Using Mixed-Integer Programming to Determine the Potential for Flour-Milling Industry Expansion

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As in most predominantly agricultural states, agricultural producers in Oklahoma have expressed an interest in value-added processing opportunities. While Oklahoma produces mostly hard red winter wheat, most Oklahoma bakers require predominantly soft wheat flour for their products, almost all of which is purchased from out-of-state suppliers. An economic engineering-based, mixed-integer programming model was used to determine the optimal number, size, and location of additional flour mills in Oklahoma to capture this excess flour demand. The results suggest that additional mills are potentially justified and that the potential for additional milling will increase if Oklahoma soft wheat production increases.

Introduction

The percentage of the consumer's food dollar attributed to production agriculture continues to decline, causing many farmers and ranchers to consider opportunities for generating more income from their crops and livestock. One outcome of this trend has been a growing interest in producer-owned, value-added processing enterprises by U.S. agricultural producers. Many such operations have experienced some degree of success (for example, Ocean Spray, U.S. Premium Beef, Dakota Growers Pasta Company), thereby allowing their owners to capture some of the margins associated with the food processing/marketing chain. This study arose from the expressed desires of Oklahoma wheat producers to consider the feasibility of flour-milling as a means to add value to their wheat.

Wheat is one of the most important crops in the Southern Plains, with more than 18 million acres devoted to its production in Kansas, Oklahoma, and Texas (USDA-NASS, 1999). The recent development of value-added processing activities by producer-owned companies in Northern Plains states (for example, Dakota Growers Pasta Company, Drayton Grain Processors, Ag-Grow Oils, Harvest States Cooperatives, etc.) has stirred interest among Southern Plains producer cooperatives wishing to develop wheat-processing enterprises. Flour-milling is a capital-intensive business with low per-unit profit margins, so low wheat procurement costs alone do not ensure a competitive advantage in the flour-milling industry. However, the expansion of firms using both flour and mill by-products justifies the examination of the potential for additional flour-milling in this region. The model described in this paper represents a comprehensive approach for evaluating comparative advantages in flour-milling. For simplicity, the reported results are for a single state—Oklahoma—although the research methods would be equally applicable to other states.

The majority of wheat grown (and processed) in the Southern Plains is hard red winter (HRW) wheat, with the resulting flour primarily used for white pan breads. However, the region also has the agronomic potential to grow soft red winter (SRW) wheat. SRW wheat flour is primarily used in cookies, crackers, and other products characterized by a lower degree of rising.

The exterior appearances of HRW and SRW wheat are very similar, a fact which leads to difficulty in rapid segregation during the harvest period. Under U.S. grade standards, the presence of as little as 3 percent of another class of wheat can reduce the numerical grade while lots of wheat containing 10 percent or more of another class is graded "mixed wheat," which generally sells at a substantial discount. The economic penalties for commingling HRW and SRW wheat, coupled with the challenges of segregating wheat during the region's rapid harvest period, have led country elevator managers to discourage SRW wheat production in traditional HRW wheat-producing areas.

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The production requirements for SRW and HRW wheat are similar. Based on variety trial results, SRW wheat tends to have slightly higher yields than HRW wheat under appropriate growing conditions although SRW varieties are more likely to fail in the drought periods that commonly occur in the Southern Plains (Krenzer, Austin, and Underwood, 1995). Prices for SRW wheat are typically lower than those for HRW wheat; the five-year average price (1992–96) for SRW wheat was $3.57 while HRW averaged $3.78 over the same time period (USDA/WAOB). Producers shifting to SRW would therefore experience roughly equivalent gross and net revenues since costs of production are similar. U.S. production of HRW wheat averaged 1.231 billion bushels during the 1995–99 period, compared to an SRW production of 515 million bushels. Roughly one-third of the HRW and SRW crops during this period were marketed as exports (USDA/WAOB).

Generally, more urbanized and densely populated states have comparative advantages in flour-milling over Southern Plains states, such as Oklahoma, because of proximity to end-users (Harwood, Leath, and Heid, 1989). However, some recent changes could lessen these comparative advantages. First, because of U.S. population growth in both the South and West, several large baking companies have moved into the Southern Plains region. Many of these food processors use either HRW flour for breads, SRW flour for cookies and crackers, or HRW/SRW flour blends for pastries, cakes, and sweet goods (ODA, 1997). Second, the Southern Plains has experienced substantial growth in confined animal production (primarily hogs and poultry), which provides a growing market outlet for mill by-products in Oklahoma. Both commercial and private feed manufacturers utilize mill by-products as feed supplements to boost the energy and protein contents of feed rations, hence the term "mill feed."

Objectives

Of the four flour mills currently located in Oklahoma, three are located in North Central Oklahoma—the heart of the state's wheat production area. However, these mills are not located near Oklahoma City or Tulsa, where the majority of the state's food processors and distributors are located. It must also be noted that most of the state's food processing growth has occurred in the eastern part of the state.

The four existing mills have a combined capacity of about 31,400 hundredweight (cwt.) of flour per day (Oklahoma Department of Commerce, 1996), or roughly 942 million pounds of flour per year (assuming a six-day work week and one day per month down-time for maintenance). This capacity accounts for less than 20 percent of the state's total wheat production, with the remainder of the state's wheat production being exported as grain. However, all of the factors associated with vertical market linkages must be considered before the true potential for industry expansion can be determined.

The overall objective of this study was to assess opportunities for increased flour-milling in Oklahoma. More specifically, the study was undertaken to compare costs of replacing flour shipments from out-of-state mills with in-state milling, thereby adding value to Oklahoma's wheat production and meeting the flour needs of in-state processors. The following steps were deemed necessary to achieve this objective:

(1) estimation of fixed and variable costs associated with flour-milling;

(2) assessment of the flour needs of food processors in the state, the costs associated with wheat procurement, transportation distances and costs from production points to potential milling sites, mill feed values, and flour delivery costs to food processors;

(3) identification of the least cost locations for additional flour-milling in Oklahoma so that community leaders and agricultural groups may better plan future development activities; and

(4) evaluation of the sensitivity of the findings to changes in wheat production (shifting from HRW to SRW wheat), wheat and flour prices, milling costs, and transportation costs.

Procedures

In a perfectly competitive market environment, prices differ by the costs of transfer among levels of the marketing channel. These transfer costs constitute the value of form, place, time, and/or possession utilities created in the productive process of marketing (Kohls and Downey, 1981). Thus, in considering the optimal distribution of expanded flour-milling capacity, all costs associated with wheat and flour marketing (transportation, storage, processing, mill feeds, and transactions) must be taken into account wherever possible.

Plant location problems, such as the one addressed here, have been most successfully analyzed by mathematical programming techniques, which provide a logically consistent method for evaluating alternative economic scenarios and industry structures (French, 1977). The optimal plant location is determined at the unique point that minimizes total transportation and processing costs by balancing the locational pulls exerted by raw material inputs and markets. Discrete space optimization—in which supply sources and market territories are grouped into finite point locations to consider a predetermined set of potentially feasible plant locations—was determined to be the best approach to this research endeavor. The specific optimization model utilized for this study was a mixed-integer mathematical programming model (Faminow, 1982).

The wheat processing plant location model used in this study was designed to minimize total transportation, mill construction, and processing costs associated with replacing out-of-state flour with Oklahoma-milled flour. Wheat, flour, and mill feed shipments were used as choice variables in the model (Figure 1). Also, binary variables determined the viable locations for additional in-state milling. The model is an economic engineering representation of a system incorporating wheat production, wheat shipping and milling, flour shipping, mill feed shipping, and flour usage.

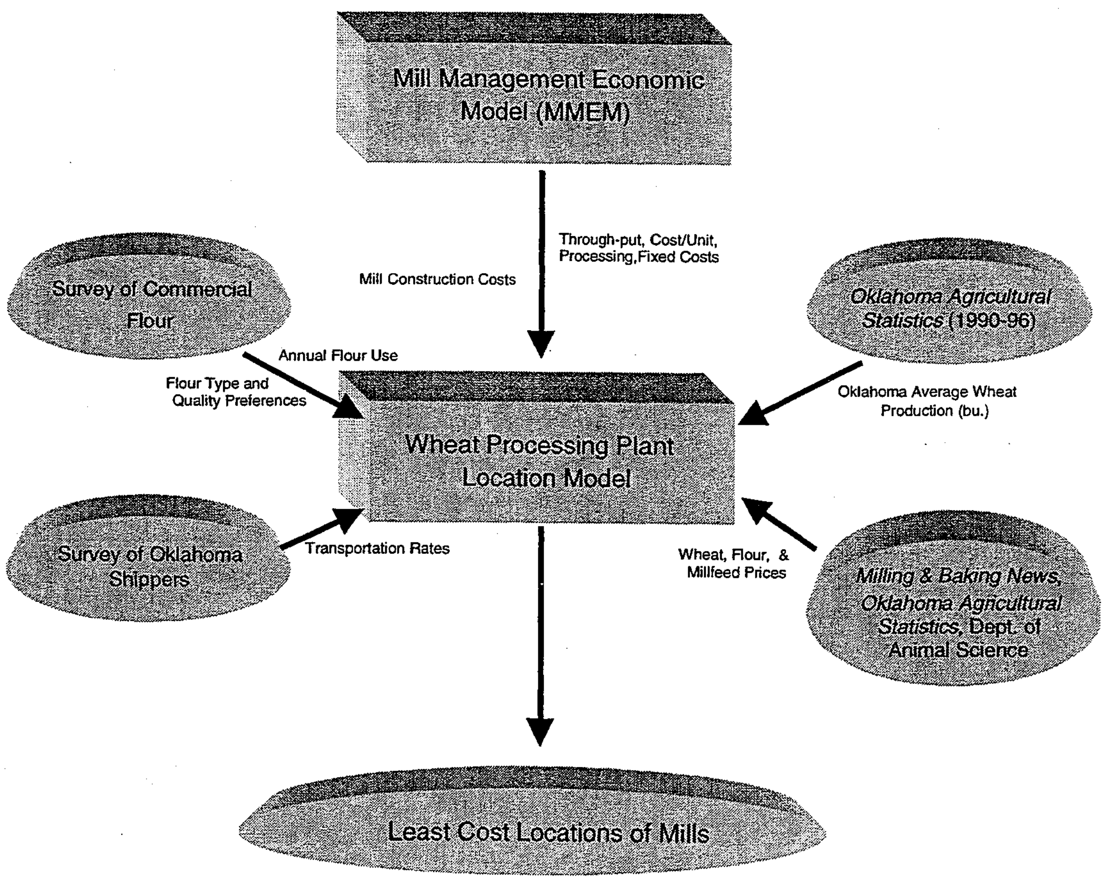

Figure 1. Oklahoma Flour Usage and Milling Potential Project Flow Chart.

The mathematical programming model used in this study is a mixed-integer programming model designed to minimize the combined costs of delivering wheat to milling sites, milling flour, marketing mill feeds, and shipping flour to end users. The model is of the mixed integer variety because additional mill construction and capacity were allowed for only three discrete mill sizes/capacities—7,000 cwt., 4,900 cwt., and 3,000 cwt. of flour per day. These capacities were based on the daily capacities of existing Oklahoma mills, which are fairly representative of Southern Plains mills and can serve as appropriate capacity references for groups considering new milling enterprises. All other variables in the model were assumed to be continuous.

The objective function for the mathematical programming model was to minimize the costs associated with meeting the flour needs (both flour type and quantity) of Oklahoma bakers currently purchasing flour from out-of-state sources. This objective could either be accomplished through continued purchases of flour from out-of-state mills or through the expansion of flour-milling activities in Oklahoma. The costs to be considered in the latter option include transportation costs for bringing wheat from production points (either Oklahoma or out-of-state sources) to potential mill sites; fixed costs associated with building a mill; variable costs of operating a mill; and shipping costs of delivering flour to demand points. Subtracted from these costs is the value of the resulting mill feed. Mathematically, the objective function is depicted as:

(1)
$$\begin{aligned}\text{Min } Z = & \sum_{i=1}^{75}\sum_{w=1}^{2}\sum_{j=1}^{8}\sum_{p=1}^{3}\beta_{ij}X_{iwjp} + \sum_{e=1}^{2}\sum_{w=1}^{2}\sum_{j=1}^{8}\sum_{p=1}^{3}\beta_{ej}X_{ewjp} + \sum_{j=1}^{8}\sum_{p=1}^{3}\sum_{f=1}^{2}\sum_{k=1}^{8}\beta_{jk}R_{jpfk} \\ & + \sum_{e=1}^{2}\sum_{f=1}^{2}\sum_{k=1}^{8}\beta_{ek}R_{efk} + \sum_{e=1}^{2}\sum_{f=1}^{2}\sum_{k=1}^{8}\rho_{ef}R_{efk} + \sum_{j=1}^{8}\sum_{p=1}^{3}\sum_{f=1}^{2}\sum_{k=1}^{8}\delta_{jp}R_{jpfk} \\ & + \sum_{j=1}^{8}\sum_{p=1}^{3}\sum_{m=1}^{10}\beta_{jm}V_{jpm} - \sum_{j=1}^{8}\sum_{p=1}^{3}\sum_{m=1}^{10}\rho_{m}V_{jpm} + \sum_{j=1}^{8}\sum_{p=1}^{3}FC_{jp}Y_{jp},\end{aligned}$$

given constraints of:

(2) $$\sum_{j=1}^{8}\sum_{p=1}^{3}X_{iwjp} - S_{iw} \le 0;$$ (wheat supply constraints)

(3) $$\sum_{f=1}^{2}\sum_{k=1}^{8}R_{jpfk} - CAP_{jp}Y_{jp} \le 0;$$ (annual flour capacity at mill)

(4) $$\sum_{j=1}^{8}\sum_{p=1}^{3}R_{jpfk} + \sum_{e=1}^{2}R_{efk} - D_{fk} \ge 0;$$ (flour shipments constraint)

(5) $$\sum_{k=1}^{8}R_{jpfk} - \sum_{i=1}^{9}\tau_{wf}X_{iwjp} - \sum_{e=1}^{2}\tau_{wf}X_{ewjp} \le 0;$$ (wheat/flour balance at mill)

(6) $$\sum_{m=1}^{10}V_{jpm} - \sum_{i=1}^{75}\sum_{w=1}^{2}X_{iwjp}(1-\tau_{wf}) \le 0;$$ (mill feed supply constraint)

(7) $$\sum_{p=1}^{3}Y_{jp} \le 1; \text{ and}$$ (mill number upper bound)

(8) $$X_{iwjp}, X_{ewjp}, R_{jpfk}, R_{efk}, V_{jpm} \ge 0.$$ (non-negativity condition)

The variables are defined as:

Z	=	total shipment, processing, and annual fixed costs;
X_{iwjp}	=	quantity of wheat type w shipped from source i to plant size p at location j;
X_{ewjp}	=	quantity of wheat type w shipped from out-of-state source e to plant size p at location j;
S_{iw}	=	quantity of wheat type w produced at source i;
R_{jpfk}	=	quantity of flour type f shipped from plant j of size p to market k;
R_{efk}	=	quantity of flour type f shipped from out-of-state source e to market k;
V_{jpm}	=	quantity of millfeeds shipped from flour size p, location j, to millfeed market m;
D_{fk}	=	total quantity of flour type f used at market k;
β_{ij}	=	unit transportation cost per *cwt.* from wheat source i to plant location j;
β_{ej}	=	unit transportation cost per *cwt.* from out-of-state wheat source e to plant location j;
β_{jk}	=	unit transportation cost per *cwt.* from plant location j to market k;
β_{ek}	=	unit transportation cost per *cwt.* from out-of-state flour source e to market k;
β_{jm}	=	unit transportation cost per *cwt.* from plant location j to millfeed market m;
ρ_{ef}	=	unit price per *cwt.* of flour type f at out-of-state source e;
ρ_{m}	=	average unit price of millfeeds;
δ_{jp}	=	unit processing variable costs per *cwt.* at plant size p location j;
Y_{jp}	=	binary variable for building plant size p at location j;
FC_{jp}	=	annual fixed costs associated with building and operating plant size p at location j;
τ_{wf}	=	wheat-to-flour transformation rate; and
CAP_{jp}	=	annual capacity of mill size p at location j.

The constraint defined in equation (2) limits the total volume of wheat shipped from in-state production areas to an amount that is equal to or less than the volume of wheat harvested in those areas. Equations (3) and (4) constrain the volume of flour determined by the model to be an amount that is within the capacity limits of suggested flour mills and the quantity of flour desired at demand points, respectively. Equations (5) and (6) restrict the outputs of flour and mill feed (respectively) to be subject to the quantity of wheat being processed at potential milling sites. Equation (7) limits the number of suggested mills at any given location to no more than 1, and equation (8) prohibits the negativity of various factors.

Data Sources

Industry accounting data are often nonexistent, unreliable, or difficult to obtain (French, 1977). An alternative is the economic engineering technique, which uses engineering coefficients for input-output relationships and applies relevant input costs and cost allocations to estimate total costs and revenues for plants of different sizes or types (Allen, Eidman, and Kinsey, 1996). Flores et al. (1993) used this approach to estimate and compare transportation, processing, and other costs associated with building and operating flour mills of different sizes.

Data requirements for the mathematical programming model (Figure 1) include:

(1) volume of wheat produced in each possible supply point and the price of wheat at each supply point;

(2) wheat shipping costs from supply points to possible mill sites;

(3) milling costs and capacity at existing mills and at potential new mill locations;

(4) wheat-to-flour transformation rates and by-product (mill feed) production;

(5) wheat flour prices and shipping costs;

(6) mill feed prices (at the mill); and

(7) quantity of flour needed at each possible demand point.

All of the cost and throughput data associated with mill construction and operation were obtained from Flores et al.'s (1993) Mill Management Economic Model (MMEM) and were then adapted to the current study. Because the MMEM was based on one mill size (7,000 cwt.), data adjustments were made to consider the other two mill sizes previously mentioned. To account for inflation, cost data were updated to current prices using the U.S. GDP deflator, 1995 base year.

Data on flour volume, quality, and type preferences were obtained through a survey of commercial food-processing companies in Oklahoma. All of the state's large commercial bakeries (more than 10,000 cwt. annual flour usage) and even many small family-owned bakeries (less than 1,000 cwt. annual flour usage) provided information on flour quantity utilization, flour type, locations of flour suppliers, and the acceptable levels of many flour quality characteristics for their operations. Based upon the flour utilization levels of the large bakeries and the sizes of non-responding small bakeries, the survey captured well over 90 percent of the flour usage by Oklahoma bakers.

Survey results showed that most Oklahoma food processors produce soft flour-based products, even though Oklahoma mainly produces HRW wheat. Cookies, for example, are the most commonly produced food items, produced in one form or another by approximately 24 percent of the companies that responded to the flour usage survey. In Figure 2, flour proportions by type of product are shown. The flour blends for each product indicate the divergence between the primary type of wheat produced in the state (HRW) and the predominantly soft red winter (SRW) wheat flour used by Oklahoma food processors (Figure 3). The extensive use of SRW wheat flour by in-state processors came as a surprise to commodity groups who assumed that baking industry expansion in Oklahoma represented additional demand for their products.

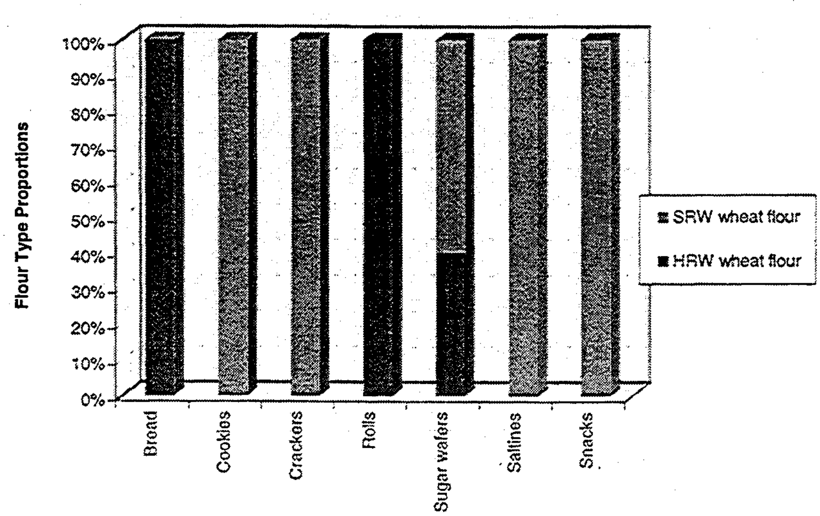

Figure 2. Soft Red Winter (SRW) Wheat vs. Hard Red Winter (HRW) Wheat Flour Proportions for Selected Products from Oklahoma Food Processors, 1997.

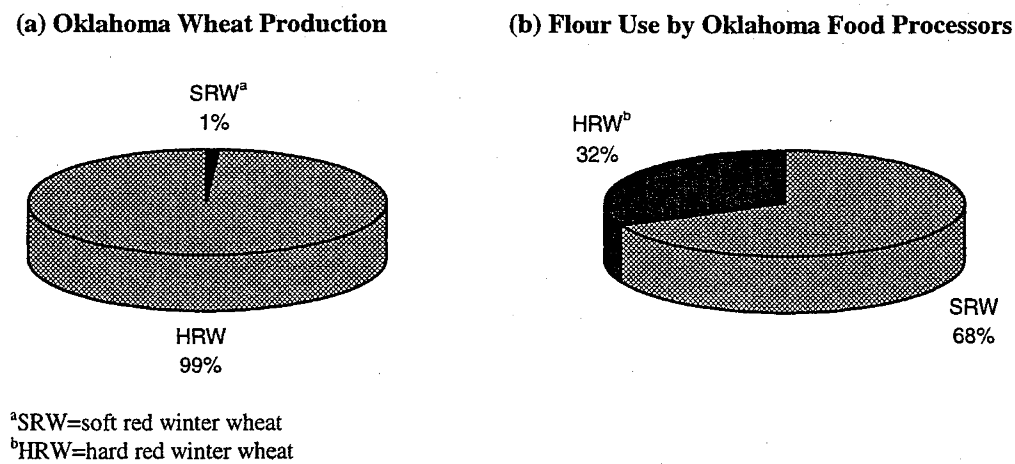

Figure 3. Comparison of 1997 Oklahoma Wheat Production and Flour Use by Wheat/Flour Type.

Quantitative data obtained from respondents also indicated that, of about 2,830,000 cwt. total annual flour usage, roughly 68 percent is SRW wheat flour. Virtually all of this flour is purchased from out-of-state mills. Carthage, Missouri, was identified as one major source of SRW wheat flour. These survey findings alone indicate that, when assessing milling potential, understanding flour demand patterns is often more important than emphasizing the wheat production of the state. The in-state utilization of SRW flour may, however, create a potential for milling SRW wheat in Oklahoma.

Another survey of Oklahoma shippers provided data on transportation rates. Average wheat production levels were computed by county using data from *Oklahoma Agricultural Statistics* publications for the period 1990-96 (ODA/USDA-NASS). Oklahoma mill feed prices were obtained from an animal feed price bulletin published by the Oklahoma State University (1996).

In Figure 1, the central components of the wheat processing plant location model are shown: the MMEM, results from the flour use survey, wheat production data by county, transportation costs from a phone survey of wheat and flour shippers, flour and wheat price data from *Milling and Baking News*, wheat price data from *Oklahoma Agricultural Statistics*, and mill feed prices.

As shown in Figure 1, the MMEM was primarily used in this study to produce estimates of the construction and operating costs of the three mill sizes allowed in the mixed-integer mathematical programming model. In addition to considering new mill locations based on the volume of local flour use, the model also considered expansion of the existing Oklahoma flour mills at estimated fixed costs less than those charged to new facilities. The model allowed for expanded capacity of existing mills or additional milling locations as long as the total costs associated with milling and wheat/flour/mill feed flows were minimized. Interstate trade was incorporated into the model by including non-Oklahoma sources for each type of wheat and flour, based upon information obtained from Oklahoma bakers and millers.

Results

The results suggest that Oklahoma could expand current milling capacity by about 23 percent to serve the needs of existing flour users in Oklahoma, but the majority of this milling would require SRW wheat. Because Oklahoma produces very little SRW wheat, 2.6 million bushels would have to be shipped into Oklahoma and then milled to replace the flour provided by out-of-state mills. The least-cost locations for new wheat-milling operations (Poet and Chickasha), producing primarily soft wheat flour, are shown in Figure 4. These suggested locations coincide with the flour needs of the largest Oklahoma baker, located near the eastern border of the state (Poet), and some of the large baking establishments in the Oklahoma City metropolitan area (that is, the center of the state) and in Southwestern Oklahoma (Chickasha).

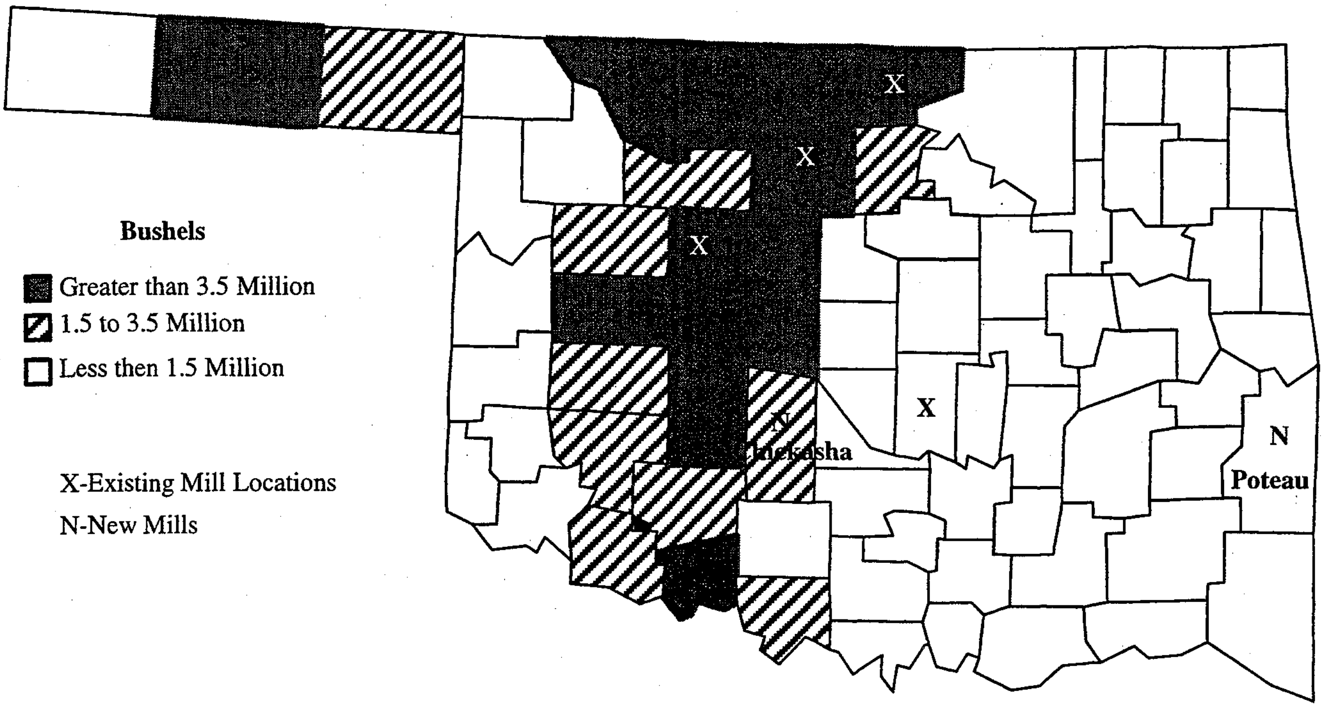

Figure 4. Oklahoma's Main Wheat-producing Counties, Existing Mills, and New Flour Mill Distribution from Model Results, 1997.

The least-cost results indicated two additional mills (Table 1), one medium-sized mill (4,900 cwt./day) operating at 80 percent capacity (Poet) and one small mill (3,000 cwt./day) operating at full three-shift capacity (Chickasha). Compared to the current situation, the results suggest that the cost of flour to end-users could be reduced by $1.66 per cwt. (roughly 15 percent of the five-year average HRW and SRW flour prices), holding wheat prices constant. It is anticipated, however, that competitive pressures would cause these savings to be shared by the miller, the wheat producer, and the flour end-user.

Sensitivity analyses were conducted by varying the cost and price parameters by +/-10 percent. The results were not significantly affected by moderate changes in transportation rates, labor costs, and the wheat/flour price spread. Varying the fixed costs per unit (reflecting different assumptions regarding economies of scale) did impact the optimal number and locations of mills, but not the total milling capacity.

Table 1. Suggested New Flour Mill Locations, Capacities, and Shipments (cwt., by wheat/flour type) to Demand Points for Oklahoma.

Demand Points	Optimal Mill Locations			
	Poet		Chickasha	
	HRW[a]	SRW[b]	HRW	SRW
Tulsa	18,327		141,240	344,128
Oklahoma City				23,001
Lawton				62,400
Norman				2,500
Marietta			25,391	337,340
Vinita	50,000			
Poteau		1,150,000		
Total Flour Shipments	1,218,327		936,000	

[a] HRW = hard red winter wheat
[b] SRW = soft red winter wheat

Because the volume of additional wheat milled is roughly 1.5 percent of the current total Oklahoma wheat production, one would anticipate only small wheat price increases from the additional milling. It is possible, though, that some producers willing to provide specific classes, varieties, and/or qualities of wheat to a mill could receive a premium. The potential decrease in the cost of flour to end-users should provide sufficient motivation for consideration of milling investment in Oklahoma. In fact, at the time of this paper's publication, the state's largest bakery operation (in Poet) is considering building a mill near its plant to mill SRW wheat purchased from out-of-state sources or contracted locally with Oklahoma wheat producers.

Conclusions and Implications

The study described in this paper illustrates that plant location modeling can be used to assess the potential for value-added processing of agricultural products. While the specific example in this study is related to flour-milling, this approach could be used for a wide array of agricultural products. By analyzing all of the costs associated with converting wheat into flour and delivering it to the final user, the results help producers and other stakeholders channel their efforts toward projects that appear to have a competitive advantage.

In this case, the model's results confirmed the traditional conclusion that mills should be located near flour users rather than in wheat production areas. The results also suggest that the regional expansion of the food-processing industry may have provided new milling opportunities. These findings illustrate how plant location modeling can identify areas that have, from a transportation cost standpoint, the highest potential for milling industry expansion.

The findings clearly suggest that vertical market linkages are critical in determining the potential for addition milling capacity. The in-state demand and milling cost advantage for SRW suggest a potential to shift Oklahoma wheat production to SRW wheat. This shift would present challenges for both the producer and first handler (country elevator).

As discussed previously, the segregation of HRW and SRW wheat is difficult, hence flour millers are reluctant to buy wheat from areas where production is not uniform. This problem could be reduced if one class of wheat is predominant in an elevator's procurement region and/or if vertical linkage programs are in place to promote production and identity-preserved handling of a specific wheat type. The fact that only a few SRW varieties have been specifically bred and tested in the Southern Plains region could also be problematic. Due to the wide year-to-year environmental conditions, a single variety can be disproportionately devastated by frost, sprouting, or other environmental factors.

Despite the agronomic similarities, a shift to SRW wheat could also provide challenges to producers who have traditionally focused on HRW varieties. These producers would likely face a learning curve in selecting varieties within the SRW class of wheat that are best suited for their particular production environment. They may also have to "fine tune" planting dates and other production practices. The transition may be somewhat more complex for the many (approximately 50 percent) producers who also manage wheat for forage production (stocker cattle). Further research and extension efforts will be necessary to coordinate HRW and SRW wheat segregation at country elevators and to strengthen the vertical linkages of the wheat production and processing industries.

This approach obviously does not consider all of the factors associated with establishing vertical market linkages. In particular, the results did not consider a price reaction by out-of-state competitor mills or the challenges of obtaining firm commitments for mill output. Future events in the Oklahoma flour-milling industry will reflect whether or not the cost advantage identified in this study is sufficient to overcome these competitive barriers.

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