Optimal Fertilizer Warehousing and Distribution Systems for Farm Supply Cooperatives

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Introduction

Fertilizer sales and application services are important business areas for farm supply cooperatives. These firms account for roughly one-third of the $800M, which U.S. producers paid for fertilizer, lime and soil amendments in 2003 (USDA, 2004). Many cooperatives are re-examining the structure and organization of their fertilizer operations. A number of forces are impacting the retail fertilizer industry. Differential production costs have shifted the production of nitrogen-based fertilizer away from domestic manufacturers to off shore suppliers. The portion of nitrogen fertilizer imported into the U.S. grew from 21% in 1999 to 42% in 2002 (U.S. Geological Survey).

The production shift has impacted the form of nitrogen fertilizers. Historically, anhydrous ammonia has been the least cost form of nitrogen fertilizer. Because the infrastructure to off-load anhydrous ammonia and transport it to demand regions is limited, the shift toward off-shore supply sources has led to a shift to urea and other dry forms of nitrogen fertilizer (Agriliance). Changing farm demographics have also contributed to the shift to dry fertilizer forms. Large-scale producers typically find it more economical for the input supplier to apply fertilizer using large-scale machinery. Most agribusinesses offering custom fertilizer application concentrate on dry and liquid (UAN) forms of nitrogen fertilizers. Security concerns associated with theft of anhydrous ammonia for use in the illegal drug manufacturing has also contributed to the shift to dry formulations.

Another factor impacting the structure of cooperative fertilizer operations has been the consolidation among local cooperatives. A USDA study identified 367 mergers and consolidations among grain cooperatives during the 1993 to1997 time period (USDA, 1998). As local cooperatives consolidate and expand their geographic trade territories they often attempt to consolidate their existing systems of multiple warehouses. Determining the feasibility of a centralized warehouse system is complex. Centralization generally reduces warehousing costs since construction and operating costs decrease with size. However centralization increases the warehouse-to-field transportation costs. Shifts in fertilizer product forms further increases the complexity of analyzing warehousing centralization as per-unit warehousing and transportation costs differ dramatically across anhydrous, dry and liquid formulations.

This study pursues two objectives related to fertilizer warehousing and application: (1) Identify the major cost components of a typical fertilizer warehousing and distribution system and product margins and fees needed to cover costs; (2) Determine the optimal level of warehouse centralization and equipment complement.

Analytical Model

The analytical model for this study is a capacitated discrete mixed integer-programming (CDMIP) model. Conceptually, the model is classified as capacitated because upper limits were imposed on warehouse storage and machinery capacities. The model is discrete because demand locations as well as flow of materials and equipment between origin-destination pairs were specified. The model is structured in a mixed integer-programming (MIP) framework because the structure accommodates discrete and continuous variables to determine optimal location and size of a facility (Tembo). The MIP also uses fixed charges that are amortized over the economic life of facilities and it allows planners to assess opportunity costs for funds (Faminow). In general, MIP has been extensively used to solve plant location and machinery selection problems (e.g. Köksalan, Süral, and Kirca; Camarena, Gracia, and Sixto; Ghassam *et al*.; and Saadoun).

The CDMIP model selects the warehouse configuration and application fleet that minimize transportation, warehousing, machinery and application costs subject to supply, demand, facility and equipment capacity constraints. This cost minimization approach is adopted because in supply chains the consolidation of materials in warehouses and coordinated use of business assets has emerged as an effective cost-saving method due to high percentage of total distribution or costs associated with transportation and fixed-asset charges (Chiang and Russell; Herer, Tzur, and Yücesan; Mason *et al.*).

In the fertilizer industry, the supply chain entails transportation of fertilizers from manufacturers or importers to storage facilities and finally to producers in known service regions. In addition to fertilizer distribution, most of the retailers also own fertilizer applicators that are rented to individual producers and other firms. Thus, a significant cost reduction in the fertilizer supply chain could be achieved through efficiency that might be apparent in coordinated transportation, warehousing, and application. Therefore, a cost minimization model was developed to represent a total coordination of business activities because improving efficiency is a goal that cannot be pursued in isolation. A conceptual model for the cost minimization problem is discussed next.

In brief, for a given fixed-cost F_j and a capacity constraint λ_j of the j^{th} facility, the cost minimization function Z for the i^{th} activity linked to the j^{th} facility, with a variable cost C_{ij} and activity level Q_{ij} is mathematically given as:

(1) $$\min_{Q_{ij}, Y_j} Z = \sum_i \sum_j C_{ij} Q_{ij} + \sum_j F_j Y_j ,$$

Subject to:

(2) $\sum_i Q_{ij} \geq D_j \ \ \forall \ j$ (demand constraint)

(3) $\sum_j Q_{ij} \leq S_i \ \ \forall \ i$ (supply constraint)

(4) $\sum_i Q_{ij} \leq \lambda_j Y_j , \ Y_j \in \{0,1\}, \ \forall \ j = 1, 2, ..., n$ (capacity constraint)

(5) $Q_{ij} \geq 0$ (non-negativity condition)

This problem set-up ensures that a cost C_{ij} is incurred only if a facility Y_j is acquired. In the CDMIP model D_j and S_i are aggregate demand and supply, respectively. Equations 1 through 5 are the basic components of an empirical model used in this study. The empirical model was developed following the CDMIP model specified above. The objective function for the empirical model is given as:

(6) $$\begin{aligned} \text{Min } \ Z = & \sum_{i=1}^{4} \sum_{s=1}^{4} \sum_{w=1}^{7} \beta_{swi} X_{swi} + \sum_{i=1}^{4} \sum_{j=1}^{2} \sum_{w=1}^{7} \sum_{f=1}^{14} \beta_{wfi} X_{wfi} + \sum_{i=1}^{3} \sum_{a=1}^{7} \sum_{f=1}^{14} \beta_{afi} X_{afi} \\ & + \sum_{i=1}^{3} \sum_{w=1}^{3} \beta_w X_{wi} + \sum_{i=1}^{3} \sum_{a=1}^{7} \beta_a X_{ai} \end{aligned}$$

The objective function is minimized subject to the following constraints:

(7) $\sum_{i=1}^{4} \sum_{w=1}^{7} X_{swi} \leq SUP_{si} \ \ \forall \ s = 1, 2, ..., 4$ (fertilizer supply constraint)

(8) $\sum_{i=1}^{4} \sum_{w=1}^{7} X_{wfi} \geq DEM_{fi} \ \ \forall \ f = 1, 2, ..., 14$ (demand constraint)

(9) $\sum_{i=1}^{3} \sum_{s=1}^{4} X_{swi} \leq \psi_w X_{wi}, \ X_{wi} \in \{0, 1\},$
$\forall \ w = 1, 2, ..., 7; \ \forall \ i = 1, 2,3$ (warehouse storage constraint)

(10) $\sum_{i=1}^{3} \sum_{f=1}^{14} X_{afi} \leq \lambda_a X_{ai} \ \ \forall \ a = 1,2,3$ (applicator capacity constraint)

(11) $\sum_{i=1}^{4}\sum_{f=1}^{14} X_{wfi} \le \sum_{i=1}^{4}\sum_{s=1}^{4} X_{swi} \quad \forall\ w = 1, 2, ..., 7$ (fertilizer flow requirement)

(12) $X_{ai} \in \{0,\ 1,\ 2,\ ...,\ n\}$ $\forall\ a = 1,\ 2,\ ...,\ 7;\ \forall\ i = 1,\ 2,3$ (integer)

(13) $\sum_{i=1}^{3}\sum_{a=1}^{7} X_{afi} = \sum_{i=1}^{3}\sum_{w=1}^{7} X_{wfi} \quad \forall\ f = 1, 2, ..., 14$ (application requirement)

(14) $X_{swi},\ X_{wfi},\ X_{afi} \ge 0$ (non-negativity condition)

Variables in the programming model are defined as following:

Z	Cost for the purchase of applicators, warehouse construction, and shipment and application of fertilizers ($).
β_{swi}	Unit transport cost per ton of fertilizer shipped from source *s* to warehouse *w* ($).
β_{wfi}	Unit transport cost per ton of fertilizer shipped from warehouse *w* to field *f* ($).
β_{afi}	Unit application cost per ton of fertilizer type *i* applied at field *f* using an applicator *a* ($).
β_{w}	Annual fixed cost associated with building and operating a warehouse *w* ($).
β_{a}	Annual fixed cost associated with purchasing and operating an applicator *a* ($).
X_{swi}	Quantity of fertilizer type *i* shipped from source *s* to warehouse *w* (tons).
X_{wfi}	Quantity of fertilizer type *i* shipped from warehouse *w* to field *f* (tons).
X_{afi}	Quantity of fertilizer type *i* applied at field *f* using applicator *a* (tons).
X_{ai}	Integer variable for purchasing an applicator *a* used to apply fertilizer in form *i.*
X_{wi}	Binary variable for construction of warehouse *w* for storing fertilizer in form *i,* equal to one if construction is feasible, equal to zero otherwise.
DEM_{fi}	Seasonal demand for fertilizer type *i* at field *f* (tons).
SUP_{si}	Supply of fertilizer type *i* at source *s* (tons).
ψ_{w}	Storage capacity of warehouse *w* (tons per season).
λ_{a}	Total material capacity of an applicator *a* (tons per season).

Four distinct models were specified and estimated in this study. The first model represented the application of anhydrous ammonium and DAP in fall followed by a "top dressing" application of UAN in spring. Anhydrous ammonium was assumed to be farmer applied with the DAP and UAN applied via the fertilizer supplier's large-scale applicators. This model can be considered the base-line scenario and represents historical application practices. The second model involved a combined fall application of DAP and Urea followed by a spring "top dressing" application of UAN. This model represents a likely response to the elimination of anhydrous ammonium. The third model involved application of a blend of urea and DAP in the fall. The fourth model involved an application of DAP in the fall followed by an application of UAN in the spring. This model relates to the latest recommendations of Oklahoma State University agronomists. The basic premise is that fall nitrogen applications based on expected average yield potential are likely to either under estimate or over estimate the nitrogen needs in each particular growing season. Producers are being encouraged to delay nitrogen applications until spring and to make applications (either variable rate or constant rate) based on the crop condition and potential. While the results of this study do not address the possible savings due to variable rate application, they do provide useful information in describing how the costs of warehousing, transportation, and application would be affected by a shift to spring nitrogen application.

A common assumption in these models is that fertilizers were applied to provide a total of 95 pounds of nitrogen and 25 pounds of P_2O_5 per acre. These models were solved using the GAMS CPLEX algorithm. The program is useful for solving different types of mathematical models such as linear and non-linear programming, relaxed mixed integer programming, mixed integer programming, relaxed mixed integer non-linear programming with discontinuous derivatives, and mixed integer nonlinear programming with discontinuous derivatives.

Data

Data for the models were obtained from an Oklahoma grain and farm supply cooperative that operates nine fertilizer warehouses in a five county trade territory. The case study situation provided a realistic configuration of transportation distances between warehouses and fertilizer supply sources, and between warehouse and field locations. The cooperative also provided information on fertilizer sales by type, available application days, hours of operation, shipment costs, and equipment road and field speed. Warehouse and equipment costs and capacity information were obtained from equipment manufactures and warehouse construction contractors. Additional data such as interest and insurance rates, fuel price, and wage rates were obtained from secondary sources. The primary and secondary data were used to approximate the variables specified in the empirical model. Detailed information regarding the estimation procedures is provided below.

Machinery Cost Estimation

Variable and fixed costs associated with the use and ownership of fertilizer applicators were estimated following the American Society of Agricultural Engineers (ASAE) machinery standards. This method was adopted because it uses standardized cost coefficients based on many years of observed engineering estimates. The method gives best estimates when all necessary information needed to estimate machinery costs are not available (Dumler, Burtons, and Kastens).

Machinery Variable costs was calculated as a sum of fuel cost, oil and filter cost, repair cost, labor cost, and machinery transfer cost. However, Machinery transfer cost to and from field is not part of the ASAE specification. The intuition behind the inclusion of this variable is that the proposed model allows machines located in one region to be used in another region, thus incurring machinery transfer costs. Fixed costs include depreciation, interest cost, and insurance expense. Property tax is typically considered a fixed cost. However, it is not included in this model based on the assumption that there is no property tax on farm machinery (Kastens). Conventionally, these costs are estimated on a cost-per-acre basis and account for field capacity of machinery, which is normally calculated using width and speed of machinery, adjusted for field efficiency. In this study the costs-per-acre were converted into costs-per-ton by dividing all fixed and variable costs by their respective fertilizer application rates measured in tons per acre.

Field capacity used to estimate various machinery costs was calculated following the ASAE Agricultural Machinery Management Standard 5.1. Fuel cost was calculated using after-tax price of diesel, and fuel consumption rates following the ASAE Agricultural Machinery Management Standard 6.3.2.1. Oil and filter cost was estimated using the ASAE Agricultural Machinery Management Standard 6.3.3 and was calculated as 15 percent of fuel cost. Repair cost was calculated based on accumulated hours of use following ASAE Agricultural Machinery Management Standard 6.3.1. Labor cost was calculated using pre-tax wage rate including all payroll benefits and machinery labor hours that are estimated based on field capacity of machinery (Cross). Applicator transfer cost was calculated as a sum of fuel cost, oil cost, and repair and maintenance cost that would be incurred if applicators were allowed to cross from their locations to other service regions.

Annual cost of economic depreciation of machinery was calculated as the difference between the dollar values of machine at the beginning of a farming year and the value at the end of the year. Depreciation cost was estimated using ASAE Machinery Management Standard 6.1. Interest cost was estimated following an approach recommended by Cross using a 5 percent rate suggested by Langemeier and Taylor. Insurance cost was also calculated following Cross's approach and was estimated using initial cost of machinery and insurance rate. Insurance rate used was 0.25 percent consistent with the ASAE recommendations.

Estimation of Fertilizer Demand

Fertilizer demand was estimated based on the acreage applied by case-study firm's custom and company's rigs in 2001/2002 wheat production year. Fertilizer tonnage was calculated by multiplying the nitrogen and phosphorous application rates for Oklahoma wheat, which are 95 pounds of N and 25 pounds of P_2O_5 per acre by historical acreage data (USDA, 2003). However, to meet the specified wheat nutrients requirement, there are many fertilizer application options for producers to choose from. Therefore, producers may demand unique mixes of fertilizers based on personal preferences. However, such unique demands can only be modeled if preferences are known with certainty. Since preferences are not known it was necessary to choose among choices a base line application system and supportive systems that might replace it when it is shocked by demand or supply factors. The base line application system is defined as an application system that represents historical practice.

Estimation of Seasonal Material Capacities of Fertilizer Applicators

The mathematical model was also structured to identify optimal numbers of each type of fertilizer applicator. To facilitate this choice, it was necessary to determine a maximum quantity of fertilizer each of the applicators could apply per season. This variable was calculated using material capacity and effective daily working hours. Material capacity was computed following the ASAE formula presented in Equation (15).

(15) $$C_m = \frac{S \cdot W . y\left(\frac{EF}{100}\right)}{8.25}$$

where C_m is material capacity (ton per acre), y is application rate (ton per acre). Effective daily working hours of a machine is defined as maximum number of hours a machine can work in one day, and was calculated by adjusting potential daily working hours (H_d) for machinery round trip travel time to and from field (H_t), as well as potential time wastage due to machinery breakdown, also known as machine failure or down time.

Adjustment for breakdown probability followed ASAE formula for accumulated down time and is a function of accumulated hours of use (u). The down time (D_t) for diesel-fueled machines was calculated as:

(16) $$D_t = 0.0003234 \cdot u^{1.4173}$$

The breakdown probability (P_b) is formally defined as the probability of any condition that prevents the operation of the machine or reduces its performance below a specified upper limit. Some of the obvious causes of machine failures are wear, accidents, improper machine operations, and improper scheduling of servicing and maintenance. The down time probability was evaluated over *m* fields and was calculated as:

$$P_b = \left(\frac{D_t}{u} \right)^m \tag{17}$$

Total seasonal material capacity of an applicator ($TAMCAP_a$) was estimated using number of days available for field operations per season (ND_a), material capacity, and effective daily working hours for the machines (shown in blanket).

$$TAMCAP_a = ND_a \cdot \left[H_d - H_t - P_b \cdot \left(H_d - H_t \right) \right] \cdot C_m \tag{18}$$

Estimation of Fertilizer Transport Costs

The proposed programming model includes costs for shipping fertilizers from manufactures or importers to specific warehouse locations and finally to wheat growers. Shipment of fertilizers from sources to warehouses was done using large commercial vehicles whereas company-owned tender trucks were used to ship fertilizers from warehouses to fields. Costs for shipping fertilizers from sources to warehouses were calculated based on commercial freight rates and actual shipment distance. Data on freight rate ($ per ton per mile) were collected during the study.

Trucking costs for shipping fertilizers between warehouses and fields were calculated based on the assumption that 20-ton tender trucks were used to ship the fertilizers. The costs per ton per mile were calculated using standard values for a 20-ton tender truck, which were 7.5 miles per gallon of fuel, $ 0.05 per mile repair and maintenance cost, and \$ 0.03 per mile tires cost (Dahl, Cobia, and Dooley).[1] Therefore, the tender truck cost per ton per mile was \$ 0.27.

Estimation of Warehousing Costs and Storage Capacities

Data regarding warehouse construction costs and storage capacities were collected when the study was conducted. Fixed costs included annual depreciation costs, opportunity costs, maintenance costs, property values and insurance costs. Warehouse annual depreciation costs were calculated using straight-line method expensed over a period of 40 years, which is the life span of concrete/masonry buildings (South Carolina State-Comptroller General's Office). Other fixed costs were calculated as percentages of warehouse construction value. Warehouse opportunity cost was estimated as 4% of the value, maintenance as 3% of the value, and property value and insurance tax together as 2.5% of the value. Fixed cost for warehousing was calculated as a sum of all these costs and was converted to cost per ton of fertilizer stored using storage capacities of the warehouses.

Description of the Warehousing Structure

The structure of the analytical model also provided a basis for assessing "economies of size" in fertilizer warehousing. To achieve this goal, two warehouse sizes (big and small) for dry and UAN facilities were incorporated in the model. Big facilities were five times the size of small facilities and were centrally located. The model permitted construction of small warehouses at any location within the business area. The

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[1] The coefficients for repair and maintenance and tire costs were inflated from their year 1995 values. The inflation process was achieved through multiplying the ratio of year 2002 to year 1995 industry consumer price indices (CPIs) by the 1995 repair and maintenance value.

model did not require a central warehouse for anhydrous ammonia fertilizer because no data on larger size facility was available. Costs for big facilities were $ 1.98/ton for dry, and $ 2.27/ton for UAN. The costs per ton for small facilities were $ 5.67 for dry, $ 6.48 for UAN and $ 7.65 for anhydrous ammonia. In terms of storage cost, big facilities were about 35% cheaper on a per ton basis.

Description of Application Equipment

Three different applicators, dry, liquid, and anhydrous were modeled in this study. Dry applicators were used to apply DAP or a mix of DAP and urea. The working width of dry applicators was 60 feet (Ft), and the field speed was 16.5 miles per hour (mph). Liquid applicators were used to apply UAN, working width and field speed for these applicators were 75 Ft and 19 mph, respectively. The dry and liquid applicators were owned and operated by the case-study cooperatives. The working widths and field speed specified above in conjunction with coefficients for self-propelled combine were used to estimate costs for dry and liquid applicators.

With respect to anhydrous application, two types (big and small) applicators were modeled. The working widths were 20 Ft for small, and 30 Ft for big applicators. The field speed for both applicators was 5 mph, and their efficiency factor (EF) was 80. These equipment were owned by the cooperatives and rented to wheat producers, therefore, it was difficult to estimate variable costs associated with the use of farmer operated applicators because farmer costs were not known. As a result, this study used $ 5.82 per-acre anhydrous ammonia application cost suggested by Doye, Sahs, and Kletke.

Ownership costs for anhydrous applicators were estimated using secondary data. Depreciation cost used was $ 1.94 per acre (Razarus and Selley). Insurance cost was estimated using purchase price suggested by Langemier and Taylor and machinery hours suggested by Harryman, Siemens, and Kirwan. Interest cost was approximated using purchase price, machinery hours, and ASAE formula for computing remaining values of field machine (RV) as percent of purchase price at the end year *n* given in Equation (19) below.

$$RV = 60 \cdot (0.885)^{(n)} \tag{19}$$

Results and Discussion

In this study four alternative fertilization systems with the nitrogen component involving fall anhydrous combined with a spring application of UAN, fall urea combined with spring UAN, fall urea only, and spring UAN only were modeled. The first system more closely reflects actual practices among Oklahoma's wheat-growers. The second system was adopted to assess the likely effects of eliminating anhydrous ammonia in the supply chain following the overall decrease in domestic production and an increased role of imported dry fertilizers. The third and fourth systems are not very common among Oklahoma farmers and were included to analyze the extent to which combined costs of satisfying nutrients demands could vary across different combinations of fertilizers. The variation was useful in identifying a least-cost way of satisfying the demand. The incorporation of the DAP and UAN combination in the analysis provided insights to the feasibility of applying very little nitrogen in fall and supplementing the demand through top dressed applications in spring which is advocated by agronomists (Gribble). Costs for the modeled fertilization systems are summarized in Table 1. The cost for the baseline-model excludes farmers' cost of applying anhydrous ammonia. The estimated costs are used to assess extents to which operating costs change from the baseline-case.

Table 1 **Operating costs for different fertilizer application systems**

Model	Costs ($) Fertilizer Transportation (From Sources to Warehouse)	Fertilizer Transportation (From Warehouses to Fields)	Fertilizer Application	Annual Warehousing	Applicator Ownership	Total Cost
Base line-case (Model 1)	166,419.01 (0.79)	114,913.46 (0.55)	206,979.95 (0.99)	269,853.45 (1.29)	1,181,751.93 (5.63)	1,939,874.79 (9.24)
Model 2	282,592.85 (1.35)	138,894.11 (0.66)	206,979.94 (0.99)	302,128.83 (1.44)	1,171,352.06 (5.58)	2,101,947.80 (10.01)
Model 3	278,485.39 (1.33)	145,055.07 (0.69)	124,003.44 (0.59)	153,089.26 (0.73)	552,904.90 (2.63)	1,253,538.06 (5.97)
Model 4	324,880.19 (1.55)	226,105.48 (1.08)	206,979.95 (0.99)	334,528.83 (1.59)	1,171,352.06 (5.58)	2,263,846.51 (10.78)

( ) Represents per acre costs.

Farmers apply anhydrous ammonia. When farmers' cost was included, the application costs for the baseline-model was $ 1,430,774.28 (6.82/acre) and the total cost was $ 3,163,712.12 (15.07/acre).

Numbers does not add up exactly due to rounding.

Source: GAMS output.

The model results provided interesting insights into costs of fertilizer warehousing and application. The costs of transporting fertilizer from source to warehouse and between the warehouse and fields accounted for almost 22% of the total system costs. Warehouse ownership accounted for 14% and variable application costs were approximately 10% of the total system costs. The largest cost components were the fixed costs associated with applicator ownership, which were 54%. Cooperatives and other agribusinesses recover fertilizer system costs through product margins and application fees. Summaries of material and application costs are provided in Table 2.

Table 2 Material and Fertilizer Application Costs for the Modeled Systems

	Cost $				
Model Description	Material	NH_3 Application[1]	Fall Fertilizer Application[2]	Spring Fertilizer Application[2]	Total Cost
Baseline-case (Model 1)	23.66	5.82	3.00	3.00	35.47
Model 2	29.52	NA	3.00	3.00	35.52
Model 3	29.19	NA	3.00		32.19
Model 4	32.06	NA	3.00	3.00	38.06

Fertilizer prices used were $ 300 per ton of NH_3, $ 256 per ton of DAP, $ 240 per ton of urea, and $ 165 per ton of UAN.

[1] Represents estimated Farmers' cost of applying NH_3.

[2] Represents estimated application fee charged by cooperatives.

The model results indicated that a product margin of $24/ton combined with a $3.60/acre application fee was required to cover costs for the baseline-model. However, results show that the product margin and application fees would need to increase to cover costs for other models. The increases in product margins would be $ 5.86 for the second model, $ 5.53 for the third model, and $ 8.40 for the fourth model whereas increases in application fees would be $ 0.11 for the second, $ 0.14 for the third model, and $ 0.55 for the forth model.

In summary model results presented in Tables 1 and 2 show that the cooperative's total transportation, warehousing and application cost did not vary substantially across systems. While a shift away from anhydrous ammonia would obviously involve transitional costs, the major impact would be the increase in material costs. However, this impact need to be weighted against potential costs and advantages associated with the timing of nitrogen application and opportunity costs associated with fertilizer applied to crops that might be damaged by pests or bad weather.

The models were also structured to assess the feasibility of centralized warehousing. Results indicated partial but not complete centralization of warehouses. The feasibility of the observed centralization was evaluated through comparing costs under partially centralized system with costs that would be incurred under non-centralized storage and totally centralized storage.

In general, the models were constructed based on the assumption that cooperatives would invest in new warehouse construction or analogously expansion of storage capacities. However, the costs of existing warehouses were fixed and irrelevant to the decision. Thus, direct comparisons of costs under partial centralized and non-centralized warehousing would be misleading. To make results comparable only transportation, application and equipment ownership costs were included in the comparisons. The identified cost difference in transportation, application, and equipment ownership could be considered by the agribusinesses and compared with the economies of size in warehouse construction. Results for the comparisons are provided in Table 3.

Table 3 **Comparison of transportation, application and equipment ownership costs for partially centralized and non-centralized business operations**

	Costs ($)	
Model Description	**Partial-Centralization**	**Non-Centralized**
Base-line model	1,670,064.31 (7.96)	1,849,129.65 (8.81)
Model 2	1,799,818.97 (8.57)	2,136,563.19 (10.18)
Model 3	1,100,448.80 (5.24)	1,345,424.42 (6.41)
Model 4	1,929,317.68 (9.19)	2,311,713.82 (11.01)

Source: Own Computation.

Results indicated that partial centralization would decrease combined costs of fertilizer transportation and application, and equipment ownership. The decreases were $ 179,065.34 (0.85/acre) for the baseline-model, $ 336,744.22 (1.61/acre) for the second model, $ 244,975.62 (1.17/acre) for the third model, and $ 382,396.14 (1.82/acre) for the fourth model. The observed cost-savings were attributable to the benefits of economies of size in warehousing and enhanced capacity utilization of the machines under partially centralized arrangement.

Sensitivity evaluations were used to assess the feasibility of totally centralized storage of fertilizers. The evaluation process was achieved through iterative reduction of annual warehousing costs for the big facilities. These reductions reflected increased economies of size for large warehouses. However, single warehousing never came into the optimal solution. To illustrate the cost differential of a single warehouse, the models were constrained to single large-scale dry and liquid warehouses. The cost disadvantage of a central warehouse relative to the optimal solutions is provided in Table 4.

Table 4 The impact of single coordinated warehouse on operating cost

	Costs ($)			
Model	**Change in Fertilizer Transportation (From Sources to Warehouse)**	**Change in Fertilizer Transportation (From Warehouses to Fields)**	**Change in Applicator Ownership Cost**	**Net Impact on Transportation and Application Cost**
Model 2	-11,159.6 -(0.05)	+354,953.54 +(1.69)	+78,986.42 +(0.38)	+422,780.32 +(2.01)
Model 3	-6,035.24 -(0.03)	+321,600.83 +(1.53)	+78,986.41 +(0.38)	+394,552.00 +(1.88)
Model 4	-60,898.40 (0.29)	+472,432.41 +(2.25)	+157,972.83 +(0.75)	+569,506.84 +(2.71)

\- Represents decrease in cost.
+ Represents increase in cost.
The baseline-model is excluded from this analysis because data on large-scale storage of anhydrous ammonia was not available.

Results presented in Table 4 show that the adoption of a single coordinated warehousing for dry and liquid fertilizers would increase operating costs and the number of applicators. The increases in costs were \$ 422,780.32 (\$ 2.01/acre) for the second model, \$ 394,552.00 (\$ 1.88/acre) for the third model, and \$ 569,506.84 (\$ 2.71/acre) for the fourth model. These increases in costs offset the financial gains from economies of size in warehousing, which are \$ 239,760.00 (\$1.14/acre) for the second model, \$ 113,400.00 (\$ 0.54/acre) for the third model, and \$ 272,160.00 (\$ 1.30/acre) for the fourth model.

In summary, this analysis indicates that in the supply and application of fertilizers, fertilizer transportation and applicator ownership and fleet costs have much impact than warehousing cost. These results suggest that cooperatives should carefully evaluate warehouse-to-field transportation costs before consolidating warehouse locations. Warehouse cost efficiencies were offset when fertilizer transportation cost increased and machinery transportation time differences associated with centralization required the purchase of additional applicators.

The empirical model was also used to examine how the optimal number of applicators under the base-line model relates to current application equipment. This comparison provided a qualitative assessment of efficiency of the case study cooperative's current compliment of application equipment. Results indicate that the cooperatives would need seven dry applicators, ten liquid applicators, and fifty-three anhydrous applicators. The current system has eight dry applicators, eight liquid applicators and ninety anhydrous applicators. The least cost compliment of application equipment was similar to the structure of case-study cooperative's equipment suggesting that the cooperative was operating its equipment near its engineered capacity. The exception was anhydrous ammonia trailers. The number of trailers suggested by the model was fewer than the number in use by the cooperative. This result validates common complaints from cooperative managers on the inefficiencies in supplying farmer-controlled equipment.

Summary and Conclusions

More recently, farm supply cooperatives in the U.S. have been striving to coordinate businesses warehousing systems to keep pace with the changes in business environment. The changes arise from growing global competition, increased regulations in the industry for environmental and safety concerns, and changing demand. However, as cooperatives attempt to consolidate warehousing activities they have to consider a tradeoff between cost savings that arise from economies of size in warehousing and increased warehouse-to-field fleet time and costs.

This study has developed mathematical models that are used to identify major cost components of fertilizer warehousing, distribution, and application and corresponding product margins and fees needed to cover costs for the studies cooperatives. The models are also used to track the likely effects of eliminating anhydrous ammonia in the supply chain as its production trend continues to decline, and a shift from dry and anhydrous applications in fall towards spring applications of liquid formulations. Additionally, the models also used to determine optimal level of warehouse centralization and equipment complement. Scenario evaluation and sensitivity analysis were incorporated in the models to assess the feasibility a single location warehousing.

Results show that in fertilizer supply and application, fertilizer transportation and applicator ownership costs have much impact than warehousing costs. Results show that cooperatives would require product margins of \$ 24, \$ 30, \$ 29, and \$ 32 per ton and application fees of \$ 3.60, \$ 3.71, \$ 3.71, and \$ 4.10 per acre for the baseline, second, third, and fourth application systems, respectively. Overall, cooperative's costs did not vary substantially across the systems. Results suggest that the major impact of shifting away from anhydrous ammonia would be the increase in producers' material costs. However, this impact need to be weighted against potential costs and advantages associated with the timing of nitrogen application and opportunity costs associated with fertilizer applied to crops that might be damaged by pests or bad weather.

Optimal solution indicated partial but not complete centralization of warehousing and application activities. Costs under partial centralized system were lower than costs under non-centralized and totally centralized system. Total centralization was infeasible because increase in transportation costs outweighed gains from economies of size in warehousing. Thus, cooperatives should carefully evaluate warehouse-to-field transportation costs before consolidating warehouse locations.

The least cost compliment of application equipment was similar to the structure of case-study cooperative's equipment, which implies that the applicators are used near engineered capacity. The exception was anhydrous ammonia trailers. The number of trailers indicated in the model solution was fewer than the number in use by the cooperative. This result validates common complaints from cooperative managers on the inefficiencies in operating farmer-controlled equipment. Another reason for the high number of anhydrous applicator is probably to accommodate peak demand, which might arise due to unpredictable weather changes.

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