AN ENGINEERING ECONOMIC MODEL OF CORN CLEANING

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ABSTRACT. *An engineering economic model showed that corn cleaning can produce net benefits of $.01 to $.03 cents per bushel, provided that corn with an initial broken corn foreign material (BCFM) content of 3% or greater is stored for at least three months. The model, which included five operational costs and nine potential benefits, gave results in close agreement with USDA survey data. Capture of benefits requires considerable operator skill, and elevators with larger volumes relative to cleaner cost can benefit more readily. Net benefits are independent of changes in corn grade standards or trade discount factors. Although the exact cost-benefit calculations are individually case-sensitive, the separation of BCFM into two factors will not greatly increase the incentives to clean for any reasonable set of cost inputs.*
Keywords. Broken corn foreign material.

A n assumption of the several proposals and legislative actions concerning corn standards is that the proposals encourage cleaner, sounder corn. Cleaner corn can be created by cleaning more often or by causing the corn to be less breakage-prone.

This assumption can be evaluated with available data on corn handling/storage costs and on corn screening properties. The principal issues are (1) costs and benefits of corn cleaning and (2) likelihood that the marketplace will offer incentives for quality improvement. The analysis should include on-farm and country elevator operations because it is well documented that first handlers of corn have control over future quality. Presumably, incentives encouraged by new standards would cause handlers to act differently and to capture new economic gains.

Broken corn and foreign material (BCFM) is described by the U.S. Grade Standards as material that will pass through a 12/64-in. (4.8-mm) round-hole screen or that can be picked by hand from the material remaining on the screen (FGIS, 1990). Broken corn and foreign material is divided into broken corn (BC) and foreign material (FM). Broken corn is the material that will pass through a 12/64-in. round-hole screen, but will not pass through a 6/64-in. (2.4 mm) round-hole screen. The remaining portion of BCFM that will pass through a 6/64-in. round-hole screen is FM. Foreign material also includes the large hand-picked material sometimes called coarse foreign

material (CFM). Broken corn foreign material (combined) is a grade-determining factor in corn.

Consisting mainly of broken kernels, BC also can contain small amounts of weed seed, cob, and other nongrain material (Bern and Hurburgh, 1992). The material classified as FM is primarily small broken corn kernel pieces, weed seed, and dust generated during corn handling (Bern and Hurburgh, 1992). The scalped material (CFM) also is classified as foreign material and consists mostly of cob pieces and large weed seeds. Scalped CFM is generally less than 0.2 to 0.3% by weight, regardless of BC or FM percentages. Bern and Hurburgh (1992) reviewed BCFM problems and effects.

Broken corn foreign material is generated throughout the corn handling chain. Poor weed control and harvesting are the major sources of noncorn material. But there are several sources for the generation of BC and stress cracks. Increased numbers of stress cracks in a kernel of corn will increase future potential to break (breakage susceptibility). Genetic differences and harvesting methods will influence breakage potential. Fast cylinder speeds and tight concave settings increase both breakage and breakage susceptibility, as will increased harvest moisture. Finally, increased drying stress (faster moisture removal) will dramatically increase breakage susceptibility. Summaries of breakage susceptibility data have been published by Hurburgh (1991) and Eckhoff (1989).

The primary reason for screening corn is to prevent the BCFM level from exceeding the limit of the desired grade. Most corn at interior country elevators is traded as grade no. 2 corn. Corn delivered to country elevators rarely exceeds the 3% BCFM limit of grade no. 2 corn (Hurburgh, 1992). With the increased handling at the elevator, corn BCFM levels will increase to approach the 3% limit. In FGIS interior inspections from 1988 to 1990, 32% of truck and hopper car interior lots graded no. 3 or worse because of BCFM (Meinders and Hurburgh, 1992a). These lots were shipped from country elevators to other handlers or to users.

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OBJECTIVE

The objective of this analysis was to estimate the costs and the benefits of corn cleaning on farms and at country elevators.

PROCEDURES

An engineering economic model was developed to estimate annualized costs and benefits from cleaning, on a per bushel of corn basis. The cost and benefit sources are:

Costs
1. Purchase and operation of cleaner.
2. Loss in weight of corn.
3. Handling and storage of screenings.
4. Transportation of screenings.
5. Additional testing at elevators.

Benefits
1. Screenings revenue.
2. Reduced freight expense for corn.
3. Reduced physical shrinkage.
4. Reduced mold, insect shrinkage.
5. Reduced corn handling costs (less turning).
6. Discounts avoided on outbound grain.
7. Aeration cost savings.
8. Reduced moisture shrinkage.
9. Reduced procurement costs based on testing for new or additional particle-size factors.

This list is more comprehensive and flexible than that used by Johnson et al. (1992) to model wheat cleaning costs in North Dakota. However, the general approach is similar to both the North Dakota State and Oklahoma State (Adam and Anderson, 1992) wheat cleaning studies.

For each cost and benefit source, a generalized mathematical equation was developed. Assumptions were made to apply the formulae to four example situations: gravity and rotary cleaning on farm and gravity and shaker cleaning at elevators. The sensitivity of each cost and benefit source to changes in key assumptions and/or variables was assessed. Cost estimates were compared with elevator operator responses to a USDA-sponsored survey (ERS, 1991).

Costs and benefits for the four case studies were aggregated in income statements for cleaning. Changes in profit and loss were evaluated, relative to the possible standards changes listed by Hill and Bender (1992).

MATHEMATICAL MODEL OF GRAIN CLEANING

Table 1 summarizes model variables, notations, and typical values for a country elevator. Any intermediate variables undefined in table 1 are defined below each equation. Physical relationships (e.g., airflow resistance of grain mixed with fines) were incorporated as needed.

Costs

1. Purchase and Operation of the Cleaner (C_1, $/bu). This cost is calculated from engineering-economic analysis of cleaner operations. Capital costs are based on compound-interest amortization of initial cost (installed). Tax savings for cash expenses are included.

Table 1. Information for calculating cleaning costs and benefits (example values for a country elevator, gravity feed cleaner)

Item	Variable	Example Value Units
Input variables		
Cleaner cost, installed	P	$40,000
Tax credit	t_c	0.0%
Interest rate	i	10.0%
Useful life	n_l	10 yrs
Repair percentage (of P)	P_r	10%
Insurance premium	P_i	$10 00/$1000.00
Depreciation allowance per year	P_D	10% of P
Annual interest payment	I	$0 00
Annual incremental labor	L	$2,000/yr
Per hour energy cost	e	$0.00
Cleaner throughput	T	10,000 bu/h
Bushels cleaned per year	V	1,000,000 bu/yr
Income tax rate	t_i	30 0%
Property tax rate	t_p	$20.00/$1000 00
Cleaning efficiency (all sizes 16 and below, fraction of E_B)	C_t	0.40
Cleaning efficiency for BCFM, percent	E_B	50%
Percent BCFM	B	3.0%
Months screenings are stored	n_s	3 0 mo
Value of storage	V_s	$0 02/mo
Cost of elevation	C_h	$0.005/bu
Transportation-corn	R_c	$0.20/bu
Test weight-corn	T_c	56 0 lb/bu
Test weight-screenings	T_s	40 0 lb/bu
Percent of screenings shipped	P_t	75 0%
Screenings value, percent of corn price	f	70%
Cost of new tests	C_5	$0 000/bu
BCFM allowed without discount	B_{max}	3.0%
Discount rate, percent of price per point	d_6	1 0%/%BCFM over 3.0%
BCFM increases after cleaning	ΔB	0.5% BCFM
Number of months corn is stored	n	6 mo
Aeration management factor	$f_2 = f_2'$	1.3
Cost of electricity	P_e	$0.07/kwh
Fan output elasticity	$\varepsilon_{Q,P}$	0 8
Airflow per watt-cleaned, cleaned calculated	Q_w, Q_w'	0 8 cfm/w,
Number of fall, spring months of storage	n_s, n_f	3, 3 mo
Discount rate for new factor(s)	d_9	$0.00/bu
Average value of new factor	Q	0.00
Limit for new factor	Q_{max}	0.00
Corn price	P_c	$2.50/bu
Intermediate calculation variable		Units
Cleanings removed per bushel	W_c	lb/bu
Total cleaning efficiency, all sizes	E_t	%
Screen opening diameter	s_i	64th-in.
Cost of screenings transportation	R_s	$/bu
Time of aeration fan operation	t, t'	h
Airflow per bushel	Q_b, Q_b'	cfm/bu
Airflow distribution multiplier	f_1, F_1'	-
Generalized Shedd curve multiplier	k_j	-
Pressure drop from Shedd equation	(ΔP)	in of water
Shedd curve multiplier for fines	k_f	-
Airflow resistance multiplier for increment of 2/64-in	k_i	-
Removal efficiency for size i particles	E_i	%

The general formula for calculation of C_1 is:

$$C_1 = \left[(P - t_c)\left(\frac{a}{p}\right)_n^i + \frac{P_r P \left(1 - \frac{t_i}{100}\right)}{100} + \frac{P_i P \left(1 - \frac{t_i}{100}\right)}{1000} \right.$$

$$+ \frac{t_p P \left(1 - \frac{t_i}{100}\right)}{1000} - \frac{It_i}{100} - \frac{P_D P t_i}{100} + L \left(1 - \frac{t_i}{100}\right)$$

$$+ \frac{ev}{T}\left(1 - \frac{t_i}{100}\right)\Bigg]\Bigg] \frac{1}{V} \qquad (1)$$

Equation 1 can be split into fixed and variable components to allow for analysis of the operation of existing cleaners versus the installation of new cleaners.

$$C_{1a} = \Bigg[(P - t_c)\left(\frac{a}{p}\right)^i_n + P\left(1 - \frac{t_i}{100}\right)\left(\frac{P_r}{100} + \frac{P_l}{1000} + \frac{t_p}{1000}\right)$$

$$- \left(\frac{t_i}{100}\right)(I + P_D P)\Bigg] \frac{1}{V} \qquad (1a)$$

where

C_{1a} = fixed cost of cleaner operation ($/bu), and

$$C_{1b} = \left(1 - \frac{t_i}{100}\right)\left(L + \frac{eV}{T}\right)\frac{1}{V} \qquad (1b)$$

2. Loss in Weight of Cleanings (C_2, $/bu). The cleanings represent weight that could have been delivered as grain. Discounts avoided (if any) and feed value of cleanings are counted as benefits in the next section.

$$C_2 = \frac{W_c P_c}{56} \qquad (2)$$

From Meinders and Hurburgh (1992b),

$$W_c = \frac{(E_t)(P_{i,16})(56)}{(100)(100)} \qquad (3)$$

where

$P_{i,16}$ = percentage of corn passing through a 16/64-in. screen

$$E_t = C_t E_B \qquad (4)$$

Meinders and Hurburgh (1992b) estimated E_B and C_t for gravity and shaker cleaners to be 50% and 0.40, respectively. Hurburgh et al. (1989) observed that E_B = 43% and that C_t = 0.075 for rotary cleaners.

From Meinders and Hurburgh (1992a):

$$P_{i,16} = 0.01Be^{0.2625s_i + 1.455} = 2.857B \text{ (if } s_i = 16) \quad (5)$$

3. Storage and Handling of Screenings (C_3, $/bu). The removal of screenings creates storage and handling expense. Hill et al. (1991c) found that screenings were stored for an average of three months. The generally accepted cost for elevating a product into and out of storage is $0.005/bushel. Storage and handling cost is calculated as:

$$C_3 = \left(\frac{n V_s T_c}{12 T_s} + C_h\right)\frac{W_c}{56} \qquad (6)$$

4. Transportation of Screenings (C_4, $/bu). The cost of transportation for corn screenings is calculated based on the transportation cost of corn with adjustments to compensate for less-dense screenings:

$$R_s = \frac{T_c R_c}{T_s} \qquad (7)$$

This assumes that a volume of screenings can be transported at the same rate as the same volume of corn. Screenings are bulkier than grain and therefore are unlikely to fill trucks or rail cars. The cost of transportation may not apply for all elevators if the elevator has its own feed use for screenings. Normally, farmers feed the screenings that they generate, which would make this cost zero. Hill et al (1991c) found that about 65% of screenings removed at interior commercial elevators were processed on-site into mixed feeds (R_s = O, in this case).

$$C_4 = \frac{0.01 W_c R_s P_t}{56} \qquad (8)$$

5. Cost of Increased Testing (C_5, $/bu). If, in the process of changing to cleaning, an elevator finds that it must test grain for one or more heretofore unmeasured characteristics, then the cost of new testing is assessed against the cleaning. This also applies to changes in grades forcing more testing and to tests (such as breakage susceptibility) designed to reduce the amount of screenings in corn. This cost does not apply to on-farm cleaning.

Testing costs can be modeled with a complete economic analysis as in equation 1 or as an estimated constant. The latter approach is used here for simplicity. For a particle size test, $0.002 per bushel will cover the labor and equipment cost (C_5 = $0.002).

BENEFITS

1. Screenings Revenue (B_1, $/bu). Screenings usually are priced relative to the price of corn. Hill et al. (1991c) found screenings to be priced between 60 and 80% of corn value, depending upon the season. Therefore,

$$B_1 = \frac{0.01 W_c P_c f}{(56)} \qquad (9)$$

2. Reduced Freight Expense for Corn (B_2, $/bu). More corn and less screenings are hauled when cleaned corn is shipped.

$$B_2 = \frac{W_c R_c}{56} \qquad (10)$$

3. Reduced Physical Shrinkage (B_3, $/bu). Cleaning removes fine material, including dust, some of which

ordinarily would be lost during handling. Bern and Hurburgh (1992) and Converse and Eckhoff (1989) reported an average of 0.1 to 0.2% dust loss in dry-corn handling, regardless of initial BCFM level. This is consistent with the opinions of handlers. Therefore, retention of this material as screenings saves:

$$B_3 = 0.002 \, P_c \, f \qquad (11)$$

This benefit would be zero if the handler was operating a pneumatic dust collection system, with the dust put with the screenings, or if the handler was applying mineral oil.

4. Reduced Mold and Insect Shrinkage (B_4, \$/bu). On average, U.S. corn deteriorates from about 2.0% total damage (DKT) at harvest to about 5.0% at export. A 3% damage increase is accompanied by about 0.5% weight loss in dry matter (Saul and Steele, 1969). Fines harbor mold and decrease aeration. This deterioration (which occurs primarily in storage on farms and country elevators) could be halved by cleaning, thus leaving more saleable weight in bins. This benefit probably would be less for clean corn than for high BCFM corn. A linear relation is estimated:

$$B_4 = 0.0025 \, P_c \, (0.33B)$$

$$= 0.00083 \, BP_c \qquad (12)$$

This benefit is not likely to be realized for storage times briefer than four months.

5. Reduced Handling Costs (B_5, \$/bu). Grain often is turned to maintain condition. Handlers estimate turning costs at about \$0.005 per bushel, including shrinkage losses. This analysis assumes that cleaned corn will require one fewer turning, if it initially contained 3.0% BCFM or more, and if storage of three months or longer is involved.

$$B_5 = C_h; \; B < 3.0\%, \; n_s + n_f \geq 3 \qquad (13)$$

6. Discounts Avoided (B_6, \$/bu). If the corn exceeds the allowable BCFM level, cleaning will avoid discount. This is the most common reason for cleaning (Hill et al., 1991a, d).

$$B_6 = \left(B + \Delta B - B_{max}\right)\frac{d_6 \, P_c}{100} \qquad (14)$$

This benefit will apply only if $B > B_{max}$. Otherwise, there is no gain from reduced discounts.

7. Reduced Aeration Costs (B_7, \$/bu).

Clean corn has relatively low airflow resistance (Grama et al., 1984), which means that fans will deliver more airflow at greater energy efficiency. Increased airflow reduces the operating time needed for temperature-change cycles.

Clean corn also has less spoutline concentration of fines. Spoutlines divert air and cause excessive aeration of the outer grain, to cool the center. Hall (1985) estimated the concentration of BCFM in spoutlines to be 10 times the average level in the bin.

The aeration benefits are modeled as the difference in energy costs for aeration of cleaned versus uncleaned corn.

This is a function of fan airflow output, fan input power, and operating time.

$$B_7 = \frac{t \, Q_b \, P_e}{1000 \, Q_w} - \frac{t' \, Q'_b \, P_e}{1000 \, Q'_w} \qquad (15)$$

The simplest case of equation 15 would be for aeration only (periodic cool-down and warm-up cycles). In this case, the time required for a temperature change cycle varies in direct proportion to airflow ($t Q_b$ = constant). Because cleaning reduces airflow resistance (Grama et al., 1984), Q_b will increase, but so will Q_w. Fans are more efficient at lower static pressures (MWPS, 1980). The average time for a temperature change cycle is 200 h at 0.1 cfm/bu (MWPS, 1980). Cycle time changes in inverse proportion to airflow. Therefore, $t Q_b$ = 20 for each cycle.

$$B_7 = \frac{20n \, f_1 f_2 P_e}{1000 \, Q_w} - \frac{20n \, f'_1 f'_2 P_e}{1000 \, Q'_w} \qquad (16)$$

where

n   = number of temperature change cycles (cooling and warming) = number of months stored

f_1, f_1' = multiplier to account for uneven airflow distribution, before and after cleaning

f_2, f_2' = multiplier to account for imprecision in operator ability, extra operation, before, and after cleaning

The f_1 multiplier was included because concentrations of fines on spoutlines will cause fans to be operated longer than necessary to control temperatures in the center. The f_2 multiplier accounts for the inevitable failure of operators to stop fans precisely when cooling is complete, plus the need for occasional hot-spot aeration independent of cooling cycles. If we assume one cooling and/or warmup cycle per month stored, then $n = n_c$ = number of months corn is stored.

The critical variables are Q_b and Q_w. Q_b is determined from both the intersection of the fan performance curve [Q versus static pressure (ΔP)] and the airflow resistance characteristic of the bin. The former is manufacturer supplied; the latter is estimated from the Shedd equation (Shedd, 1953; ASAE, 1990) with multipliers (Bern et al., 1982; Grama et al. 1984).

$$\Delta P = \Sigma \, k_j \, (\Delta P)_s \qquad (17)$$

An exact solution will require an analysis of each situation, where the fan performance equation is set equal to equation 17. The fines multiplier, say k_f, is one of the k_j's in the multiplier equation. Values of k_f can be calculated from equation 18 (Bern and Hurburgh, 1992):

$$k_f = 0.030p_{16} + 0.057p_{14} + 0.102p_{12} + 0.256p_{10}$$

$$+ \, 0.631p_8 + 1.344p_6 + 0.648p_4 + 1.0 \qquad (18)$$

where

p_{16} = percentage of material between 14 to 16/64 in. (size 1)

p_{14} = percentage between 12 to 14/64 in. (size 2)

p_{12} = percentage between 10 to 12/64 in. (size 3)
p_{10} = percentage between 8 to 10/64 in. (size 4)
p_8 = percentage between 6 to 8/64 in. (size 5)
p_6 = percentage between 4 to 6/64 in. (size 6)
p_4 = percentage between 0 to 4/64 in. (size 7)

Equation 18 can be modified using the Bern and Hurburgh (1992) and Meinders and Hurburgh (1992a) particle-size distribution equation:

$$k_f = \left[\sum_{i=4}^{16} k_i B \left(e^{0.2625 s_i + 1.455} - e^{0.2625 s_{i-1} + 1.455} \right) \right] + 1.0 \quad (19)$$

and for cleaned corn,

$$k'_f = \left[\sum_{i=1}^{7} k_i \left(1.0 - \frac{E_i}{100} \right) \right.$$
$$\left. \times B \left(e^{0.2625 s_i + 1.455} - e^{0.2625 s_{i-1} + 1.455} \right) \right] + 1.0 \quad (20)$$

An estimate for the E_i's was derived by Meinders and Hurburgh (1992b). The relative decrease in static pressure after cleaning is:

$$\frac{(\Delta P')100}{(\Delta P)} = \frac{k'_f (100)}{k_f} \quad (21)$$

If an estimate of the change in Q with respect to a change in ΔP is available, then solution of equations 19, 20, and 21 provides an estimate of the airflow gain from cleaning. Fans differ in their sensitivity to pressure changes. One data source estimates an 0.8% increase in airflow per 1% decrease in pressure (MWPS, 1980). Let $\varepsilon_{Q,P}$ represent the elasticity of fan output relative to pressure, and then:

$$Q'_b = Q_b \left[1.0 + \left(1.0 - \frac{k'_f}{k_f} \right) \varepsilon_{QP} \right] \quad (22)$$

The same data clearly indicate that Q_w is an increasing function of Q_b. The current draw of a fan motor is approximately constant, regardless of output:

$$Q'_w = \frac{Q'_b Q_w}{Q_b} \quad (23)$$

A substitution of equations 22 and 23 into equation 16 yields:

$$B_7 = \frac{0.02 n P_e}{Q_w} \left[f_1 f_2 - \frac{f'_1 f'_2}{1.0 + \varepsilon_{QP} \left(1.0 - \frac{k'_f}{k_f} \right)} \right] \quad (24)$$

The distribution and management factors (f_1 and f_2, respectively) are important. Grain handlers' experiences support the theoretical conclusion that much extra aeration is needed if fines build up in the center of bins. As an example, if f_1 = 4 and if f_2' = 2, then the aeration savings for cleaning are doubled.

The factors f_1 and f_2 probably are functions of BCFM percentage. The Hall (1985) data suggest that f_1 = 4 if BCFM = 4%. Therefore, a linear relation is estimated for f_1, f_1' as a function of BCFM; in short, the BCFM percentage is substituted for f_1, f_1'. The constraint that the time for one cycle [(20 $f_1 f_2)/Q_b$ or (20 $f'_1 f'_2 k'_f)/(k_f Q'_b)$] cannot exceed 720 h (one month continuous running) should be placed on equation 16. If the constraint is reached, then the maximum cost (before or after cleaning) is (720 $Q_b P_e)/(1000 Q_w)$.

8. Moisture Shrinkage (B_8, $/bu). For average north-central U.S. weather conditions, Hurburgh (1987) reported that the moisture loss from evaporation (in percent of corn weight) is:

$$M_t = 0.0050 \, Q_b \, t/56 \text{ in the fall, and} \quad (25)$$

$$M_t = 0.0075 \, Q_b \, t/56 \text{ in the spring} \quad (26)$$

This loss will continue down to 12 to 13%, the approximate equilibrium moisture content for summer storage. Because, for each cycle, $Q_b t$ = 20:

$$M_{if} = \frac{0.1 \, n_f \, C_1 \, C_2}{56} \text{ and} \quad (27)$$

$$M_{is} = \frac{0.15 \, n_s \, C_1 \, C_2}{56} \quad (28)$$

Thus:

$$B_8 = 0.1 \, n_f C_1 C_2 P_c + 0.15 \, n_s C_1 C_2 P_c - 0.1 \, n_f C_1 C_2 P_c$$
$$- 0.15 \, n_s C_1 C_2 P_c \quad (29)$$

with constraints

$$M_{if} + M_{is} \le 1.70$$

and

$$M'_{if} + M_{is} \le 1.70$$

which prohibit drying below 12% moisture (from 15% moisture). Equation 29 is rearranged, with the addition of factor f_b, to account for the percentage of overdry corn blended back with stored wet corn:

$$B_8 = \frac{P_c}{56} \left[0.1 \, n_f \left(C_1 C_2 - C'_1 C'_2 \right) \right.$$
$$\left. + 0.15 \, n_s \left(C_1 C_2 - C'_1 C'_2 \right) \right] \left(1.0 - \frac{f_b}{100} \right) \quad (30)$$

9. Additional Discounts Charged (B_9, $/bu). To the extent that additional testing for particle size factors, in response to standards or practice changes, (C_5) generates

Table 2. Cost/benefit model variables, cleaning case studies

Item	Farm Rotary Cleaner	Farm Gravity Cleaner	Elevator Gravity Cleaner	Elevator Shaker Cleaner
Cleaner cost, installed	$5,280	$3,700	$40,000	$60,000
Tax credit	0%	0%	0%	0%
Interest rate	10.0%	10.0%	10.0%	10.0%
Useful life	10 years	10 years	10 years	10 years
Repair percentage	5%	5%	1%	5%
Insurance premium	$10/$1,000	$10/$1,000	$10/$1,000	$10/$1,000
Depreciation allowance	10%	10%	10%	10%
Annual interest payment	$0.00	$0.00	$0.00	$0.00
Annual incremental labor	$0.00	$0.00	$2,000	$4,000
Per hour energy cost	$0.26	$0.00	$0.00	$1.30
Throughput	2,500 bu/h	3,000 bu/h	10,000 bu/h	10,000 bu/h
Bushels cleaned per year	50,000 bu	50,000 bu	10^6 bu	10^6 bu
Income tax rate	30%	30%	30%	30%
Property tax rate	$20/$1,000	$20/$1,000	$20/$1,000	$20/$1,000
Cleaning efficiency (all sizes 16 and below, fraction of E_B)	0.75	0.40	0.40	0.40
Cleaning efficiency for BCFM, percent	43	50	50	75
Percent BCFM	1.5%	1.5%	3.0%	3.0%
Months screenings are stored	1.0	1.0	3 mo	3 mo
Value of storage	$0.02/bu/mo	$0.02/bu/mo	$0.02/bu/mo	$0.02/bu/mo
Cost of elevation	$0.005	$0.005	$0.005/bu	$0.005/bu
Transportation-corn	$0.05/bu	$0.05/bu	$0.20/bu	$0.20/bu
Test weight-corn	56 lb/bu	56 lb/bu	56 lb/bu	56 lb/bu
Test weight-screenings	40 lb/bu	40 lb/bu	40 lb/bu	40 lb/bu
Percent of screenings shipped	0	0	75%	75%
Screenings value, fraction of corn price	0.80	0.80	0.70	0.70
Cost of new test	$0.00	$0.00	$0.00	$0.00
BCFM allowed without discount	3.0%	3.0%	3.0%	3.0%
Discount rate, percent of price per point	1.0%	1.0%	1.0%	1.0%
Inbound discount	0.00	0.00	$0.00	$0.00
BCFM increase after cleaning	0.5	0.5	0.5	0.5
Number of months corn is stored	6	6	6	6
Aeration management factor	1.5	1.5	1.3	1.3
Cost of electricity	$0.07/kw h	$0.07/kw h	$0.07/kw h	$0.07/kw h
Fan output elasticity	0.8	0.8	0.8	0.8
Airflow per watt-uncleaned	0.8 cfm/w	0.8 cfm/w	0.8 cfm/w	0.8 cfm/w
Number of fall, spring months of storage	3, 3 mo	3, 3 mo	3, 3 mo	3, 3 mo
Discount rate for new factor(s)	0.0	0.0	0.0	0.0
Average value of new factor	0.0	0.0	0.00	0.00
Limit for new factor	0.0	0.0	0.00	0.00
Corn price	$2.50/bu	$2.50/bu	$2.50/bu	$2.50/bu

discounts that can be recovered operationally (for example, by blending) rather than passed through, there will be a decrease in procurement costs. Note that this is not the same as avoiding outbound discounts (B_6).

$$B_9 = \left(Q - Q_{max}\right)\frac{d_9 P_c}{100} \qquad (31)$$

If ($Q - Q_{max}$) cannot be recovered in some way, then B_9 will not be realized.

APPLICATION OF THE GRAIN CLEANING MODEL

CASE-STUDY EXAMPLES

Case studies of corn screening on farms and at country elevators were analyzed. The input variables are given in table 2. The information in this example may apply directly to other operations and circumstances. The examples are based on cost estimates obtained from local contractors, for the most common types of cleaning equipment. The income statements for the four examples are given in table 3.

Note that V/P (annual volume relative to price) for farm cleaning is considerably less than that for elevator cleaning, which increased the on-farm cleaner operation cost considerably. This, in turn, made on-farm cleaning of average corn approximately a break-even proposition. Farmers would have to be astute managers to capture small net benefits. The farmers' situation is improved if natural air (fan power intensive) drying is used.

Elevator operators were assumed to be somewhat better than farmers at capturing aeration benefits (lower aeration management factor). An average of $0.001 per bushel inbound discount to farmers was assessed. This was based on a $.02 per bushel discount on 5% of receipts (Hill et al., 1991b). No premium was paid to sellers of low FM corn.

The shaker cleaner is more expensive (V/P = 16.7 versus 25 for gravity), more efficient (75% versus 50% for gravity), and more costly to maintain (5% per year versus 1%). Cleaning yielded net benefits that were small and dependent upon operator skill.

Several elevator-operating practices would reduce net benefits. Oil addition or pneumatic dust collection would eliminate shrinkage benefit. Coring of bins would reduce nonuniformity of airflow.

Clearly, the key to capturing benefits from cleaning is aeration management. The aeration and moisture-shrink

Table 3. Cost/benefits for corn cleaning case studies (in $/bu)

Cost	On-farm Cleaner		Elevator Cleaner	
	Rotary	Gravity	Gravity	Shaker
Fixed cost of cleaner	(0.020)	(0.014)	(0.006)	(0.011)
Variable cost of cleaner	(0.001)	(0.000)	(0.002)	(0.003)
Weight loss	(0.032)	(0.022)	(0.043)	(0.065)
Screenings storage	(0.001)	(0.000)	(0.001)	(0.002)
Transportation of screenings	(0.000)	(0.000)	(0.002)	(0.004)
Cost of increased testing	(0.000)	(0.000)	(0.002)	(0.004)
Total costs	(0.054)	(0.036)	(0.054)	(0.085)
Benefits				
Screenings value	0.026	0.017	0.030	0.045
Reduced freight	0.002	0.000	0.003	0.005
Shrink savings	0.004	0.004	0.003	0.003
Spoilage savings	0.000	0.003	0.006	0.006
Less handling	0.000	0.000	0.000	0.000
Discount avoided	0.000	0.000	0.013	0.013
Aeration savings	0.011	0.013	0.015	0.022
Moisture shrink	0.004	0.008	0.000	0.012
New discount	0.000	0.000	0.000	0.000
Total benefits	0.050	0.046	0.070	0.106
Net gain (loss)	(0.004)	0.010	0.016	0.021

Figure 1–Cost/benefit for corn cleaning at 40% removal efficiency for BCFM.

savings (the largest benefit) are both dependent upon reduced fan-operation time. The major contributor to shorter operating time is the elimination of spoutlines, and therefore of uneven air distribution. Increased output per watt contributes somewhat but not to the same extent. The entire analysis presumes that the operator has the skills and the detection equipment to determine when the cooling fronts have reached the top of a bin.

On the cost side, weight loss dominates, and the more cleaning is done, the more weight is lost. Thus, unless aeration management captures benefits, more cleaning will not give net benefits over costs. Only two costs, C_{1a} and C_{1b}, vary with volume cleaned. Cleaner operating costs change in nearly direct proportion to volume cleaned. The fixed operating costs are substantially greater than the variable costs for these assumptions.

For cleaning outbound corn, (no storage) only benefits 1, 2, 3, and 6 apply. In the example scenarios, the elevator would have to face discounts of about $.04 per bushel to cover costs. This would occur at about 5% BCFM. Farmers and country elevators do not clean regularly before shipping because they rarely have BCFM levels high enough to justify the expense. On the contrary, exporters facing absolute contractual limits must clean.

SENSITIVITY ANALYSIS

The critical variables are cleaner efficiency, storage time, and percentage of BCFM before cleaning. Their effects are summarized, for the assumptions in table 1 and in figures 1 and 2.

For comparison purposes, the nonvarying-input parameters were held the same in both cases. Because there is a direct proportion of cleaner operating cost to volume cleaned, any situation in which V/P = 25 will be covered by this same analysis. If a farm cleaner costs about $5,000, then, for V/P = 25, V = 125,000 bushels (about 850 acres of corn)—a large operation.

The higher efficiency produced more net benefit at all BCFM levels so long as storage is involved. This is because the airflow benefits rise quickly. Predictably, if storage is not involved, there will be net costs for cleaning
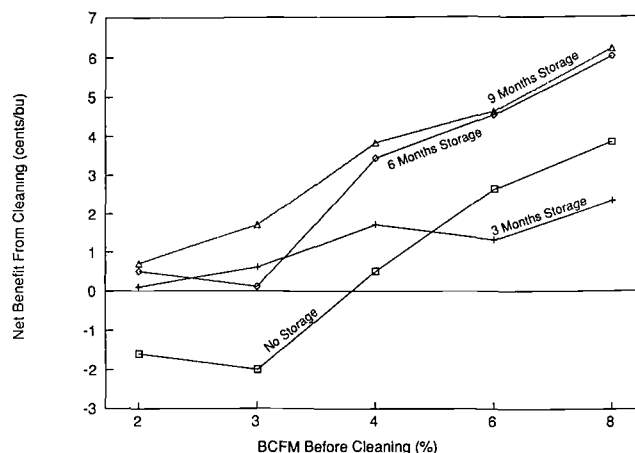
until the BCFM levels are substantially above the allowable limits.

The lines cross because the moisture shrink and aeration benefits fluctuate with time. Six months storage is about optimal to capture the greatest benefits. Longer storage times eliminate the potential moisture-shrink savings.

A more expensive cleaner will shift the lines down proportionally. The cleaner-operation cost in the example is about $.01 per bushel. Thus, half the volume, or cleaner costing twice as much to buy, would lower the lines by $.01 per bushel. The average reported cleaner operation cost in the USDA-Economic Research Service study ($.03 per bushel) would place the break-even point at about 4% BCFM, if storage of three or more months is involved. It was not clear whether survey respondents included costs other than operation in their answers (ERS, 1991).

A cushion of $.02 per bushel would be reasonable to protect against benefits not being realized, higher-than-expected costs, etc. Under that scenario, BCFM > 3.0% and storage time of longer than three months is needed to produce consistent profits. Astute operators may do better,
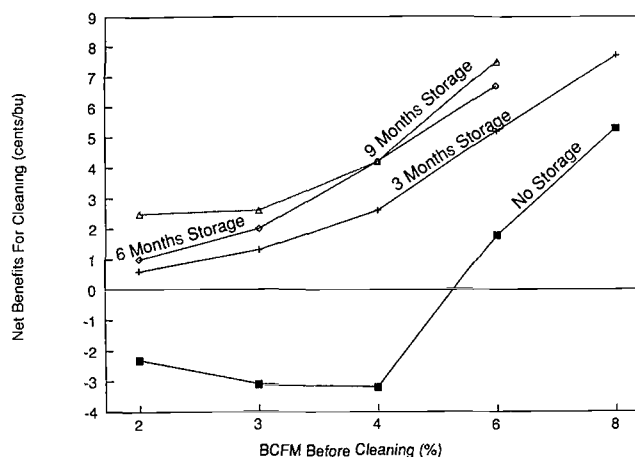
Figure 2–Cost/benefit for corn cleaning 75% removal efficiency for BCFM.

however. More efficient cleaners are more likely to give benefits at lower BCFM levels.

Figure 3 shows, for one case (six months storage, 40% efficiency), the relative contributions of the costs and benefits over BCFM levels. The major effect of aeration management at low BCFM levels is clear. Operators that fail to capture these benefits would experience net losses unless they have high BCFM corn subject to heavy discount. The more certain benefits (discount avoided, screenings revenue) do not become large until BCFM > 4%. Yet all costs are relatively certain at all levels of BCFM. Operators opt out of cleaning as a grain management tool because there is too much risk for them in capturing indirect benefits. This model shows that skilled operators with sufficient volume could significantly increase their operating margin by storing cleaned grain.

CONCLUSIONS

According to an engineering-economic model that included five costs and nine potential benefits:

- Corn cleaning can produce net benefits to a farm or elevator operator if (1) the BCFM percentage is 3% or greater, and (2) storage of three months or more is involved.
- Net benefits of $.01 to $.03 per bushel are possible on corn stored for three months or more, provided operators capture all possible management opportunities. The costs of cleaning are more certain than the benefits. Operator skill is required to capture theoretical net benefits.
- The initial cost of the cleaner relative to the bushels cleaned is the largest controllable cost factor. Thus, economies of scale are substantial.
- Farm cleaners are more expensive than commercial cleaners, per bushel cleaned, which will make capture of net benefits more difficult at the farm level. Elevator operators can capture net benefits more easily than producers.
- Costs and benefits in individual situations are highly case-specific. The model provides a framework for individualized decision making.
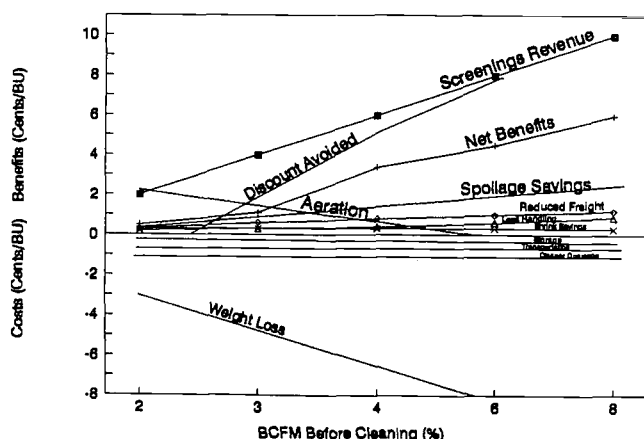

Figure 3–Cost/benefits for corn cleaning, assuming six months storage.

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