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# Wheat Cleaning Decisions at Country Elevators

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This article presents a mathematical programming model of wheat cleaning and blending decisions at a country elevator. Simulations are performed to illustrate the sensitivity of cleaning to selected variables, including the value of screenings, transportation costs, and market discounts for excess dockage. In addition, the model is used to assess the impact of including dockage in the grade standards for wheat.

*Key words:* blending, decision model, dockage, grain quality.

## Introduction

Issues related to grain cleanliness have been debated for at least a decade. While other exporting countries (e.g., Canada and Australia) clean wheat intensively before export, U.S. dockage levels are not subject to formal regulation. Existing U.S. standards treat dockage (like protein) as a non-grade-determining factor.[1] Contract specifications and commercial incentives determine dockage levels in U.S. wheat exports and throughout the marketing system. This study develops a model which can be used to analyze the economics of cleaning decisions. Simulations are performed to illustrate impacts of important variables on cleaning decisions and to assess implications of alternative regulations. The model is normative: it identifies an "optimal" set of actions by an elevator given an objective of profit maximization. The model can be used to predict how individual firms would respond to regulations which have been proposed in this industry.

Wheat cleanliness issues have been addressed in a number of studies (Adam and Anderson; Fridirici et al.; Leibfried; Mercier et al.; U.S. Congress, Office of Technology Assessment 1989a, b). Implications of combining dockage with foreign material in the grading standards for wheat were analyzed from an aggregate perspective by Mercier et al. The methodology used in that study makes use of historical shipment data. This implicitly assumes that market participants' behavior would be unchanged under a new regulatory regime. In contrast, our model is developed from the perspective of a merchandiser who can control some quality factors (specifically, dockage levels). Hence, it provides a more realistic basis for assessing likely effects of new regulations.

Analytical models of grain blending and conditioning (e.g., cleaning, drying, sizing) decisions either take the form of a budget analysis (e.g., Adam and Anderson; Kiser), or normative models of blending. Budget analyses are limited in several respects. First, the intensity of cleaning operations (i.e., quantity of grain cleaned and amount of dockage removed) is predetermined, rather than endogenous. Second, these analyses do not allow for blending activities, which are of great practical significance for elevators.

Traditional optimization models of blending decisions (e.g., Schruben; Ladd and Martin

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in the case of grains) also are limited. These focus on blending alternatives (e.g., to satisfy grade factor limits or other quality specifications) without considering other conditioning activities. In practice, conditioning activities can be viewed as alternatives to blending. The economics of some conditioning activities (i.e., cleaning) also are influenced by transport activities and by the value of by-products. These are important features of the model presented below.

In the next section, the decision model is formally described. Data for the analysis are summarized in the third section. The fourth section presents results of sensitivity analyses along with simulations intended to quantify costs of cleaning under different assumptions. The article concludes with a summary.

## Model Development

### *Setting and Objective Function*

The decision model has many features of a classic blending problem. An elevator has a number of grain bins, each containing some quantity of wheat with specific quality attributes. Quantities and qualities vary across bins and are taken as given by the decision maker. Wheat can be sold directly from each bin or blended to meet a set of contract specifications (e.g., protein, test weight, dockage, damage, or defects). Different prices apply to wheat that is sold separately and to wheat that is blended to satisfy contract specifications. The objective is to maximize sales revenue net of various costs.

Introduction of wheat cleaning adds complexity to the problem. Unlike other wheat quality attributes which can be altered only through blending activities, the level of dockage in each bin can be controlled independently through cleaning operations. The elevator sells wheat on a dockage-deductible basis; that is, the sales price applies to net weight (i.e., net of dockage). Since freight charges are based on gross weight inclusive of dockage, the elevator realizes savings on freight costs by cleaning before shipment. In addition, material removed through cleaning operations (screenings) can be sold as livestock feed. The sum of freight savings and screening values less the cost of cleaning represents an implicit "cleaning margin," which may be positive or negative. Positive cleaning margins provide incentives to remove dockage from wheat before shipment.

Operating costs for standard disk-cylinder cleaning equipment depend on quantity cleaned and on intensity of cleaning operations. Cleaning to lower dockage levels reduces operating efficiency. Cleaning operations also involve a loss of saleable wheat, as shrunken and broken kernels are removed along with dockage. This "wheat loss" can represent a substantial part of cleaning costs, depending on the level of shrunken and broken kernels in the grain being cleaned and the relative values of wheat and wheat screenings.

The elevator seeks to maximize sales revenues net of cleaning and transportation costs:

$$\textit{Net Revenue} = WREV + SREV - TCC - TRAN,$$

where $WREV$ denotes revenue from sale of wheat, $SREV$ denotes revenue from sale of screenings, $TCC$ denotes total cost of cleaning, and $TRAN$ denotes the transportation cost. The maximization is subject to a number of constraints concerning resource availability and contract limits, as described below.

### *Marketing Alternatives, Cleaning Costs, and Quality Constraints*

Ten storage bins are indexed by $i$ ($i = 1, 2, \ldots, 10$), containing wheat with different levels of the following attributes: dockage ($DK$), protein ($PRO$), test weight ($TW$), shrunken and broken kernels ($SB$), foreign material ($FM$), damage ($DAM$), and defects ($DEF$). The elevator can satisfy two (or potentially more) sets of contract specifications through blending; alternatively, the elevator can sell wheat directly from bins without blending. Formally, let $K$ represent a set of marketing choices:

$$k \in K = \{NB, B1, B2\},$$

where $NB$ indicates *do not blend,* $B1$ indicates *blend number 1,* and $B2$ indicates *blend number 2.* For later convenience, define $H$ as a subset of $K$, consisting of the two blends:

$$h \in H = \{B1, B2\} \subset K.$$

Let $J$ represent a set of (binary) cleaning choices:

$$j \in J = \{C, NC\},$$

where $C$ indicates *clean,* and $NC$ indicates *do not clean.*

Let $X(i, j, k)$ denote the quantity (60-pound bushels) from bin $i$ devoted to cleaning alternative $j$ and marketing alternative $k$. Thus, $X(i, C, NB)$ represents the quantity of wheat from bin $i$ that is cleaned but sold directly without blending; $X(i, NC, B1)$ is the quantity from bin $i$ that is not cleaned, but blended and sold under the first set of contract specifications. All of the grain is allocated (sold) under some combination of cleaning and marketing alternatives:

$$\sum_j \sum_k X(i, j, k) \leq QTY(i) \quad \text{for all } i,$$

where $QTY(i)$ is the total quantity of wheat (bushels) available in bin $i$.

Cleaning costs depend on the operating efficiency of the disk-cylinder equipment. This equipment's rated capacity, denoted $RCAP$, represents maximum throughput (bushels per hour) under ideal conditions. In practice, operating efficiency depends on the intensity of cleaning operations, i.e., the initial dockage level and the dockage level after cleaning. A linear relationship is specified:

$$PRC(i, k) \leq a_0 + a_1 \cdot DK(i) + a_2 \cdot EDK(i, k),$$

where $PRC(i, k)$ denotes proportion of rated capacity, $DK(i)$ is the initial dockage level (percentage) in bin $i$, and $EDK(i, k)$ is the desired ending dockage level after cleaning operations. Operating efficiency is inversely related to the initial dockage level (the coefficient $a_1$ is negative) and directly related to the ending dockage level ($a_2$ is positive). An upper bound is also applied:

$$PRC(i, k) \leq 1,$$

so that actual throughput rates are not allowed to exceed rated capacity for the equipment.

The initial dockage $DK(i)$ is given, but the decision maker chooses $EDK(i, k)$ for each bin and marketing alternative. For obvious reasons, the ending dockage level is constrained to be less than the beginning dockage level:

$$EDK(i, k) \leq DK(i).$$

The time required to complete a cleaning operation, $MT(i, k)$ depends on the quantity of wheat cleaned, the cleaner capacity, and operating efficiency:

$$MT(i, k) = \frac{X(i, C, k)}{[RCAP \cdot PRC(i, k)]}.$$

An hourly cost, $CPH$, is imputed to cleaning operations. This represents the sum of variable costs (labor, electricity, replacement parts) for the disk-cylinder equipment. Additional handling costs (such as elevation costs) may be associated with cleaning operations. Let $HC$ denote this extra handling cost, expressed in dollars per bushel. Cleaning costs are given by:

$$CC(i, k) = CPH \cdot MT(i, k) + HC \cdot X(i, C, k),$$

$$TCC = \sum_i \sum_k CC(i, k),$$

where $CC(i, k)$ denotes the cost of cleaning grain from a particular bin and for a particular marketing alternative and $TCC$ denotes the total cleaning cost.

In addition to equipment operating costs, the model allows for a loss of saleable wheat. This wheat loss consists of shrunken and broken kernels that are removed along with dockage during cleaning operations. Specifically, removal of shrunken and broken kernels is assumed to be proportional to dockage removal:

$$ESB(i, k) = SB(i) \cdot [EDK(i, k)/DK(i)],$$

where $ESB(i, k)$ denotes ending shrunken and broken percentage after cleaning operations and $SB(i)$ denotes the initial percentage before cleaning. Screenings are given by:

$$S(i, k) = \frac{DK(i) - EDK(i, k) + SB(i) - ESB(i, k)}{100} \cdot X(i, C, k),$$

$$TS = \sum_i \sum_k S(i, k) \cdot \frac{60}{2{,}000},$$

where $S(i, k)$ represents screenings (60 pounds) from a particular cleaning operation and $TS$ represents total screenings (tons). The ratio 60/2,000 is used to convert units of measurement. Screenings are sold at a price, $PS$ (dollars/ton), yielding revenue:

$$SREV = PS \cdot TS.$$

The value of wheat loss depends on the quantity of shrunken and broken kernels removed and on the value of screenings relative to wheat.

To facilitate other model specifications, let $Y(i, j, k)$ denote bushels after (optional) cleaning operations:

$$Y(i, j, k) = \begin{cases} X(i, C, k) - S(i, k) & \text{if wheat is cleaned,} \\ X(i, NC, k) & \text{otherwise.} \end{cases}$$

These are gross bushels (inclusive of dockage) sold directly, or blended under a set of contract specifications. For the two blends, total gross bushels ($TGW$) are given by:

$$TGW(h) = \sum_i \sum_j Y(i, j, h) \qquad \text{for } h = B1, B2.$$

Bushels net of dockage, denoted $N(i, j, k)$, are defined:

$$N(i, j, k) = \begin{cases} Y(i, C, k) \cdot \left[\dfrac{100 - EDK(i, k)}{100}\right] & \text{if wheat is cleaned,} \\ Y(i, NC, k) \cdot \left[\dfrac{100 - DK(i)}{100}\right] & \text{otherwise,} \end{cases}$$

and total net bushels ($TNW$) for the two blends are given by:

$$TNW(h) = \sum_i \sum_j N(i, j, h) \qquad \text{for } h = B1, B2.$$

These variables are embedded in the objective function. Let $P(i)$ denote the price at which the elevator can sell wheat (on a dockage-deductible basis) directly from bin $i$, and let $PC(h)$ denote the price associated with blend contract $h$. Revenue from wheat sales is given by:

$$WREV = \sum_i \sum_j P(i) \cdot N(i, j, NB) + \sum_h PC(h) \cdot TNW(h).$$

Transportation costs are calculated from the gross weight of shipments:

$$TRAN = T \cdot \left[\sum_i \sum_j Y(i, j, NB) + \sum_h TGW(h)\right],$$

where $T$ denotes the per-bushel freight cost.

Let $M(i, j, k)$ denote bushels net of dockage and shrunken and broken kernels:

$$M(i, j, k) = \begin{cases} N(i, C, k) \cdot \left[\dfrac{100 - ESB(i, k)}{100}\right] & \text{if wheat is cleaned,} \\ N(i, NC, k) \cdot \left[\dfrac{100 - SB(i)}{100}\right] & \text{otherwise.} \end{cases}$$

For the two blends, the associated totals are defined:

$$TMW(h) = \sum_i \sum_j M(i, j, h) \qquad \text{for } h = B1, B2.$$

These quantities are used to specify consraints associated with contract limits for foreign material and damage.

Opportunities for blending are limited by the quantity and quality of wheat in different bins and by contract specifications. For each of the two blends, contract limits are specified for protein, test weight, dockage, shrunken and broken kernels, foreign material, damage, and total defects. These have the following form (for $h = B1, B2$):

$$\mathit{Protein}\ (h) = \sum_i \sum_j \left[\frac{N(i, j, h)}{TNW(h)}\right] \cdot PRO(i) \geq \text{constant;}$$

$$\mathit{Test\ Weight}\ (h) = \sum_i \sum_j \left[\frac{N(i, j, h)}{TNW(h)}\right] \cdot TW(i) \geq \text{constant;}$$

$$\mathit{Dockage}\ (h) = \sum_i \left[\frac{Y(i, C, h) \cdot EDK(i, h) + Y(i, NC, h) \cdot DK(i)}{TGW(h)}\right] \leq \text{constant;}$$

$$\mathit{Shrunken\ and\ Broken}\ (h) = \sum_i \left[\frac{N(i, C, h) \cdot ESB(i, h) + N(i, NC, h) \cdot SB(i)}{TNW(h)}\right] \leq \text{constant;}$$

$$\mathit{Foreign\ Material}\ (h) = \sum_i \sum_j \left[\frac{M(i, j, h)}{TMW(h)}\right] \cdot FM(i) \leq \text{constant;}$$

$$\mathit{Damage}\ (h) = \sum_i \sum_j \left[\frac{M(i, j, h)}{TMW(h)}\right] \cdot DAM(i) \leq \text{constant;}$$

and

$$\mathit{Total\ Defects}\ (h) = \mathit{Foreign\ Material}\ (h) + \mathit{Damage}\ (h) + \mathit{Shrunken\ and\ Broken}\ (h) \leq \text{constant.}$$

Minimum contract limits apply to protein and test weight. Maximum limits apply to dockage, shrunken and broken kernels, and damage and defects.

*Solution Procedure*

The elevator's problem is solved using GAMS/MINOS, a general nonlinear optimizer. Nonlinearities occur in several constraints[2] and the "feasible region" for the problem is not convex. This means that, contrary to standard blending models, there is no mathematical assurance that a "local" optimum is actually "global." One way to deal with this difficulty is to solve the model with different sets of initial values for selected variables. If the optimizer generates the same solution irrespective of the chosen initial values, there is reason to believe that a global solution has, in fact, been identified (see Brooke, Kendrick, and Meerhaus, pp. 157, 204–06).

**Table 1. Quality Attributes and Other Bin Parameters, 1987**

| | Bin Number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| *PRO* (%) | 12.54 | 12.43 | 13.58 | 13.58 | 14.50 | 14.42 | 15.45 | 15.40 | 16.57 | 16.47 |
| *DK* (%) | .64 | 1.95 | .61 | 2.15 | .56 | 2.58 | .59 | 2.69 | .55 | 3.33 |
| *TW* (lbs./bu.) | 60.53 | 59.01 | 60.61 | 59.42 | 59.93 | 58.12 | 59.57 | 58.65 | 59.81 | 57.81 |
| *SB* (%) | 1.04 | 1.30 | .83 | 1.14 | .93 | 1.14 | .78 | .97 | .74 | 1.20 |
| *FM* (%) | .08 | .41 | .17 | .18 | .07 | .29 | .06 | .23 | .05 | .54 |
| *DAM* (%) | .32 | 1.05 | .50 | .41 | .37 | .70 | .46 | .59 | .60 | 6.3 |
| *DEF* (%) | 1.45 | 2.42 | 1.36 | 1.75 | 1.35 | 2.15 | 1.30 | 1.79 | 1.39 | 2.33 |
| *QTY* (000s bu.) | 4 | 6 | 8 | 11 | 14 | 22 | 12 | 14 | 4 | 5 |
| *PRICE* ($/bu.) | 2.93½ | 2.92 | 3.04½ | 3.03 | 3.39 | 3.33 | 3.89 | 3.85½ | 4.27½ | 4.24 |

Notes: *PRO* = protein, *DK* = dockage, *TW* = test weight, *SB* = shrunken and broken, *FM* = foreign material, *DAM* = damage, *DEF* = defects, and *QTY* = quantity.

To ensure robustness of our results, we conducted simulations with a range of initial values for key variables. Specifically, initial values for bushels cleaned, $X(i, j, k)$, and ending dockage levels, $EDK(i, k)$, were varied by increments between their upper and lower bounds. The model was repetitively solved and values of the objective function were compared. When supplied with initial values at a bound [e.g., $EDK(i, k) = DK(i)$], the optimizer identified some solutions that were evidently not global. However, simulations undertaken with interior initial values (strictly in-between the upper and lower bounds) consistently led to one solution, for which global optimality was not disproved. Interior starting values are used in all of the simulations reported below.

## Data for Model Simulations

Cleaning technology and costs were derived from an elevator survey and engineering cost study (Scherping et al.). Other features of the model are based on regional crop-quality data, average price relationships, and discussions with industry representatives. Since prices and quality attributes of wheat available for blending vary over time, framing a "typical" cleaning/blending problem is inherently difficult. Our approach is to perform simulations with two different sets of parameters, corresponding to two different crop years. The two years, 1987 and 1990, provide an interesting contrast. Average dockage levels were high in 1987, and the value of screenings was low, whereas the opposite was true in 1990.[3] Simulation results for 1987 and 1990 illustrate the sensitivity of model results to these key parameters.[4]

**Table 2. Quality Attributes and Other Bin Parameters, 1990**

| | Bin Number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| *PRO* (%) | 12.44 | 12.48 | 13.44 | 13.51 | 14.42 | 14.44 | 15.40 | 15.28 | 16.54 | 16.95 |
| *DK* (%) | .36 | 1.65 | .36 | 2.08 | .38 | 1.93 | .37 | 2.09 | .52 | 1.61 |
| *TW* (lbs./bu.) | 61.67 | 59.70 | 61.23 | 58.76 | 61.17 | 58.66 | 60.79 | 58.86 | 59.12 | 57.74 |
| *SB* (%) | 1.00 | 1.30 | 1.02 | 1.41 | .89 | 1.50 | 1.10 | 1.42 | 1.41 | 1.54 |
| *FM* (%) | .02 | .09 | .04 | .07 | .03 | .11 | .03 | .17 | .05 | .04 |
| *DAM* (%) | .12 | 1.41 | .30 | 1.52 | .23 | 1.14 | .25 | .69 | .09 | .15 |
| *DEF* (%) | 1.14 | 2.81 | 1.36 | 3.00 | 1.16 | 2.75 | 1.39 | 2.30 | 1.56 | 1.73 |
| *QTY* (000s bu.) | 9 | 5 | 20 | 9 | 18 | 12 | 11 | 7 | 5 | 4 |
| *PRICE* ($/bu.) | 2.77 | 2.75½ | 2.82½ | 2.80 | 3.02 | 3.00 | 3.28 | 3.24½ | 3.32½ | 3.31½ |

See table 1 notes.

Grain quality data were taken from results of an annual wheat quality survey (D'Appolonia et al.; Shelton et al.). Collectively, the samples describe a distribution of HRS quality attributes for a particular crop year. We assign quality attributes to bins of our hypothetical elevator as follows. Individual samples from the regional survey are interpreted as truckloads of grain received. Truckloads are allocated to ten bins, depending on protein and dockage levels. Bins are "filled" according to a scheme that is consistent with observed country elevator practices. Thus, truckloads with protein and dockage within specified ranges are pooled together. Within each pool (i.e., each bin), averages are computed for all quality attributes.[5] The resulting matrix of attributes, displayed in tables 1 and 2, provides the basis for our blending problem.

In addition to quality attributes, tables 1 and 2 list quantities and prices for each bin. The quantities reflect observed distributions (i.e., proportion of grain allocated to individual bins) for individual crop years. Quantities are in thousands of bushels; for simplicity, they are normalized to sum to 100,000. Prices ($/bu.) are based on actual market quotations and include applicable premiums for protein and test weight.[6] These represent (gross) opportunity costs for bushels that are blended under terms of a given contract.

The cleaning cost specification has two principal components: the efficiency of the disk-cylinder equipment and the operating cost per hour. A leading manufacturer provided estimates of throughput rates for different beginning and ending dockage levels. Regressing the proportion of rated capacity (*PRC*) on beginning and ending dockage, we obtained the following equation (*t*-statistics in parentheses):

$$\underset{(21.03)}{PRC = .7449} - \underset{(11.54)}{.1019\,DK} + \underset{(8.88)}{.3882\,EDK} \qquad \text{Adj. } R^2 = .95.$$

Operating costs are estimated at $5.05 per hour. This includes costs of electricity, labor, and replacement parts for the disk-cylinder cleaner. It does not include depreciation or opportunity costs of capital. Extra handling costs (*HC*) are assumed to be zero. Per-bushel costs depend on operating efficiency and, hence, on beginning and ending dockage levels.[7] For base-case simulations, the screenings value is $10 per ton in 1987 and $30 per ton in 1990, average North Dakota values in those years. The transport cost in the base case is $.85 per bushel. This is a weighted-average transport cost from North Dakota to principal markets.

## Simulation Results

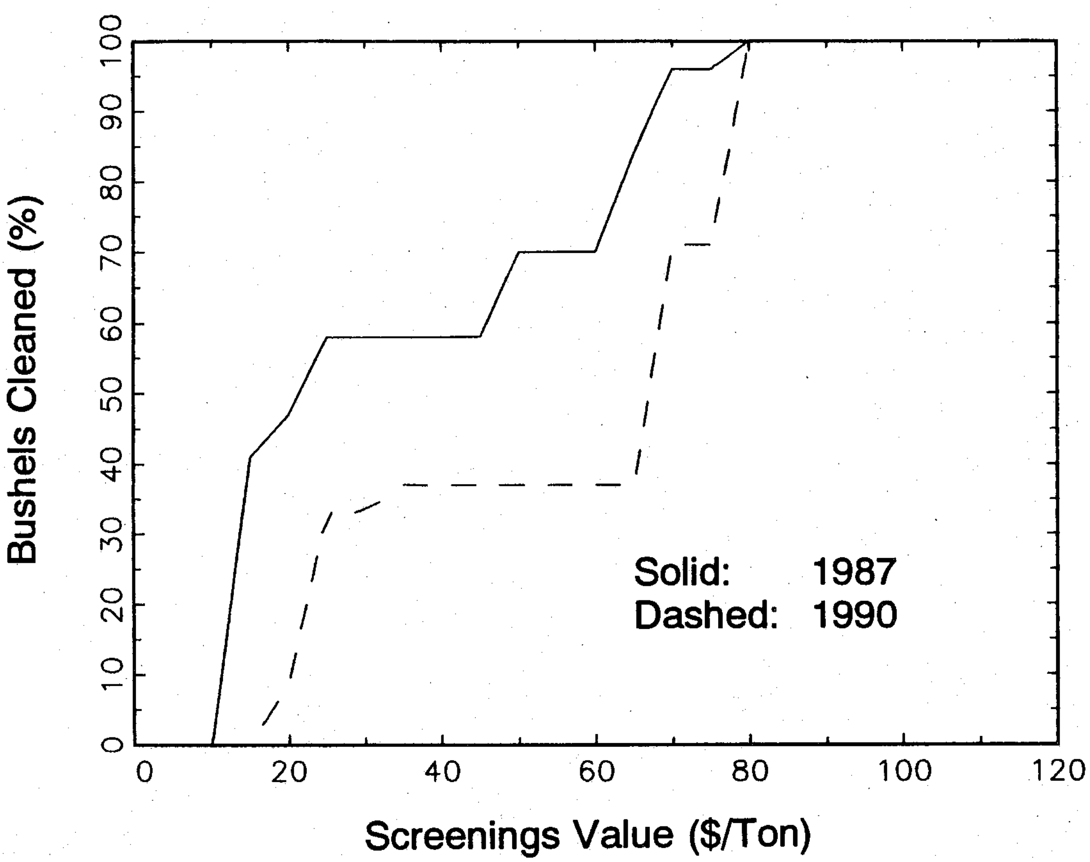
Results of several simulations are reported in this section. First, the model is solved with different values of two key parameters—screenings value and transport cost—to illustrate the sensitivity of model solutions. Second, simulations are performed to evaluate the "minimum discounts" necessary to induce cleaning, given a set of contract specifications. Third, we examine the impact of including dockage as a grade-determining factor.

### *Sensitivity Analysis*

Incentives to clean are directly influenced by the screenings value and by the transport cost. The "supply function" for cleaning provides one way to illustrate the economics of cleaning. However, the supply of screenings may shift from year to year, depending on overall levels of dockage in wheat received by the elevator and other parameters.

Figures 1 and 2 show the elevator's supply of cleaning activity as a percentage of shipments for the two years, using crop quality data from 1987 and 1990. The figures are based on sets of simulations in which the screenings value and the transport cost were varied parametrically. For simplicity, other parameters were adjusted to remove any influence of contract limits on cleaning.

The price of screenings (fig. 1) shows a pronounced impact on cleaning activity for both years. For screenings prices below $15 to $20 per ton, the implicit margin is apparently negative: cleaning does not occur and no screenings are produced. Larger amounts of




Note: Assumes transport cost of $.85/bushel.

**Figure 1. Bushels cleaned as a function of screenings value**

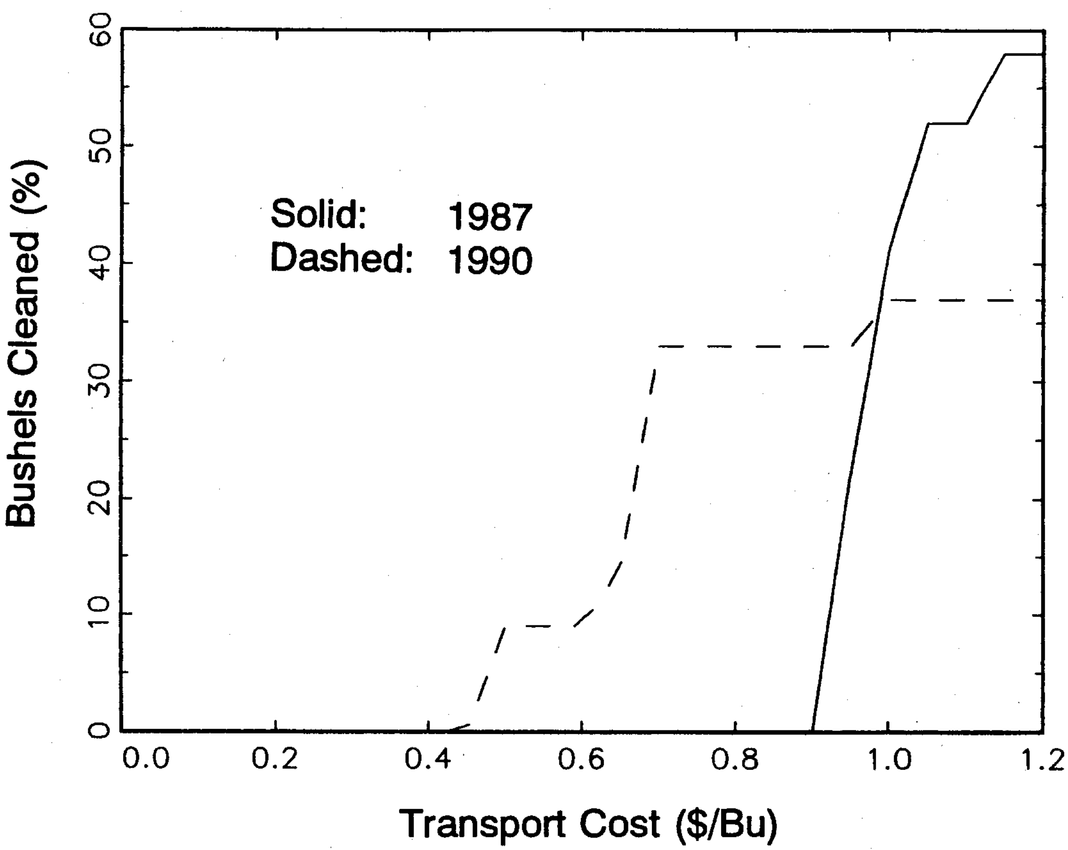
cleaning are associated with each price in 1987, due to higher average dockage levels. Market and quality conditions of 1990 are such that a higher price for screenings is necessary to induce cleaning. That can be attributed to lower beginning dockage levels[8] and higher levels of shrunken and broken kernels (which affect wheat loss).

For perspective, the impact of changes in the price of screenings can be expressed on a per-bushel basis. As the price of screenings increases from $10/ton to $40/ton (holding all other parameters fixed), the elevator's net revenue per bushel of wheat sold increases by 1.5¢ in 1987, and by .6¢ in 1990.

Transport costs also affect the extent of cleaning (fig. 2). Higher costs induce more cleaning because of greater implied savings on freight. Paradoxically, the impact is more pronounced under conditions of 1990, when dockage levels were low. The screenings value was also higher that year—$30 per ton, versus $10 per ton in 1987. Given the low screening values in 1987, transport costs of $.90 per bushel (higher than assumed in the base case) would be necessary to induce cleaning at our hypothetical elevator. This highlights the *combined* importance of two factors—transport costs and the screenings value—for the profitability of cleaning.

*Commercial Discounts*

Another factor that can influence cleaning (and likely will be of increasing importance in the future) are premiums or discounts. Contract terms which include premiums for cleaner wheat or discounts for lots with dockage exceeding a particular level, though not pervasive




Note: Assumes screenings price of $10/ton in 1987 and $30/ton in 1990.

**Figure 2. Bushels cleaned as a function of transport cost**

in current trading practices, may induce more cleaning. Under these circumstances, the seller must analyze whether it is more profitable to accept the discount and avoid cleaning costs or to avoid the discount by cleaning to satisfy the contract limit. The answer depends on the magnitude of the discount, the maximum dockage limit, levels of dockage in the elevator's bins, and possibilities for blending.

Simulations were performed to provide insight into the effects of discounts. The goal was to determine, for a given set of contract terms, the "minimum discount" necessary to induce cleaning. To that end, a set of terms was specified (table 3) with a price sufficiently high to induce a large sale of blended wheat.[9] For experimental purposes, various maximum dockage limits were specified.

Calculating a "minimum discount" proceeds in two steps. First, the model is solved with a maximum contract limit for dockage. This yields a profit level for the elevator. Second, the dockage limit is relaxed, and the contract price is lowered (by quarter-cent increments) until the same profit level is attained. The difference between the original price and the lower price (with relaxed dockage limit) is interpreted as the discount necessary to induce cleaning. If the discount were any smaller, the elevator would maximize profits by not satisfying the contract limit and absorbing the discount.

This procedure was followed for a range of contract limits under both sets of wheat quality conditions (i.e., 1987 and 1990). Results are shown in figure 3. For both years, the lower the dockage limit, the greater the discount necessary to induce cleaning. Discounts are larger under quality conditions of 1987, due to higher average levels of dockage and low screening values. Under 1990 quality conditions, discounts are required only to

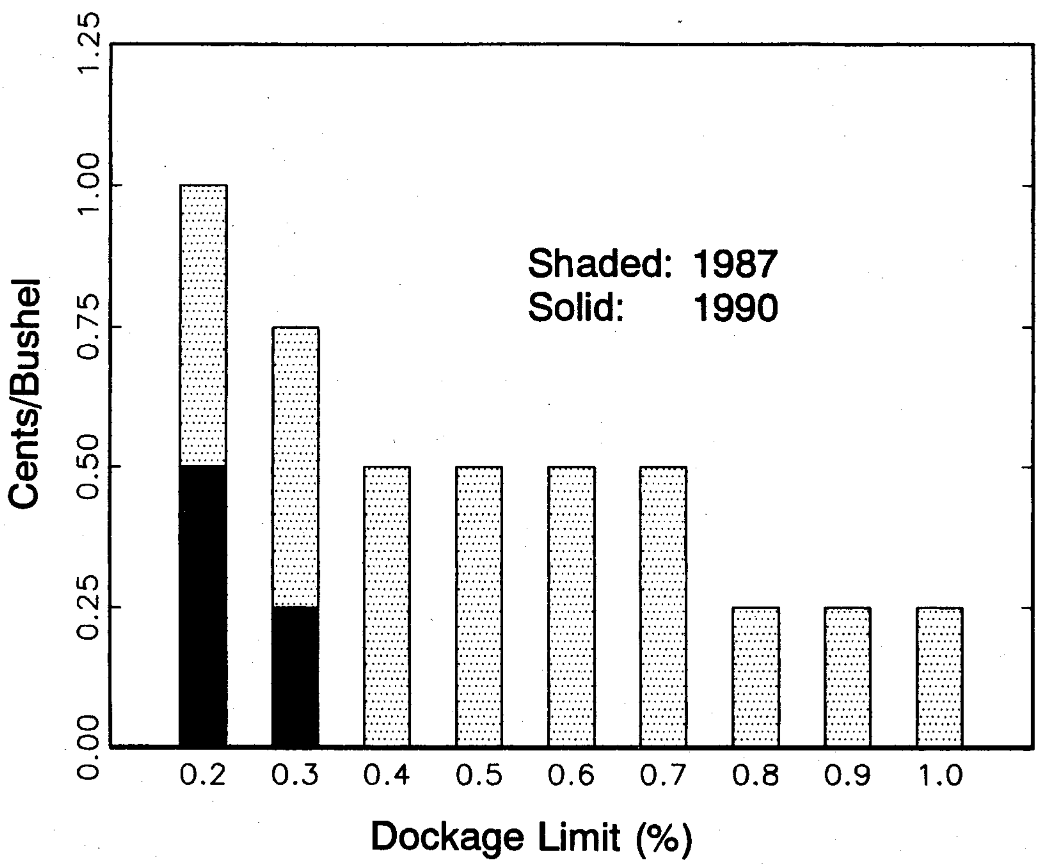



**Figure 3. Minimum discounts necessary to induce cleaning**

induce cleaning below .4% dockage. Some cleaning was profitable under base-case assumptions for 1990, even in the absence of discounts.

*Change in Grade Standards*

A proposal has been made that dockage be incorporated in the official grade standards for wheat. In particular, a maximum limit of .5% dockage would be specified for grades #1–3, and a maximum limit of 2.5% dockage would be specified for grades #4–5. Proponents argue that, since foreign buyers typically specify grade #2 or better, the effect would be to lower average levels of dockage in U.S. wheat exports, thereby improving competitiveness.

The elevator model can be used to demonstrate how a change in grade standards could affect a merchandising firm. Simulations were conducted in which grain sales were confined to two possible blends—the first identified with grade #3 contract limits and the second with grade #4 contract limits. This highlights the significance of the breakpoint in proposed grade limits for dockage (i.e., between grades #3 and #4). Based on our assumptions about grain quality (tables 1 and 2), all of the elevator's wheat would meet or surpass the *current* grade #3 limits (before inclusion of dockage).

Our purpose is to estimate the cost to the elevator of including dockage as an additional grade factor, assuming the elevator blends (and cleans) simply to meet grade limits. Accordingly, simulations were conducted both with and without the indicated dockage limits. With grade #3 selling at a premium relative to grade #4, the elevator would sell all wheat (in either crop year) as grade #3 (or better) under current grade standards. With

**Table 3. Assumed Contract Terms for Evaluation of Discounts**

| | |
|---|---|
| Minimum Protein: | 14% |
| Minimum Test Weight: | 59 lbs. |
| Maximum Dockage: | * |
| Maximum Damage: | 1% |
| Maximum Defects: | 3% |
| Contract Price | |
| 1987: | $3.50/bu. |
| 1990: | $3.05/bu. |

* Maximum dockage varied between .2% and 1%.

the introduction of grade limits for dockage, the elevator is induced to "upgrade" some of its wheat through cleaning—provided that a higher price for grade #3 more than offsets cleaning costs.

Price relationships are a crucial aspect of this problem. For illustrative purposes, simulations were conducted with different assumptions about the price difference between grades #3 and #4. Results are displayed in table 4. The proposed change in grade standards would affect the extent of cleaning activity in 1987. Under existing grade standards and base-case assumptions, the elevator had no incentive to clean in that year. Introducing a dockage limit induces cleaning. Under new grade standards, the extent of cleaning in 1987 depends on the size of the price premium for grade #3: a larger premium induces more cleaning.

In contrast, the change in grade standards does not affect cleaning in 1990. Under base-case assumptions, the elevator had other incentives to undertake cleaning activities in that year and could satisfy the new grade standard for dockage without additional expense. In principle, the net impact of a change in standards would depend on what happens to price relationships, including market discounts for dockage and other grade factors. Although prices could be altered by a change in standards, these effects are difficult to predict.

## Summary and Implications

Dockage in wheat is a non-grade-determining factor in the U.S. marketing system. In individual transactions, dockage is a contract term that is subject to negotiation between buyers and sellers. Other countries include the equivalent of dockage as a grade-determining factor with stringent limits. The configuration of grade limits (in conjunction with inter-grade price differentials) provides incentives to clean in these countries. Similar proposals have been made in the United States. Specifically, the 1990 Farm Bill enables

**Table 4. Impact of Including Dockage as Grade Factor Limit**

| Price Difference | Current Grade Standards | | Proposed Grade Standards | |
|---|---|---|---|---|
| Grade #3 Price Minus Grade #4 Price | % Cleaned | % Sold as Grade #3 or Better | % Cleaned | % Sold as Grade #3 or Better |
| | 1987 Crop Quality | | | |
| 2¢ | 0 | 100 | 38 | 81 |
| 4¢ | 0 | 100 | 52 | 100 |
| | 1990 Crop Quality | | | |
| 2¢ | 28 | 100 | 28 | 100 |
| 4¢ | 28 | 100 | 28 | 100 |

the Federal Grain Inspection Service (FGIS) to establish or amend grade standards with an objective of matching levels of "cleanliness" offered by competing countries.

This study develops a mathematical programming model to analyze cleaning decisions at country elevators. The analysis incorporates a detailed model of cleaning costs and places cleaning activities within the broader framework of a blending and merchandising problem. By incorporating alternatives to cleaning, i.e., blending from different bins and shipping wheat without cleaning, the model provides a realistic basis for assessing the impact of selected variables and for evaluating how alternative regulations would affect the economics of cleaning.

Model parameters were chosen to represent a typical country elevator in North Dakota and to demonstrate sensitivity of cleaning decisions to factors that vary through time. Of particular importance are the level and distribution of dockage and other quality characteristics in the crop and the screenings value. The year 1987 was characterized by a crop with greater dockage and lower screening values than was 1990.

The screenings value and the transport cost have an important influence on incentives to clean, and thus on the proportion of wheat that is cleaned before shipment. For each of our representative years, screening values greater than $20 to $25 per ton induced cleaning. Savings on transportation costs provide an additional incentive, particularly when high freight costs are combined with high screening values. Under our base-case assumptions for 1987, cleaning was profitable only for longer hauls, i.e., with transport costs in excess of $.90 per bushel. In 1990, transport costs of approximately $.50 per bushel were sufficient to induce cleaning.

The level of discount (premium) necessary to induce additional cleaning before shipment was shown to vary from year to year. For 1987, a minimum discount of .5¢ per bushel was necessary to induce cleaning down to .5% dockage. No such discounts were necessary in 1990 because of other incentives favorable to cleaning.

Cleaning wheat is a routine part of elevator operations in some parts of the United States, particularly in the spring wheat growing regions. Cleaning is purely a commercial decision at present, not affected by nonmarket regulations. Margins associated with cleaning reflect the cumulative impact of a number of variables, including the amount of inbound dockage, the screenings value, and transport costs. In addition, cleaning decisions may be influenced by contract terms such as premiums for cleaner wheat or discounts for lots with dockage exceeding a particular level. Though not pervasive in current trading practices, discounts for excess dockage can induce cleaning to satisfy the demands of individual buyers.

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## Notes

[1] The Federal Grain Inspection Service (FGIS) defines dockage as "all matter other than wheat that can be removed from the original sample by use of an approved device according to procedures prescribed in FGIS instructions. Also, underdeveloped, shriveled, and small pieces of wheat kernels removed in properly separating the material other than wheat and that cannot be recovered by properly rescreening or recleaning" (U.S. Department of Agriculture, p. L-3).

[2] For example, screenings depend on the product of endogenous variables—bushels cleaned and ending dockage level. Hours of cleaning (and hence, cleaning costs) depend on the ratio of bushels cleaned to operating efficiency, another endogenous variable.

[3] Between 1984 and 1990, average dockage levels for HRS wheat ranged from .9% to 2.7% at North Dakota elevators. Average screening values ranged from $10 to $43/ton during the same period (Scherping et al.).

[4] Undoubtedly, the price of screenings is influenced by the market supply of screenings. However, for purposes of modeling an individual decision maker in a competitive industry, it is appropriate to treat this price as exogenous.

[5] This mimics the "blending" of incoming grain through binning decisions. However, these decisions are not formally part of our analytical model.

[6] Based on Minneapolis spot prices with relevant premiums and discounts, as quoted in *The Fargo* [North Dakota] *Forum* (17 September 1987 and 14 September 1990). Protein premiums account for most of the price variation in tables 2 and 3; the largest adjustment for test weight is 3.5¢/bushel.

[7] For the range of dockage levels shown in tables 2 and 3, cleaning costs (exclusive of wheat loss) would vary between .6¢ and 1.2¢/bushel.

[8] With lower beginning dockage, a larger volume of grain is cleaned in order to generate a given quantity of screenings.

[9] Only one "blend" contract was necessary for purposes of simulations reported in this section. The assumed contract terms (specified in table 3) induce different sale volumes in 1987 and 1990, owing to different price relationships and quality distributions. Sales under terms of the blend contract represent 69% of total sales in 1987, and 80% of total sales in 1990.

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