Effect of Proposed Grain Standards on Marketing Costs of the U.S. Sorghum Sector: An Interregional Transshipment-Plant Location Model

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Abstract

Recent legislative initiatives call for studies to evaluate costs associated with cleaning U.S. grains to meet more stringent standards. This paper reports on a study which developed a mixed-integer programming model of the U.S. sorghum sector to (1) determine the least-cost geographic location for new cleaning investment at the country, terminal and port elevator stages of the marketing system and (2) measure additional system marketing costs associated with implementing the proposed standards. Results show the least-cost cleaning location to be at country and terminal elevators in excess supply regions. Implementing the proposed standard would increase system costs about 2 percent.

Keywords: grain quality, plant location, mixed-integer, sorghum

Exports of U.S. grain often have higher dockage and foreign material content than grains from other exporting nations and there is concern that this unfavorably affects the competitive position of the U.S. in international markets. (U.S. Congress, 1989a, 1989b; U.S. Senate). In reaction, the Senate and House Agricultural Committees enacted legislative initiatives on grain quality for inclusion in the Food, Agriculture and Conservation and Trade Act of 1990. This legislation has created a need to know how grain marketing costs would be affected by requiring U.S. grain to meet more stringent standards. This paper reports on a study which developed a multiperiod, multiproduct, transshipment model of the U.S. sorghum sector to determine where in the marketing system (country, terminal and port elevators) grain cleaning capacity should be located and how system costs change under implementation of the proposed standards.

The paper reviews location models applicable to the grain cleaning location problem and offers background on the sorghum sector, the proposed sorghum standard and grain cleaning. This is followed by a presentation of the developed model, data requirements, results and conclusions. A mathematical representation of the model is presented in the appendix.

Location Models

Spatial models are often used to analyze questions regarding interregional competition and the optimal regional location of economic activity (e.g. Byrkett, Miller and Taiganides). These models may feature transshipment in a multicommodity, multiperiod distribution network. Recent efforts have built on this framework to include detail regarding transportation and logistics (Koo,

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Thompson and Larson; Barnett, Binkley and McCarl). Other spatial models are designed to determine the optimal number, size, and location of marketing facilities within a subregion. The fixed charge associated with the investment/or economies of scale (size) in the investment require the plant location problem be represented as a mixed-integer programming model. Due to the high computational cost associated with mixed-integer programming models, alternative solution techniques have been employed. Early plant location efforts employed a heuristic iterative method which was based on the Stollsteimer model (Tyrchneiwicz and Tosterud; Chern and Polopolus; Ladd and Lifferth).

This iterative procedure has several limitations. First, the procedure is not designed to determine plant location in a distribution network that features transshipment. Further, the iterative method requires extensive computer solution time for large problems and it often becomes difficult to implement for particular plant location problems (Hilger, McCarl, and Uhrig). Fuller, Randolph and Klingman examined a plant location problem involving the cotton ginning industry in the Rio Grande Valley of Texas and New Mexico. The authors formulated the transshipment portion of the problem in a network flow framework and solved with use of a special purpose network algorithm to obtain a minimum-cost flow solution. Then, with use of an implicit enumeration procedure, the optimal number, size and location of cotton-ginning plants within the subregion were identified. This approach becomes computationally cumbersome when the problem includes a large number of integer variables and/or extensive transshipment activities.

Hilger, McCarl and Uhrig developed a mixed-integer programming algorithm based on Benders Decomposition to determine the optimal location of grain subterminals in northwest Indiana. The Benders procedure interfaces standard mixed-integer and linear programming routines, and since this method does not require examination of all possible plant combinations, large problems do not involve excessive solution time. More recently, Mosely, Spreen, and Pheasant developed a mixed-integer programming model to determine the optimal number and location of feedlots and slaughter plants in Florida.

The model developed for this study is similar to interregional competition models which feature transshipment in a multicommodity, multiperiod distribution network and plant location models which involve integer (0-1) decisions. Solution to the developed model is obtained with recently developed mathematical programming software which includes an efficient mixed-integer solver.

Background

Annual production of grain sorghum in the United States has averaged 665 million bushels in recent years with about 75 percent of production concentrated in Texas, Kansas and Nebraska. Other significant producing states include Missouri, Arkansas, Oklahoma, South Dakota, Mississippi, Louisiana, Illinois and Colorado (USDC). Grain sorghum is primarily used as a feed concentrate for livestock and poultry. Approximately 65 percent of total annual disappearance is attributed to livestock/poultry consumption while most of the remainder is exported (USDA, 1990).

The grain sorghum inspection records of the Federal Inspection Service (FGIS) during 1987-1991 indicate an average of 3.7 percent of the sorghum required cleaning to meet the current No. 2 standard, whereas up to 53 percent of the sorghum would require cleaning under the proposed standard. A survey of U.S. grain elevators by the National Grain and Feed Association suggests additional investment in cleaning capacity would be required to carry out necessary cleaning if the proposed standards were implemented.

Cleaning is expected to remove dockage, foreign material and to a degree, shrunken and broken kernels. Both foreign material and dockage are non-grain materials (weeds, stems, dirt). Currently, dockage is not a grading factor; however, foreign material is a grade determining factor, and, in the case of sorghum, foreign material (FM) and broken kernels (BN) are combined in the grading standard[1]. The current U.S. No. 2 sorghum grade standard allows for a combined 8 percent limit on broken kernels and foreign material. Proposed changes center on separating foreign material and broken kernels into two grade factors and making dockage and, in some cases, foreign material, a deductible. The analyzed proposal lowers the limit on BN and FM for U.S. No. 2 sorghum from a combined 8 percent to 4 percent for BN and 1 percent for FM. Hereafter, the proposed standard is referred to as 4% BN, 1% FM.

Cost budgets developed by Grant et al. and Adam et al., show economies of size in grain cleaning. Specifically, Grant et al. show port elevators are more efficient for cleaning grain sorghum than country and terminal elevators. This suggests that larger elevators (terminals and port elevators) may be the least-cost cleaning location in the market channel. But, the least-cost cleaning location in the market channel is affected by other factors than unequal cleaning costs at country, terminal or port elevators. For example, the proximity of the cleaning location to the demand regions for grain and liftings or cleanings must affect the least-cost cleaning location and hence the total marketing system cost. Demand locations for liftings (cattle feeding areas) are most likely located near country or terminal elevators in the supply regions. Consequently, the cost associated with the transportation of liftings would be less when cleaning at country and terminal elevators than cleaning at port elevators. Thus, the least-cost cleaning location may partially be determined by trade-offs between scale (size) economics in the grain cleaning activity and transportation costs associated with the marketing of clean grain and liftings.

Additional factors impacting the least-cost cleaning location and total marketing costs include (1) the current cleaning capacity of country, terminal and port elevators in various regions; (2) storage capacity of country elevators and their capacity to store off-farm sorghum sales; (3) the differing foreign material, broken kernel and dockage content of sorghum produced in various excess supply regions; (4) transportation cost savings associated with removal of dockage and foreign material; (5) the seasonal grain demands for various grain qualities and their distances from excess supply regions; (6) the availability of alternative transportation modes in various excess supply regions and associated differences in transportation costs; and (7) applicability of proposed standard to all grain traded or only export-destined grain.

The Model

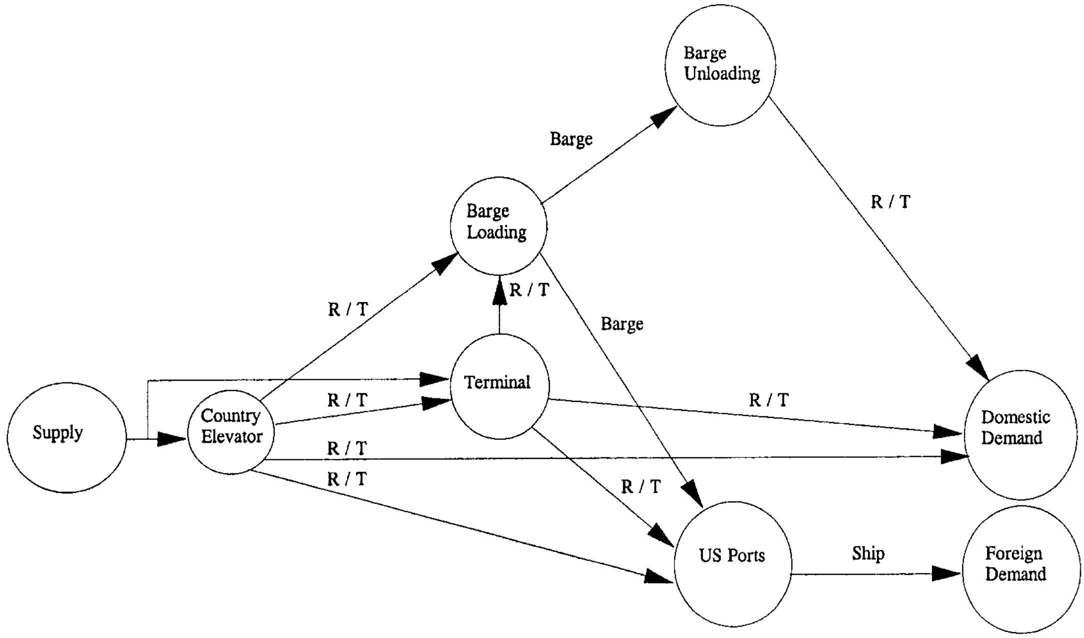
A cost-minimizing, multiperiod, multiproduct, mixed-integer programming model of the grain sorghum sector is developed that represents (1) excess supply and excess demand regions with their predetermined surpluses and deficits; (2) country, terminal and port elevators with handling and storage costs as well as these facilities' current cleaning capacity and costs; and (3) all linking transportation costs (figure 1). The model is designed to optimally locate cleaning equipment at country, terminal and port elevators[2] in the various regions by minimizing total annual marketing cost subject to: (1) country elevator, terminal, port elevator, barge-loading, and barge-unloading balance equations; (2) domestic and foreign demand balance equations; (3) grain industry operating characteristics and associated grain flow constraints; and (4) cleaning capacity constraints. See appendix A for a mathematical representation of the model.

The model features 31 domestic excess supply regions with their representative country elevator, 35 domestic excess demand regions, 13 foreign excess demand regions. The model represents four quarters of a sorghum crop year. The model also includes 7 terminal elevator centers, 18 barge-loading sites, 5 barge-unloading sites and 5 port areas with the representative port elevators. The developed model includes 332 integer variables, 46,092 continuous variables and 1,807 constraints.

The multiproduct dimension of the model includes grain sorghum which (1) originally met the proposed standard, (2) does not meet the proposed standard, and (3) did not originally meet the proposed standard but has been cleaned to meet the standard.[3] The model allows these three products to be shipped throughout the elevator and distribution network to meet predetermined demands.

Appropriate transportation modes (rail, truck and barge) link country elevators, terminals, ports, barge-loading sites and barge-unloading sites with domestic demand regions while ports are linked to foreign demand regions by ship rates. The cost of grain shipment includes handling (loading and unloading) and transportation. Storage costs are included for storage at country and terminal elevators. Cleaning costs differ by type of grain

Figure 1. Spatial and Market Channel Dimension of Model



R/ T= Rail or Truck

handling facility (country, terminal and port elevator) and include variable cleaning costs and annualized fixed charges. Fixed charges are incurred if country, terminal or port elevators increase cleaning capacity.

To reflect operating characteristics of the regions grain handling industry and associated grain flow patterns, storage constraints are placed on country elevator storage. The storage constraint creates the observed flow of sorghum to the regions' terminal elevators.

The empirical analysis is based on the following assumptions: (1) implementation of the proposed sorghum standard would not affect the geographical distribution of total supply/demand among surplus/deficit regions, (2) interregional grain flows do not occur among elevators at the same level in the market channel, (3) grain demands which do not require grain quality commensurate to the proposed standard may be met by grain which does meet the proposed standard, and (4) on-farm grain consumption and intraregional grain marketings would not be subject to the proposed standards.

The model was solved with the General Algebraic Modeling System (GAMS) using OSL/IBM library for integer programming. Approximately 50 minutes were required to solve the model on a HP9000/720 system.

Data

The model includes 31 domestic excess supply regions in Kansas (9), Texas (6), Nebraska (4), Missouri (3) and Oklahoma (2); other states with an excess supply region are Arizona, Colorado, Kentucky, Louisiana, New Mexico, South Carolina and South Dakota. Thirty-five domestic excess demand regions are in Texas (10), Oklahoma (8), Missouri (5), California (2) and Nebraska (2); the remaining states with an excess demand region include Alabama, Arizona, Arkansas, Georgia, Illinois, Mississippi and Utah. Excess supply regions are linked to domestic excess demand regions by 7 terminal centers, 18 barge-loading and 5 barge-unloading locations as well as direct routes. Five port areas are linked directly to excess supply regions and to terminal and barge-loading sites as well as 13 foreign excess demand regions. Terminal elevator locations are at Amarillo and Ft.

Worth, Texas; Kansas City and Wichita, Kansas; Omaha, Nebraska; St. Louis, Missouri and Memphis, Tennessee, and port areas include Mobile, Alabama; New Orleans, Louisiana; Galveston, Corpus Christi and Brownsville, Texas; Portland, Oregon and Seattle, Washington. Barge-loading and unloading sites are on the Missouri, Arkansas, Tennessee and middle and lower Mississippi rivers. Data on excess demands and supplies and grain handling (loading, unloading), storage and transportation costs (truck, rail, barge, ship) are from Fuller et al. (1990).

The cleaning process removes dockage and foreign material from the grain and creates a byproduct which is identified as liftings/cleanings. The quantity of liftings removed from the grain is dependent on the stringency of the standard. Based on Federal Grain Inspection Service (FGIS) records it is estimated that 2.1 percent of the grains' original weight is lost to liftings under the current standard, while with the 4% BN, 1% FM standard, the weight loss is estimated to be 4.1 percent, respectively.

If the proposed standards were implemented, increased removal of broken kernels and foreign material would be required, thus lowering cleaners throughput levels and current cleaning capacity. The current sorghum cleaning capacity at country elevators was estimated to be about 13 million bushels per quarter; however, if the proposed 4% BN, 1% FM standard were adopted, cleaning capacity would be reduced to about 10.0 million bushels per quarter. Based on cleaning requirements associated with current standards, sorghum cleaning capacities of terminal and port elevators in the study region were estimated to be 2.7 and 6.7 million bushels per quarter, respectively. If the proposed 4% BN, 1% FM standard were accepted, respective capacities are expected to decline to 2.1 and 5.2 million bushels per quarter (Grant et al.).

The elevator cleaning cost function is discontinuous because of the annual fixed cost or charge associated with the addition of a new cleaner (figure 2)[4]. The annual fixed charge associated with the addition of a cleaner varies from $16,434 for a country elevator to $117,419 for a port elevator. Further, because of the need to remove additional liftings, variable cleaning costs increase with the more stringent standard (4% BN, 1% FM). Since the cleaning rate is reduced by the proposed standard, the annual cleaning capacity of a cleaner is proportionally reduced (figure 2). The estimated variable cleaning costs at country elevators are $0.0107, and $0.0140 per bushel with the current and 4% BN, 1% FM standards, respectively. The capacity of a cleaner designed for country elevators is .819 million bushels when cleaning to meet current standards and .637 million bushels with the 4%BN, 1%FM standard (figure 2). In addition, total per bushel costs are lowest for large cleaners at high volume facilities. For example, cleaners operating at full capacity are projected to incur costs of about $.01 per bushel at port elevators but nearly $.03 per bushel at country elevators. Estimated cleaning costs at elevators are based on the use of rotary screen cleaners (Grant et al.).

Model Validation and Procedure

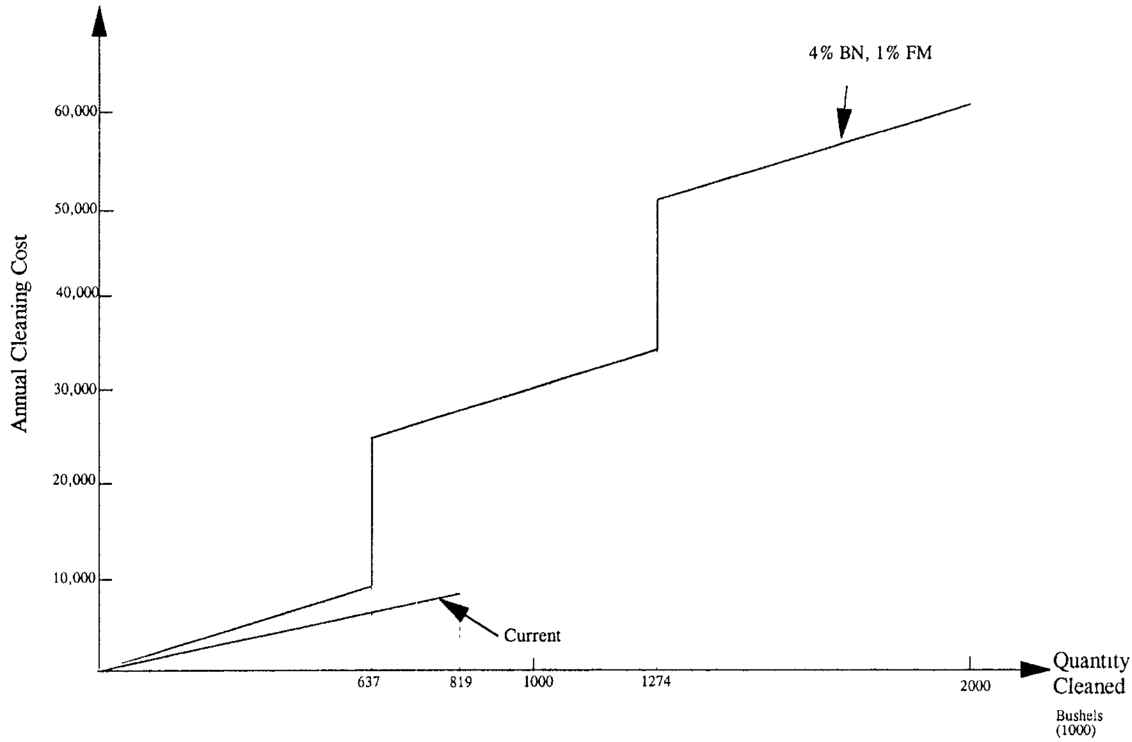
The model is calibrated to represent demand/supply and costs for the latter 1980s and sorghum cleaning requirements associated with the current No. 2 standard. The solution to this model represents the base period marketing costs and flows. An effort was made to validate the model by comparing model-generated grain flows with historical flows. Unfortunately, no historical data were found on interregional flows between country, terminal and port elevators; however, information on historic flows via port areas were obtained and these data were compared with model-generated flows for purposes of validation (*Feed and Grain Market News*). Model-generated sorghum flows via port areas is virtually identical to historic flows, thus the validation effort shows the developed model to be adequate to carry out study objectives.

To evaluate the effect of the proposed standard, the model representing the current standard is modified to reflect increased cleaning necessitated by the proposed 4% BN, 1% FM sorghum standard. The solutions to the models are contrasted for purposes of determining the effect of the proposed standard.

Results

Costs and cleaning locations associated with the current No. 2 grain sorghum standard (base

Figure 2. Estimated Costs of Cleaning at a Country Elevator Under the Current and 4% BN, 1% FM Standards



model solution) are contrasted with solutions of the modified base model which represent the proposed 4% BN, 1% FM standard. Four models are the focus of this study. Model 1 depicts the base conditions where it is presumed all sorghum involved in interregional trade will meet the current No. 2 standard. Model 2 represents operations under the proposed standard and it also presumes all sorghum involved in interregional trade will be cleaned to meet this standard while Model 3 presumes only export-destined grain meets the proposed standard[5].

Historic grain stock and railroad waybill data suggest that in some years up to 40 percent of the sorghum involved in interregional trade transits at terminal elevator locations. This routing is undoubtedly due to a variety of factors[6]. To reflect operating characteristics of the regions grain handling industry and associated grain flows, storage constraints are placed on country elevator storage capacity in Models 1, 2 and 3 (current standard and proposed standard). The storage constraint facilitates replication of the observed flow of sorghum to terminal elevators. Accordingly, Models 1, 2 and 3 optimize additional cleaning capacity given the historic flows via terminal elevators. In Model 4, the country elevator storage constraint is removed from Model 2 so that grain may bypass terminal elevators. The solution to the modified model (Model 4) is contrasted with the earlier solution (Model 2) to evaluate the impact of the country elevator storage constraint (historic flows via terminal elevators) on least-cost cleaning location (country, terminal and port elevators) and system costs.

Model 1: Current Standard

About 3 percent or 12.8 million bushels of sorghum fail to meet the current No. 2 standard (table 1). The base solution shows cleaning costs of $136,011 and the generation of 0.27 million bushels of liftings which are marketed at a cost of $37,400. Total marketing costs (grain handling, storage, transportation, cleaning and associated activities) are $316.97 million and average system costs are $.8122 per bushel (table 2). Virtually all cleaning is carried out at country elevators (12.25 million bu.) and liftings are marketed to nearby cattle feeding locations.

Table 1. Estimated U.S. Sorghum Sector Investments and Cleaning Activity and Costs for Current and Proposed Standard

	Elevator	Additional Cleaner Investment ($)	Quantity Cleaned (million bu.)	Cleaning Cost ($)	Marketing Cost of Liftings ($)
Current Standard[a]	Country	0	12.25	131,097	35,100
(Model 1)	Terminal	0	0.56	4,914	2,300
	Port	0	0.00	0	0
		0	12.81	136,011	37,400
Proposed Standard/	Country	9,153,144	116.02	2,708,865	648,300
All Interregional	Terminal	2,642,336	87.04	1,366,347	695,900
Grain Flow[b]	Port	0	0.00	0	0
(Model 2)		11,795,480	203.06	4,075,212	1,344,200
Proposed Standard/	Country	4,715,256	68.50	1,517,765	382,800
Export Grain Flow[c]	Terminal	990,876	46.81	683,785	374,200
(Model 3)	Port	0	1.59	0	24,600
		5,706,132	116.90	2,201,550	781,600

[a]All sorghum involved in interregional trade meets current No. 2 standard.
[b]All sorghum involved in interregional trade meets the proposed 4% BN, 1% FM standard.
[c]Only export-destined sorghum meets the proposed 4% BN, 1% FM standard.

Table 2. Estimated U.S. Sorghum Sector System Costs for Current and Proposed Standard.

System Cost Components		Current Standard[a] ($)	Proposed Standard/ All Interregional Grain Flow[b] ($)	Proposed Standard/ Only Export Grain[c] ($)
Storage		13,790,303	13,613,705	13,696,930
Cleaning		136,011	4,075,212	2,201,550
Marketing of Liftings		37,400	1,344,200	781,600
	Total	316,970,000	316,300,000	315,690,000
	Average[e]	0.8122	0.8276	0.8183

[a]All sorghum involved in interregional trade meets current No. 2 standard.
[b]All sorghum involved in interregional trade meets the proposed 4% BN, 1% FM standard.
[c]Only export-destined sorghum meets the proposed 4% BN, 1% FM standard.
[d]Includes cost of loading/unloading grain at country elevators, barge-loading sites, barge-unloading sites, terminals and ports as well as truck, rail, barge and ship cost.
[e]Estimated by dividing total system cost by bushels of marketed grain. Bushels of grain marketed is obtained by subtracting liftings from total excess supply or surplus (390.56 million tons). Liftings are estimated to be 8.35 million bushels when the proposed standard includes all interregional flows and 4.79 million bushels when only export grain meets the proposed standard Quantities of grain marketed under the two scenarios are 382.21 and 385.77 million bushels, respectively.
**The model doesn't allow elevators at the same level of the marketing channel to ship to each other (i.e., country elevators cannot ship to other country elevators).

Under the current No. 2 standard, producers ship 372 million bushels to country elevators and about 18 million bushels to terminals. Country elevators subsequently ship about 136 million to terminals and the remainder (236 million bushels) to ports, domestic excess demand regions and barge-loading locations. Terminals ship to ports and domestic demand regions. Approximately 111.5 million bushels are exported from the Louisiana and east Gulf ports, 10.6 million from Pacific northwest ports and the remaining 55 million bushels from Texas Gulf ports.

Model 2: Proposed Standard Affects all Grain in Interregional Trade

In this scenario, all grain involved in interregional trade must meet the proposed 4% BN, 1% FM standard. The introduction of the standard would necessitate the cleaning of 203.06 million bushels. Cleaning costs are $4.075 million and the cost of marketing the liftings is $1.344 million (table 1). Grain handling and transportation costs decrease $5.739 million as compared to the current No. 2 standard and storage costs decrease modestly ($.177 million) (table 2). The decline in these costs is primarily due to the removal of liftings and the resulting transportation cost savings. Estimated total system costs decrease modestly but per bushel system costs increase to $.8276, for 382.20 million bushels of sorghum marketed. Flow patterns remain virtually unchanged.

Results show additional investment in sorghum cleaning capacity is optimally located at country elevators and terminals in production regions and, to a considerable extent, at country elevators (table 1). Implementation of the 4% BN, 1% FM standard would involve an investment of $11.795 million (country elevators $9.153; terminals $2.642) with about 78 percent located in the major producing states (Kansas (36%), Nebraska (10%), Texas (22%), Missouri (10%) (table 3).

Model 3: Proposed Standard Affects Only Exported Grain

In this scenario only exported sorghum (177 million bushels) must meet the proposed 4% BN, 1% FM standard. Domestic demands may be met by sorghum which does or does not meet the proposed standard.

Approximately 377.7 million bushels of excess sorghum supply meet the current No. 2 standard without cleaning but if the 4% BN, 1% FM standard were implemented, only 187.8 million bushels would meet the proposed standard without cleaning. Regardless, the quantity of grain meeting the proposed standard (187.8 million bu.) exceeds foreign demand (177 million bu.); thus, it may be least-cost for no cleaning to occur.

The solution to this model shows 116.9 million bushels would be cleaned with implementation of the 4% BN, 1% FM standard. Thus, it is least-cost to carryout substantial cleaning even though adequate supplies of grain meet the proposed standard. Further, flow patterns in this scenario are identical with those in Model 2. The identical flow pattern suggests the additional cost of rerouting grain which meets standard is greater than the cost of cleaning.

Investment in cleaning capacity is reduced by removing the need that domestic demands be satisfied by sorghum which meets the proposed standard. Implementation of the 4% BN, 1% FM standard would require investments of $5.706 million, with principal investments located in Kansas ($2.411), South Dakota ($0.970), Nebraska ($1.268) and Texas ($1.248) (table 3). Results show 80 percent of the additional cleaning capacity is located in the four major sorghum producing states.

Model 4: Country Elevator Storage Constraint Removed

Models 1, 2 and 3 include constraints on country elevator storage capacity to affect the observed historical flows to terminal elevator locations. In this scenario, Model 2 was modified so historic grain flow patterns need not be followed. As in the above scenario, an estimated 203.06 million bushels require cleaning (table 1), but in this scenario, the selected cleaning location and system costs have been altered. Given the historical flow patterns (Model 2), about 57 percent (68.5 million bu.) is cleaned at country elevators (table 1) but if historical flows are disregarded (Model 4), over 95 percent of the cleaning is carried out at these locations. And, all new investment in cleaning capacity is located at the country elevator stage of the marketing channel. About 84 percent of this investment ($10.539 million) is located in the four major producing states (Kansas, Nebraska, Texas, and Missouri).

Analysis of system costs offers insight into factors affecting the relocation of the cleaning activity and total system costs. Disregarding historical grain flow patterns, i.e., removing the country elevator storage constraint, generates net system savings of $22.510 million; however, only a modest portion of these savings ($1.446 million) are attributable to the relocation of the cleaning activity to country elevators. The remaining savings, $21.064 million, are the result of reduced grain handling (grain loading/unloading cost) and lower logistics and transportation costs that result from bypassing terminal elevators. Savings attributable to increased cleaning at country elevators ($1.446 million) are primarily due to reduced transportation and storage costs that result from the removal of liftings and the proximity of country elevators to cattle feeding areas and the associated transportation cost savings.

The analyses show cleaning costs are lowered ($1.446 million) by cleaning nearly all sorghum at country elevators; however, it does not suggest the feasibility of modifying historical flow patterns (removing storage capacity constraint at country elevators) to capture these savings. As noted above, system cost savings of $21.064 million are currently available by bypassing terminal elevators. But, the incentive to bypass terminals has apparently been inadequate since there has been modest changes in flows in recent years. If increasingly stringent sorghum standards were adopted and more cleaning required, additional system savings of about $1.446 million would be available by increasing the cleaning capacity of country elevators. However, it seems doubtful that this marginal increase in savings ($1.446 million) would justify the investment since currently available savings of $21.064 million have not proven an adequate incentive to bypass the region's terminal elevator system.

Summary and Conclusions

This study developed a model to (1) locate new grain cleaning investment in a multicommodity, multiperiod distribution network that featured transshipment at country, terminal, and port elevators and (2) estimate marketing costs associated with implementing the proposed sorghum standard.

The model includes 31 domestic excess supply regions with each region's representative country elevator, 35 domestic demand regions, 13 foreign excess demand regions, 18 barge-loading sites, 5 barge-unloading sites, 7 terminal centers with their representative terminal elevators, 5 U.S. port areas with their representative port elevator and 4 quarters of a crop year. It is important that the model account for transshipment, seasonality and quantities of sorghum which do and do not meet the proposed grade standard. The fixed costs or charges associated with the addition of cleaners at country, terminal and port elevator stages of the marketing channel require a mixed-integer programming model to optimally locate grain cleaning capacity in this large distribution network.

Scenarios are examined which involve various assumptions regarding portion of grain demand (domestic and foreign) which must be satisfied by grain which meets the proposed standard and historic grain flows via terminal elevators. Model solutions that represent the current and the proposed 4% BN, 1% FM grade standards are contrasted.

As expected, the analyses generally show per bushel cleaning cost to increase with implementation of the 4% BN, 1% FM standard. Introduction of this standard would increase costs about $.026 per bushel of grain cleaned (Model 1 vs. Models 2 and 3) while per bushel system costs increase about $0.006 per bushel when only export-destined grain meets grade (Model 3) and $0.015 per bushel when all sorghum in interregional trade meets the proposed standard (Model 2).

The results show cleaning in the sorghum production region (country elevators, terminals) is generally more efficient than cleaning in port areas. Given the historic operations of the grain handling industry in the sorghum producing region and associated grain flows, about 57 percent of the new cleaning capacity is located at country elevators and the remaining 43 percent at terminals (Models 2 and 3). If historic grain flows are disregarded (Model 4) and grain is permitted to bypass terminal elevator locations, country elevators become the least-cost location for additional grain cleaning activity. This outcome is primarily the result of transportation and storage cost savings that result from the removal of liftings and country elevators' proximity to cattle feeding areas and the transportation cost savings associated with the marketing of liftings.[7]

This paper focuses on marketing costs associated with implementing more stringent cleanliness standards for sorghum. No effort is made at identifying the additional market share or enhanced price that may result from marketing a cleaner product. Regardless, this study shows that implementing more stringent standards would involve very modest increases in marketing costs (≤2 percent), and this implies the benefits of cleaning need not be large in order for cleaning to be economically feasible.

In conclusion, implementing the proposed sorghum standards would increase system marketing costs less than 2 percent. In general, the least-cost location for additional cleaning capacity is in the producing regions at country and terminal elevator locations. Terminal elevators play an important role in cleaning additional sorghum if historical flow patterns are maintained. If historical flows are disregarded, terminal elevators would be bypassed since it is least-cost for virtually all cleaning to be carried out at country elevators.

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Appendix A: Mathematical Description of the Model

(1) Objective Function:

The objective function minimizes the total annual costs of transportation, handling, storage, cleaning, investment and the disposal of liftings subject to constraints (2) through (6)[8].

$$\textit{Minimize} \quad \sum_{k} \sum_{k \neq k} \sum_{i} \sum_{q} \sum_{m} ckk_{kkm} \, QF_{kkiqm} + \sum_{k} \sum_{d} \sum_{q} \sum_{m} \sum_{i} ckd_{kdm} \, (QCDD_{kdiqm} +$$

$$\lambda_{i1} \, QCUDD_{kdqm}) + \sum_{k} \sum_{f} \sum_{i} \sum_{m} \sum_{q} ckf_{kdm} \, QFD_{kfimq} + \sum_{k} \sum_{i} \sum_{q} cs_k \, I_{kiq,q-1} +$$

$$\sum_{k} (\sum_{q} vc_k \, QCL_{kq} + \sum_{i} 2^{i-1} fc_k \, Z_{ki}) + \sum_{k} \sum_{q} p_k \, l_k \, QCL_{kq}.$$

Where the first term in the objective function represents the transshipment costs for the alternative qualities of grain sorghum at the various elevator types; the second term represents the transportation costs associated with shipments from elevators to domestic demand locations; the third term represents transportation costs associated with shipments from elevators to foreign demand regions; the fourth term reflects the storage costs; the next term represents the variable and fixed costs resulting from cleaning activities; and finally the last term represents the cost associated with disposal of cleanings.

(2) Elevator Balance Equation:

$$\sum_{m} (\sum_{k \neq k} QF_{kkiqm} + \sum_{d} (QCDD_{kdiqm} + \lambda_{i1} \, QUCDD_{kdqm}) + \sum_{f} QFD_{kfrmq}) + I_{kiq,q+1} +$$

$$\lambda_{i2} \, QCL_{kq} - I_{kiq,q-1} - \sum_{g} \sum_{m} QF_{gkimq} - S_{kiq} - \lambda_{i3} \, (1 - \alpha) \, QCL_{kq} \leq 0$$

for all k, r and q.

Elevator balance equation balances quarterly receipts, shipments, product transformation and ending inventories for clean, unclean and cleaned sorghum products for each elevator.

Specifically, for each type of grain quality, for each quarter and for each elevator, this equation balances the elevator's shipments to other elevators, domestic demand regions and foreign demand locations plus the ending inventory of grain plus unclean grain being cleaned (in case of unclean grain) with grain receipts from farmers and other elevators plus beginning inventory of grain plus quantity of grain being cleaned adjusted for loss (in case of cleaned grain). In a situation, when the proposed grading standards are applicable only to grain shipped to foreign locations, QCCU represents the quantity of clean grain shipped to domestic demand locations to substitute for unclean grain.

(3) Elevator Carryover Capacity Constraint:

$$\sum_{i} I_{kiq,q-1} \leq cap_k \qquad \textit{for all k and q.}$$

This equation forces the quantity of grain sorghum stored at each elevator in each quarter to be less than or equal to associated storage capacity.

(4) Cleaning Capacity Equation:

$$QCL_{kq} \leq \gamma_k + \sum_{i=1}^{I} 2^{i-1} \, \beta_k \, Z_{ki} \qquad \textit{for all k and q.}$$

Equation (4) determines the investment activity for each elevator. This constraint requires that the quantity of grain being cleaned in each quarter and in each elevator to be less than the current cleaning capacity plus added cleaning capacity.

(5) Domestic Demand Balance Equation:

(*a*) $\sum_{k} \sum_{m} \sum_{i \neq 2} (1 + \lambda_{i3}\, \alpha)\, QCDD_{kdiqm} \geq D_{d1q}$ *for all d and q.*

(*b*) $\sum_{k} \sum_{m} (QCDD_{kdiqm} + QCUDD_{kqmd}) \geq D_{diq}$ *for all d, q, and r=2.*

Equation 5a requires the quantity of clean and cleaned grains shipped from all elevator locations to each domestic demand region to be greater than or equal to domestic demand for clean grain in that region. In order to balance the demand and supply in the system, the quantity of cleaned grain shipped from different marketing outlets are adjusted to reflect losses associated with the liftings.

Equation 5b requires the quantity of clean and unclean grain shipped from all elevator locations to a domestic region to be greater than or equal to the domestic demand for unclean grain in that region.

(6) Foreign Demand Balance Equation:

$\sum_{k} \sum_{m} \sum_{i \neq 2} (1 + \lambda_{i3}\, \alpha)\, QFD_{kfimq} \geq D_{fq}$ *for all f and q.*

This equation forces the quantity of clean and cleaned grain shipped from all elevators to each foreign demand location to be greater or equal to the foreign demand. The total quantity of cleaned grain shipped is, however, adjusted to reflect the loss associated with the liftings.

The variables, parameters and subscripts included in the model are defined as follows:

Variables:

QF_{kkrqm}: is quantity of grain of quality r shipped from elevator k to elevator k (if k ≠ k) by mode of transportation m in time period q, in mil/bu;

QFD_{kfrmq}: is quantity of grain of quality r shipped from elevator k to foreign demand location f by mode of transportation m in time period q, in mil/bu;

$QCDD_{kdrqm}$: is quantity of grain of quality r shipped from elevator k to domestic demand region d by mode of transportation m in time period q, in mil/bu;

$QCUDD_{kdqm}$: is quantity of clean grain shipped from elevator k to domestic demand region d to substitute for unclean grain by mode of transportation m in time period q, in mil/bu;

$I_{krq,q-1}$: is quantity of grain of quality r stored at elevator k between periods q and q-1, in mil/bu;

QCL_{kq}: is quantity of grain cleaned at elevator k in period q, in mil/bu;

Z_{ki}: number of cleaning machines required at elevator k, binary variable.

Parameters:

S_{krq}: quantity of grain sorghum of quality r shipped from surplus region to elevator k in period q, in mil/bu;

D_{frq}: foreign demands in quarter q, in mil/bu;

D_{drq}:	domestic demands for grain quality r in quarter q, in mil/bu;
ckk_{kkm}:	cost of transport via mode m from elevator k to elevator k, in $/bu;
ckd_{kdm}:	cost of transport via mode m from elevator k to domestic demand region k, in $/bu;
ckf_{kfm}:	cost of transport via mode m from elevator k to foreign demand region f, in $/bu;
cap_k:	storage capacity at elevator k, in mil/bu;
sc_k:	cost of storage between period q and q-1 for elevator k, in $/bu;
p_k:	percentage of liftings per bushel at elevator k, %;
l_k:	per unit cost of disposing liftings at elevator k, $/bu;
γ_k:	current cleaning capacities for elevator k, mil/bu;
β_k:	cleaning capacity of a new cleaning machine at elevator k, mil/bu;
vc_k:	per unit cleaning costs at elevator k, in $/bu;
fc_k:	annualized fixed cost of an additional cleaning machine at elevator k, in $;
α:	percentage of liftings, in %;
λ_{rj}:	indicator variable (where λ_{rj} =1 if j=r, and λ_{rj} = 0 if j≠r).

Subscripts:

k:	elevator locations k=1,2,...68 (where it includes 31 country elevators, 7 terminal locations, 18 barge-loading locations, 5 barge-unloading locations and 7 U.S. port locations;
g:	excess supply locations g=1, 2,...31;
q:	time period, q=1, 2, 3, 4;
m:	transportation modes, m=1,2,3 (m=1 is rail, m=2 is truck, and m=3 is ship);
d:	domestic demand locations, d=1,2,...35;
f:	foreign demand locations, f=1,2,...13;
r, j:	type of products, r, j=1,2,3 (where r=1 is clean grain, r=2 is unclean grain and r=3 is cleaned grain) ;
i:	number of cleaning facilities purchased at each elevator, i=1, 2,...10.

Endnotes

1. Dockage is all matter that passes through a 2.5/64 inch roundhole screen and includes primarily weeds, stems and dirt. Foreign material is all matter which passes over the number 6 riddle as well as matter that remains on top of a 5/64 inch triangular hole sieve.

2. Grant et al. found on-farm grain sorghum cleaning costs to be comparatively high and generally infeasible for most farmers. For this reason, on-farm cleaning was not considered as a possibility.

3. The cleaning of grain generates liftings or cleanings. The model is driven by predetermined demands for grain that meets standard and grain that does not meet standard. It is necessary that region demand reflect the loss of grain that results from cleaning. Instead of arbitrarily decreasing the demand proportionally by demand region, the model was formulated so that any reduction in regional demand was determined endogenously. This was facilitated by including grain that was cleaned to meet standard as a separate commodity.

4. Country elevator cleaning costs in Figure 2 reflect a rotary screen cleaner operating 455 hours per quarter. Under the current standard, the estimated throughput of the cleaner is 1,800 bushels per hour and the associated variable cost of cleaning is $0.0107 per bushel. Since additional materials will need to be removed from the grain under the proposed standard (4% BN, 1% FM), cleaner throughput is projected to decline to 1,400 bushels per hour while the associated variable cost increases to $0.0140 per bushel. It follows that a cleaner's output under the current and proposed standard would be 819,000 and 637,000 bushels per quarter, respectively. The fixed cost of the existing cleaner is sunk and not relevant to final

decisions; accordingly, only variable cost is used when estimating costs of the existing cleaner. Under the proposed standard, the existing cleaner reaches capacity at 637,000 bushels and additional cleaning capacity is only possible with investment in a new cleaner. Associated with investment in a new cleaner are fixed costs of $16, 434, thus the source of the stepped or discontinuous cost relationship shown in Figure 2.

5. Analysis which includes additional proposed sorghum standards and different cleaning technologies are presented in Ziari et al.

6. Historic incentives to construct country and terminal storage facilities, railroads transit rate structure, farm programs, production of other grains, storage costs, variability in plains grain production, and blending capabilities at terminals are a few of the presumable myriad of forces which effect grain flows to terminal elevators in the plains. The developed model does not attempt to account for each of these forces but rather is constrained to reflect the observed flow through terminal elevator facilities.

7. Model 2 was modified to determine whether a reduction in the cost of marketing the liftings at port elevators would relocate sorghum cleaning to the port area. The cost of marketing liftings at port elevators was reduced from $.378 per bushel to $.195 per bushel, the same cost as experienced by terminals. The solution showed the quantity cleaned at ports to increase from 0.0 to 3.60 million bushels. This is a modest relocation of cleaning activity in view of the 203 million bushels which required cleaning.

8. The model doesn't allow elevators at the same level of the marketing channel to ship to each other (i.e., country elevators cannot ship to other country elevators).