar processor. With little additional capacity, a firm providing this service to the sugar processor could provide the entire transportation capacity needed by the plant in this problem (harvest and non-harvest).

Transportation Costs

Minimizing transportation costs within the given constraints of the logistical system will be a major objective of the plant. The truck costs used in this analysis are derived from experience and analysis of existing trucking operations that are similar to the requirements of this plant. The following assumptions were used to determine truck costs for this problem: average speed of 40 miles per hour, a maximum of 300 truck days available per year, an average day length of 12 hours (straw bale configurations and safety regulations may prevent night time hauling), and 15 tons of wheat straw per load. The following costs were used in the analysis: $1.96 per loaded mile for non-harvest trucking, $2.35 per loaded mile for trucking during harvest, $15 per load for loading in the field, $10 per load for loading at the remote storage location, and $10 per load for unloading at either the plant or a remote storage location.

Location of Remote Storage Facilities

The optimal location occurs when total logistical system costs are minimized, assuming there must be 10 remote storage facilities. The intensity of management required during harvest makes it unrealistic to assume that transportation rates will be constant over the year. The transportation rate during harvest was, therefore, assumed to be 20 percent greater than the rate for the rest of the year.

Each remote storage facility is assigned to a sector of production that is not delivered directly to the plant at harvest. This analysis will attempt to determine the optimal location of the remote storage facility in relation to the production sector. The following simplifying assumptions are necessary for the analysis to proceed: plant inventory is 25 percent of annual plant demand and the 10 remote storage facilities are all of equal capacity. Also, the previous assumptions that production and participation are uniformly distributed still hold.

Alternative distances were selected and analyzed to determine the optimal location for the remote storage facility. In the analysis, the following alternative distances between the plant and the remote storage facilities were selected: 13 miles, 23 miles, 33 miles, and 43 miles. These distances equate to a point inside the region supplying the plant directly; a point between the region supplying the plant directly and the region that is to be delivered to the remote storage facility; a point centrally located in the region supplying the remote storage facility; and a point on the outer edge of the region supplying the remote storage facility (which is also the outer edge of the total supply area). Figure 4 graphically displays these alternative points relative to the plant. Table 2 indicates the average trip distance between the point of production (wheat field) and the remote storage location for each of the four scenarios and the corresponding average trip distance between the remote storage facility and the plant. Additionally Table 2 shows the average trip distance between the point of production (wheat field) and the plant for the region that supplies the plant directly.

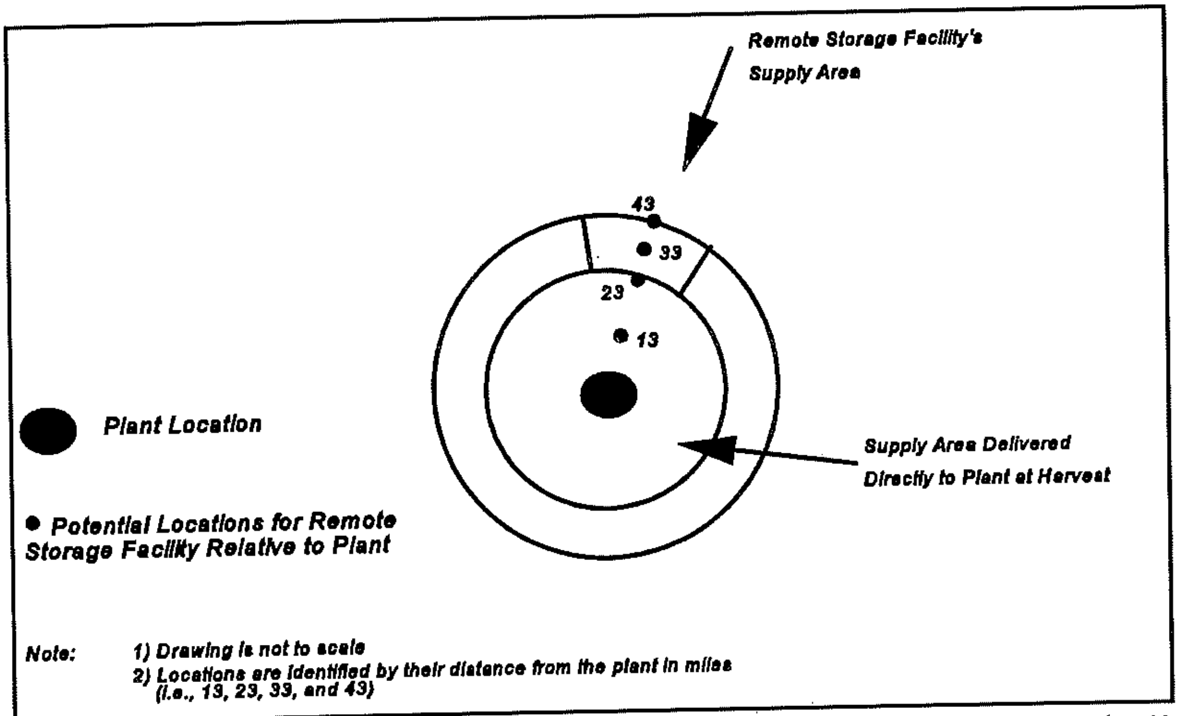

Figure 4. Alternative Locations for Remote Storage Facilities Relative to the Plant for the 43 Mile, 100 Percent Participation Scenario.

Table 2. Average Trip Distance Between Wheat Field and Remote Storage Location, Remote Storage Location and Plant, and Wheat Field and Plant for Alternative Remote Storage Facilities Located at Alternative Radii from the Plant.

	Average Trip Distance[a] (Round-Trip Miles)		
Remote Storage Location (As a Radius From Plant)	Field-Remote Storage	Remote Storage-Plant	Field-Plant
13	62	37	45
23	36	65	45
33	22	93	45
43	32	122	45

[a] The Pythagorean Theorem was used to calculate average trip distance. This measurement is more realistic than simply using the radii; road networks are usually built in a grid. According to the Pythagorean Theorem, the hypotenuse of a triangle (H) squared is equal to the sum of each of its legs (L_1 and L_2) squared. That is, $H^2 = L_1^2 + L_2^2$. The radii of a given location, then, forms the hypotenuse of a triangle. Using the Pythagorean Theorem, the length of each leg can be found. The sum of the triangle's legs is the average trip distance.

The exact optimal location of the remote storage facilities is dependent upon the size of the total region supplying the plant. However, given the uniform distribution assumptions incorporated in this analysis, the relative position of remote storage facilities (e.g., inside the region supplying the plant directly or on the boundary between the plant's supply region and the region supplying the remote storage facility) will be the same for any region. Total logistical costs for 10 remote storage facilities located 13, 23, 33, and 43 miles from the plant, where total supply area is 43 miles, are graphically displayed in Figure 5. The total logistical costs at the 13 mile location are $1.55 million; at the 23 mile location, $1.53 million; at the 33 mile location, $1.63 million; and at the 43 mile location, $1.96 million. The optimal location for the 10 remote storage facilities is at a radius of 23 miles. At this radius, the storage facility is located on the inside edge of its supply area. At this location, the reduction in harvest transportation costs are balanced with the additional costs a longer movement from the remote storage facility to the plant during the rest of the year would incur. It is important to recall that this assumption assumes that there are no fixed costs related to increasing the number of storage facilities.

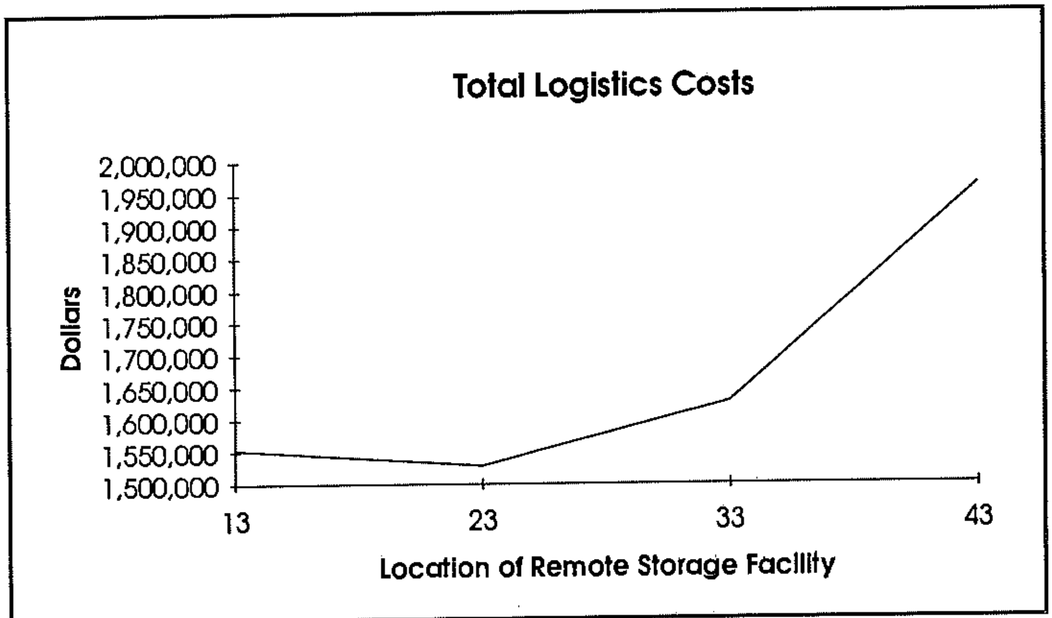

Figure 5. Total Logistical Costs for Four Alternative Remote Storage Facility Locations. (Locations are labeled by their radius, in miles, from the plant.)

CONCLUSIONS

This analysis has primarily focused on the materials management issues associated with the procurement of wheat straw for a processing plant in Pickert, North Dakota. This plant will consume 150,000 tons of dry wheat straw annually. The plant produces a substitute to particle board for use by the furniture manufacturing industry. Several simplifying assumptions have been used in this analysis. They include:

- ✓ Uniform disitribution of production
- ✓ Uniform distribution of participation
- ✓ High technology storage facilities are cost prohibitive
- ✓ All remote storage facilities are of equal size
- ✓ Additional transportation capacity required for harvest secured contractually
- ✓ Harvest transportation costs 20 percent higher than rest of year
- ✓ Loading expenses are higher at field than remote storage facility
- ✓ Inventory delivered to plant at harvest equals 25 percent of annual usage

Wheat straw will need to be secured from approximately 350,000 acres annually. Incorporating various production variables into the analysis, it requires 3.8 million acres of farm land to annually have 350,000 acres of wheat eligible for straw collection. This represents approximately a 43 mile circular area surrounding the plant. As participation rates decrease, however, the total acres and area required to secure 350,000 acres of eligible wheat production increase. At 50 percent participation, the radius of the area is approximately 60 miles.

Inventory storage at the plant is limited by the high risks of destruction, primarily fire. This project has determined the optimal number and location of remote storage facilities within the given assumptions for the plant. A continuum of solutions ranged from the unacceptable storage of all straw inventory at the plant to the unrealistic infinite number of storage facilities.

The accuracy of the optimization is reduced by the lack of knowledge regarding costs and economies involved in storage. A geographic approximation model assisted in determining that 10 was the optimal number of remote storage locations.

Location optimization of the remote storage facilities was possible by comparing total logistical costs for various scenarios. The optimal location occurred at the 23 mile radius of the plant. Total logistical costs were minimized at this location. Fundamental to this portion of the analysis is the assumption that transportation costs are higher during the harvest season. The accuracy of this assumption is improved by the intense management this season intuitively will require. The alternative location scenarios analyzed were:

- Inside the region where all production is delivered directly to the plant at harvest (13 mile scenario).
- On the outside edge of the production region delivered directly to the plant at harvest (or on the inside edge of the production region delivered to a remote storage facility at harvest) (23 mile scenario).
- Centrally located in the production region delivered to the remote storage facility (33 mile scenario).
- On the outside edge of the production region delivered to the remote storage facility (this is also the outside edge of the total supply region) (43 mile scenario).

The materials management issues involved in this analysis are complex. Successful management of them will be critical for this plant's profitable operation. Several issues involved in this analysis need to be revisited by the parties involved in the operation of the plant. These include: plant inventory storage, the value of remote storage locations, the costs of operating remote storage facilities, the viability of securing contractual transportation capacity, and the location of production participation. All of these factors are critical to the type of analysis performed here. The accuracy of these assumptions is critical to the reliability of the analysis. Time constraints and limited available information, particularly regarding inventory costs and specific production information, prevented a more accurate analysis at this time.