AN ANALYSIS OF FACTORS INFLUENCING WHEAT FLOUR YIELD

by

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ABSTRACT

The cost of wheat is the largest input cost for a flour mill, and as a result, profitability in wheat flour milling is determined in large part by milling efficiency – i.e., the amount of flour extracted per unit of wheat milled. In this project the objective was to quantify the influence of several measurable variables on flour mill efficiency. Data was collected from two commercial milling units of similar size. Linear regression was then used to estimate the relationship between flour yield and variables measuring grain characteristics and environmental factors. The analysis suggests that increasing ambient temperature and the occurrence of downtime both have a significant negative effect on flour yield. A significant difference in flour yield efficiency was also found between the two mills.

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CHAPTER I: INTRODUCTION

Wheat represents the largest input cost in flour milling. Gwirtz (2005) reported that the cost of wheat accounted for 84.2% of flour mill input cost, followed by labor at 10.1%. Flour yield, a measure of how much of the wheat kernel is converted to flour, is the most important technical and economic factor in wheat milling (Posner and Hibbs, 2005).

A wheat kernel (Figure 1.1) is made up of three main parts: bran, germ, and endosperm. One of the main goals of the wheat miller is to separate the wheat kernel as efficiently and completely as possible into these three parts. How well this is done affects the quality and economic values of the three components with the largest economic gain coming from complete separation of the bran from the endosperm. This separation determines the percent of the kernel that is converted to flour. This can be expressed as a percentage of the total kernel. A key consideration is not to remove too much of the bran layers with the endosperm. Removing bran with endosperm causes flour ash content to increase which decreases the baking quality of the flour.

Managing yield is critical to flour mill profitability. Consider the impact of a one percent variation in yield for a typical mill producing 10,000 cwt of flour per day. At an extraction rate of 75%, 10,000 cwt of flour requires 22,222 bushels of wheat. If extraction is increased to 76%, the daily amount of wheat required falls to 21,930 bushels, a savings of 292 bushels/day. Over the course of 365 days with wheat priced at $7.60/bushel, the total savings on wheat purchase cost amounts to over $810,000. While this example ignores a number of factors such as decreased by-product revenue and decreased operating cost, it does illustrate the potential economic impact of a relatively small change in efficiency. For a somewhat more complete example, consider a plant processing 20,000 bushels of wheat/day. At a 75% extraction rate, the yield is 9,000 cwt of flour and 3,000 cwt of by-product. Increasing the yield to 76% produces an additional 120 cwt of flour and a reduction of 120 cwt of by product. If the price of flour is $22.00/cwt and the price of by product $170/ton, the impact on net revenue per day is $1,680, which translates into $591,300 for 365 days. Similar examples are provided by Gwirtz (2002). While the impact of varying efficiency depends on wheat, flour and by-product prices, it is clear that under most circumstances increasing the efficiency of flour extraction will contribute significantly to milling profitability.

Commercial flour mills typically operate 24 hours a day, up to 7 days a week. Assessment of how well the mill is performing involves measuring each production day's flour yield for each milling unit. While variations between daily production yields are expected to occur, it is nevertheless important for the mill manager to understand what factors have the greatest impact on daily yield. These factors might include grain characteristics such as moisture content or kernel weight, or environmental characteristics such as temperature and/or humidity in the mill, and if a shift experiences downtime. Human factors such as the level of skill or experience of the miller may also play a role in explaining variation in yields.

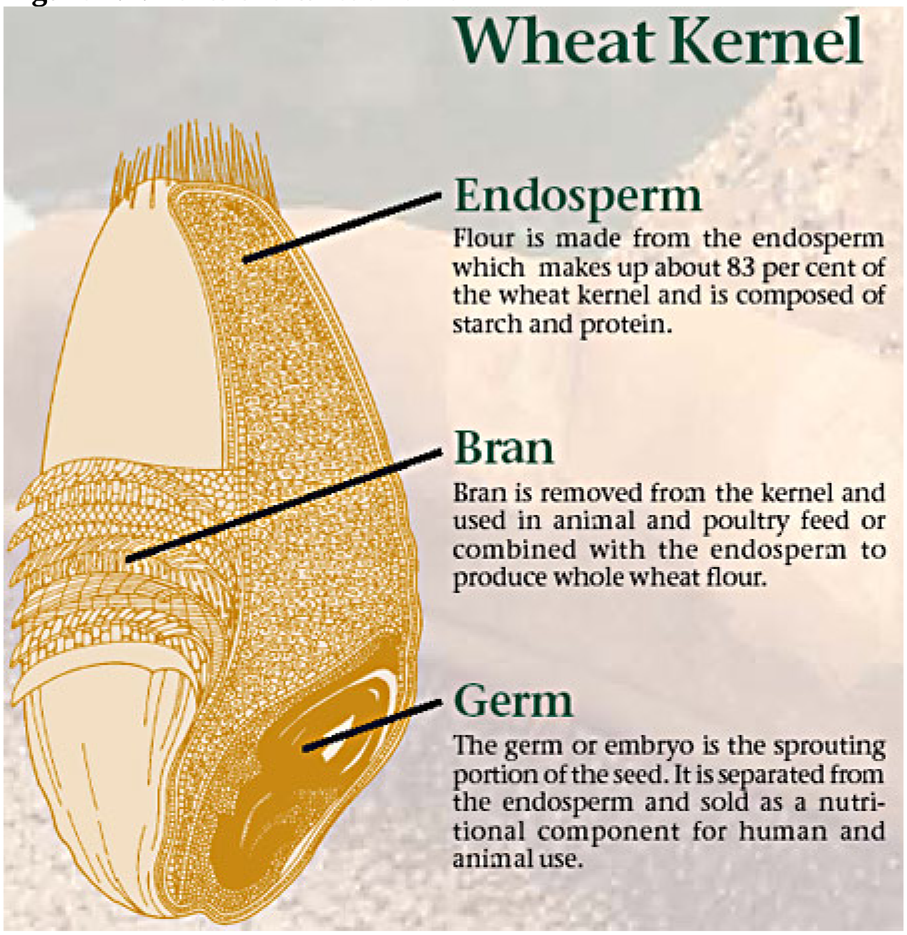
1.1 Commercial Mill Data

Gwirtz (2005) emphasized the importance of knowing how a mill is performing over smaller increments of time (i.e., daily versus monthly) as milling margins get tighter. For this analysis, daily data were obtained from a mill made up of two separate milling units of similar size that operate 24 hours a day. Operations consist of each milling unit having a shift foreman on each of the three shifts. The shift foreman (or miller) is responsible for cleaning and tempering the wheat, and adjusting the milling machines to an optimum level to produce quality flour per company guidelines. The miller must possess mechanical, lab, electrical, and troubleshooting skills. The efficiency with which this job is performed can determine whether the mill shows a profit (Nault, 1964).

1.2 Objectives

The objective of this project is to determine the effect of certain variables on flour mill daily yield. The analysis employs a regression model in which daily flour yield is the dependent variable. Analyzing the effect of grain and environmental characteristics on flour yield provides the framework for analyzing the impact of variation in those factors on mill profitability.

Figure 1.1: Parts of a wheat kernel



Source: Canadian Wheat Board "From Wheat to Bread." www.cwb.ca

CHAPTER II: LITERATURE REVIEW AND THEORY

Previous work examining mill efficiency points to a number of environmental factors and grain characteristics that influence the efficiency with which flour is extracted from wheat grain. The dependent variable for this analysis is flour yield.

Yield can be calculated in different ways. Typically, it is expressed as the number of bushels of wheat required to produce 100 lbs (1 cwt) of flour. For example, if 73% of the kernel weight is converted to flour, it takes 136.99 lbs of wheat (1 / 0.73) to produce 100 lbs. of flour. Since a bushel of wheat weighs 60 lbs, the yield can be expressed as 2.28 bu./cwt. In this format, the lower the number the more efficient the yield. In this study, I have chosen to express the yield as a percentage of the kernel extracted – i.e., as 73% in the example above. Recording yield this way allows for a more intuitive understanding of how variables correlate with yield since positive changes will represent improvements.

Shift yield is computed by taking the weights recorded from process scales at the beginning of each day. The process scales used are those measuring clean tempered wheat to mill and flour. Both scales record in pounds. Yield is estimated as flour weight divided by clean tempered wheat weight.

The variables hypothesized to influence daily flour yield include two grain characteristics - wheat to roll moisture and wheat to roll total kernel weight (TKW), and three environmental factors - temperature, humidity, and whether the day experienced a downtime event.

2.1 Wheat to roll moisture

Wheat to roll moisture measures the moisture content of the wheat as it approaches the first grinding machine. Critical steps in preparing wheat to be processed are cleaning the wheat, adding moisture to the kernel, and then allowing it to rest. This stage toughens the bran and mellows the endosperm which allows for easier separation of the two. Tempering time should be long enough to allow the moisture in the kernels to come to equilibrium and equally toughen the bran and mellow the endosperm of all sizes of kernels. Experienced millers know that having clean, consistent, well-prepared wheat at the first grinding stage is a key component toward mill balance, which results in the most favorable flour extraction and flour quality (Posner and Hibbs, 2005). Wheat to roll moisture is a measurement of how well the wheat was prepared for milling and how well moisture is added. Moisture addition influences both product yield and mill operation (Owens, World Grain July 2003).

To accurately assess the effect of moisture on yield, one should account for the moisture content of both the incoming wheat and the flour produced. Ideally, the weights of both wheat and flour would be adjusted to a given moisture content (e.g., 14.2% for flour, 15.2% for wheat) before calculating yield. In that situation, one would be measuring the effect of varying moisture levels on the efficiency of extracting the endosperm. If there is an optimum moisture content that maximizes extraction, and if that optimum level falls with the observed range in the sample of data, then one would expect a quadratic relationship between yield and moisture content in which yield first rises with increased moisture and then falls after the optimum level has been passed. If that is the case, then it would be important to identify that optimum level, and try to determine whether that optimum depends on other factors such as protein content, ambient temperature, etc. It is believed that the optimum moisture level lies in the range of 15-16% and that moisture levels outside this range will have a negative effect on yield. Most commercial mills aim for moisture levels near 15%.

If grain and flour weights are <u>not</u> adjusted to a fixed moisture level, the effect of moisture on yield becomes more complex. If moisture is lost during the milling process and if the moisture content of the flour is less than that of the incoming wheat, then an increase in the moisture content of the incoming wheat will show up as a decrease in the calculated yield, simply as a result of the additional moisture having a greater effect on the denominator in the yield calculation. On the other hand, if flour retains more of the incoming moisture relative to the bran and wheat germ components, increased moisture in the incoming grain may result in a higher yield of flour. The effects related to varying moisture content mask the effect of moisture on extraction efficiency and make it difficult to determine an optimum moisture level. Nevertheless, even when wheat and flour weights cannot both be adjusted (perhaps because data are not available), it is still important to control for varying moisture levels so as not to bias the estimation of other coefficients in the model. Given the possibility of an optimum moisture level, models will be estimated that allow for both a linear and a non-linear (quadratic) effect of moisture on yield.

2.2 Wheat to roll TKW

Thousand-kernel weight (TKW) is the weight of 1,000 counted kernels converted to a 12% moisture basis. A sample with more weight per 1,000 kernels should have a higher percentage of endosperm than a lighter sample, and thus should yield more flour. One reason to use TKW over alternative measures such as test weight is that there is very little relationship between either kernel size or wheat endosperm content and test weight (Stevens, IAOM Bulletin Jan 2005).

TKW will be modeled as having a linear relationship with yield. The expectation is that the coefficient on TKW will be positive, thus the following null and alternative hypotheses are tested: Ho: $B_{TKW} \leq 0$; Ha: $B_{TKW} > 0$.

2.3 Temperature and Humidity

Temperature and humidity effects in mills have been studied over the last 70 years and the conclusions are that both temperature and particularly humidity play a role in how the mill performs. Air stabilization has been shown to increase stock uniformity, increase extraction, and improve flour quality. Most commercial mills do not have air stabilization systems to control temperature and humidity. Likewise, the mills from which the data were obtained for this study did not have air stabilization systems. Controls used were opening and closing windows, and air returned into the plant from the pneumatic systems as temperatures dropped. Temperature and humidity were recorded on the roll floor for this study and were included to investigate their correlation with yield.

Jeffers and Rubenthaler (1977) found that as mill temperature increased due to friction and use, flour yield decreased, with correlations of -0.98 to -0.99 between roll temperature and flour yield. Similarly, Hook, Bone and Fearn (1984) found that an increase in temperature within a range from 15C to 25C (59F to 77F) was accompanied by a decrease in flour extraction. They also found that a decrease in relative humidity was associated with improved extraction. Given these prior results, the expectation is that increases in temperature and relative humidity will have negative effects on flour yield. The following null and alternative hypotheses are tested: Ho: $B_{\mathrm{Temp},} B_{\mathrm{RH}} \geq 0$; Ha: $B_{\mathrm{Temp},} B_{\mathrm{RH}} < 0$.

To investigate the possibility that there are optimum levels of temperature and relative humidity, models with quadratic specifications of these variables will also be estimated. Temperatures and humidity falling outside of an optimum range would reduce the yield of the mill.

2.4 Mill

Due to differences in design, age, wear and tear, etc., different mill units would be expected to vary in terms of their extraction efficiency. This study used data from two mill units identified as Mill A and Mill B. Mill A was a non-traditional flow mill with a designed capacity of 9,000 cwt per day. Mill B was a more traditional flow mill with a capacity of 10,000 cwt per day. A dummy variable will be used in the regression model to investigate variation in extraction efficiency between the two mills.

2.5 Downtime

Downtime occurs when production is shut down for any reason. Downtime is an important variable to track because anytime production is stopped, yield losses occur associated with the milling unit going down and starting back up. Equipment is not running at optimum settings anytime downtime occurs. Restoration of optimum production performance can take from one hour to longer following downtime. Thus, a reduction in yield is expected on any day that encounters downtime.

Downtime has an obvious effect on profitability in terms of lost production time, and the longer a downtime event, the greater the loss. But the effect on extraction efficiency is a consequence not of the length of time production is halted but instead a result of the machinery not operating at optimum levels while going down or restarting. Thus, extraction efficiency is impacted by the number of downtime incidents and not the overall length of time the mill is down. For the duration of this study, mill operators were asked to record whether or not a particular shift experienced downtime. Using that data, two dummy variables, D1 and D2, were created to represent days when either one, or two or more shifts experienced downtime. It is anticipated that the coefficients on both dummy variables will be negative, and that the magnitude of the negative coefficient will be greater for D2.

2.6 Other variables

The literature suggests that other variables may also have an influence on flour extraction efficiency. One such variable is temper time - the amount of time that the wheat rests after water is added to it. It is important because this rest time allows the moisture to come to equilibrium among the kernels of wheat. During this process the bran is toughened and the endosperm mellowed.

The mills from which data were obtained aimed for a moisture content between 16% and 17% at wheat to roll. Temper time for both units exceeded the 15 hours needed for moisture equilibrium (Posner and Hibbs, 2005) with A Mill having 17 hours and B Mill having 22 hours of temper time. For example, Farrell (1935) found that the rate of water absorption in Hard Red Winter Wheat came to equilibrium at around 9 hours of temper time. Because temper time does not vary except between the two mills, it is not used as an explanatory variable in this study. However, as noted above, a dummy variable is used to investigate differences in yield across the two mills. In interpreting the influence of that dummy variable, the observed effect may in part reflect the difference in temper time.

The amount of wheat flowing to the mill can also have an effect on flour yield. Overloading can have a negative effect on mill operation causing poorer yields. Wingfield (1985, p 4561) stated that "increasing the load to the mill beyond the optimal level will result in lowered flour yields and deterioration of the flour quality." Too little wheat going to the mill can cause quality issues and lowers the capacity of the mill. During this study the mill load setting was held constant by the shift miller at the milling superintendent's instructed setting. This was done using a Buhler wheat scale at the input of each mill, set to meter tempered clean wheat and verified by real time graphing at the superintendent's office. Thus, since the wheat flow was not varied within each mill, it is not included as an explanatory variable in the model.

The level of experience of the miller might also influence milling efficiency since the miller is responsible for adjusting machine settings, temper time, flow rates etc. For this study, individual shift data were not available on a sufficient number of variables to be able to control for the potential effect of an individual miller. Each data point represents a daily average of the (typically three) shifts worked that day. However, the data collection covered a sufficient time period (May 21, 2009 through Oct 11, 2009, 144 days) to allow each shift miller to perform several two-week rotations across shift times and across the two milling units. The fact that millers were rotated in this manner should minimize any potential correlation between miller experience and any of the other explanatory variables in the model such as temperature or mill unit. Thus, even if miller experience is a relevant variable, the examination of correlation with included variables will indicate the direction of any potential bias in the estimated coefficients that results from its omission (see Studenmund, p. 170).

Other characteristics of the wheat grain such as protein content may also influence flour yield. However, protein content was not recorded for this project. Each mill pulled from the same wheat and the same blends were used for each mill. Differences could arise however, from the different performance of each cleaning house and from the fact that each mill did not always pull the same blend at the same time.

Additionally, measurement devices such as scales, moisture meters, and kernel counters for TKW have their own margins of accuracy. For example, TKW was very reliant on how fast the machine counted by using vibration. The vibration in itself creates a density segregation that can lead to errors in the kernels being counted and weighed. Process scales are accurate up to plus or minus 1.5%. All of these factors can create errors in the data, and thus add to the error in any regression model.

CHAPTER III: DATA, ANALYSIS, AND RESULTS

Data were collected from two milling units to allow for estimation of the following model relating flour yield to grain and environmental variables.

(1) Flour yield = *f*(moisture, tkw, temperature, humidity, downtime)

3.1 Data Collection

Daily data were collected between May 21, 2009 and October 11, 2009, a time frame that included a seasonal change in the climate of the mill. During this period, a total of 129 daily observations on flour yield were recorded. Wheat use was measured using process scales for wheat-to-roll (WTR). Yield was calculated by dividing pounds of flour per day by pounds of wheat used per day in each mill. Flour moisture levels were not recorded so it was not possible to adjust flour yield to a constant moisture level.

A tempered wheat-to-roll sample was collected for each mill at the beginning of each shift. This sample was taken to the lab where wheat moisture was determined on a Foss machine and a TKW count determined using a TKW machine. The shift tempered wheat to roll moisture results and TKW results were averaged to create average daily values for moisture and TKW.

Temperature and humidity data were collected every hour with a remote device on the roll floor of the mill. Hourly readings were averaged to determine daily temperature and humidity.

Daily production reports were used to identify any occurrence of downtime on either A or B mill. For estimation purposes, downtime is reported using two dummy variables: D1 – which takes a value of one if one shift experienced downtime, zero otherwise, D2 – taking a value of one if two or more shifts experienced downtime. The occurrence of more than one downtime incident on a shift was not recorded.

3.2 Data Description

Tables 3.1 and 3.2 present summary statistics for the data. From the original data with 129 observations, days when fewer than three shifts were worked (11 for Mill A, 12 for Mill B), or when downtime or other data was not recorded (10 for Mill A, 9 for Mill B) were dropped from the sample leaving a total of 108 observations for each mill. Dropping days when only one or two shifts were worked also served to remove some outliers from the data set. Since both mills are contained in the same complex, data on temperature and relative humidity are similar for both, with the difference arising from the slight variation in the days included in each sample.

As noted, both mills have similar capacity with average flour output of approximately 9,000 cwt/day in mill A, and 9,700 cwt/day in mill B. Average yield is slightly better in mill B at 77.57% compared to 76.04% in mill A. Wheat characteristics are similar for both in terms of moisture level and TKW measures. Downtime occurred more frequently on A mill with 24 days having one shift experience downtime and 5 days with two shifts having downtime. On B mill, 19 days had one shift experience downtime, and 3 days had two shifts experience downtime. Downtime was not recorded on all three shifts on any day during the sample period.

Table 3.1: Summary Statistics for A Mill (n=108)

Variable	Definition	Mean	St.Dev.	Min.	Max.
Wheat	Cwt of wheat-to-roll	11,831	484	10,039	12,564
Moisture	Wheat-to-roll % moisture	15.32	0.41	14.00	16.34
Flour	Cwt of flour	8,995	391	7,357	9,663
Yield	Cwt flour / cwt wheat (%)	76.04	1.61	71.64	82.95
TKW	Thousand kernel weight (grams)	34.17	1.82	29.66	38.26
Temp	Avg daily temp. (F)	88.90	6.81	70.46	101.46
Rel.Hum.	Avg. daily relative humidity	39.71	6.87	17.15	59.67
D1	= 1 if 1 shift had downtime	0.222	0.42	0	1
D2	= 1 if 2 shifts had downtime	0.046	0.21	0	1
	(79 days with no downtime)				

Table 3.2: Summary Statistics for B Mill (n=108)

Variable	Definition	Mean	St.Dev.	Min.	Max.
Wheat	Cwt of wheat-to-roll	12,518	457	10,427	13,112
Moisture	Wheat-to-roll % moisture	15.22	0.38	13.88	16.10
Flour	Cwt of flour	9,709	379	8,136	10,332
Yield	Cwt flour / cwt wheat (%)	77.57	1.53	72.64	82.30
TKW	Thousand kernel weight (grams)	34.64	1.75	30.40	39.00
Temp	Avg daily temp. (F)	88.69	6.96	70.46	101.46
Rel.Hum.	Avg. daily relative humidity	39.53	7.11	17.15	59.67
D1	= 1 if 1 shift had downtime	0.176	0.38	0	1
D2	= 1 if 2 shifts had downtime	0.028	0.17	0	1
	(86 days with no downtime)				

3.3 Analysis

A linear regression model was used to investigate correlations between wheat and mill characteristics and flour yield. The dependent variable in the model is yield, calculated as pounds of flour produced divided by pounds of wheat used per day in each mill. The independent variables represent characteristics of the incoming wheat and the operation of the mill. The baseline model specification is represented by equation (2)

$$\text{(2)}\quad \text{Yield} = \alpha + \beta_1\, \textit{Moisture} + \beta_2\, \textit{TKW} + \beta_3\, \textit{D1} + \beta_4\, \textit{D2} + \beta_5\, \textit{Temp} + \beta_6\, \textit{RH} + \varepsilon$$

where *Moisture* and *TKW* represent the moisture content and thousand kernel weight of the wheat, *D1* and *D2* are dummy variables indicating downtime as described above, and *Temp* and *RH* are the daily average temperature (in degrees Fahrenheit) and % relative humidity respectively. Quadratic relationships between moisture, temperature, and relative humidity with yield will be investigated using specifications adding squared terms on those variables. Separate models are estimated for the A and B mills, but a joint model will also be estimated to investigate whether the difference in milling efficiency between the two mills, as indicated by the data in tables 3.1 and 3.2, remains after one controls for wheat and environmental characteristics, and downtime.

3.4 Results

Table 3.3 and 3.4 presents the regression results for different specifications of the models. Table 3.3 presents estimates of the baseline regression model for each mill. Table 3.4 adds estimates of the quadratic terms for moisture, temperature, and relative humidity.

Table 3.3: Linear regression models for wheat yield

Variable	Mill A	t-stat	Mill B	t-stat
Constant	68.707		110.137	
Moisture	0.764	1.57	-1.487***	-3.04
TKW	0.020	0.25	-0.147**	-1.81
Temp	-0.060**	-2.10	-0.044*	-1.71
Rel.Hum.	0.010	0.44	-0.023	-1.13
D1	-0.433	-1.21	-0.042	-0.12
D2	-0.949	-1.38	-2.076**	-2.48
R-Sq	0.228		0.221	
Adj R-Sq	0.182		0.175	
N	108		108	

*, **, *** indicate statistical significance at the 10%, 5%, and 1% levels.

Table 3.4: Quadratic regression models for wheat yield

Variable	Mill A	t-stat	Mill B	t-stat
Constant	350.824		-76.898	
Moisture	-36.404**	-2.06	26.477	1.35
Moisture^2	1.213**	2.11	-0.913	-1.42
TKW	0.003	0.04	-0.143	-1.63
Temp	0.137	0.31	-0.676	-1.49
Temp^2	-0.001	-0.42	0.004	1.39
Rel.Hum.	-0.313**	-2.08	-0.013	-0.09
RelHum^2	0.004**	2.14	0.000	0.03
D1	-0.226	-0.65	-0.039	-0.11
D2	-0.730	-1.09	-2.181**	-2.60
R-Sq	0.306		0.251	
Adj R-Sq	0.243		0.183	
N	108		108	

*, **, *** indicate statistical significance at the 10%, 5%, and 1% levels.

Results from the linear models indicate that the independent variables explain about 22% of the daily variability in yield for both mills. Adding quadratic terms for moisture, temperature and humidity results in a slight increase in the adjusted R-square value for both mills.

The effect of higher moisture content in the wheat-to-roll is negative and statistically significant in the linear model for Mill B, but is positive and insignificant in the model for Mill A. These conflicting results are not unexpected given the narrow range of moisture levels represented in the data set – from a minimum of 13.88% to a maximum of 16.34%. The fact that the range of moisture levels is so narrow is no accident since those moisture levels are targeted to be in the range in which milling efficiency is optimized. If the range of moisture levels been wider, it is likely that the true effect would have been clearer.

The addition of quadratic terms for moisture content does little in terms of clarifying the effect. For Mill A, the coefficient on the linear term is negative and that on the squared term is positive, and both coefficients are statistically significant at the 5% level. The signs indicate that there is a moisture level at which yield is minimized (rather than maximized) – which is not what one would expect. For Mill B, the coefficient on the linear term is positive and that on the squared term negative, indicating a moisture level at which yield is maximized. The estimated coefficients imply that the derivative of yield with respect to moisture content is given by: $dY/dM = 26.477 - 0.913*2*\mathit{Moisture}$. Setting that derivative equal to zero indicates that yield is maximized at a moisture level equal to 26.477/1.826 = 14.5%.

The scatter plots of yield versus moisture in Figures 3.1 and 3.2 illustrate the narrow range of moisture levels in the data and the fact that there is no clear pattern in the relationship between moisture and yield within that range. Thus, the difference in the regression results from the two mills is not surprising. The apparent outlying observations with low moisture levels in both mills (14.00 in Mill A, 13.88 in Mill B) did not influence the regression results. When the linear and quadratic models were estimated without those low moisture observations there were no changes in coefficient signs or significance levels.

Figure 3.1: Yield vs Moisture (A Mill)

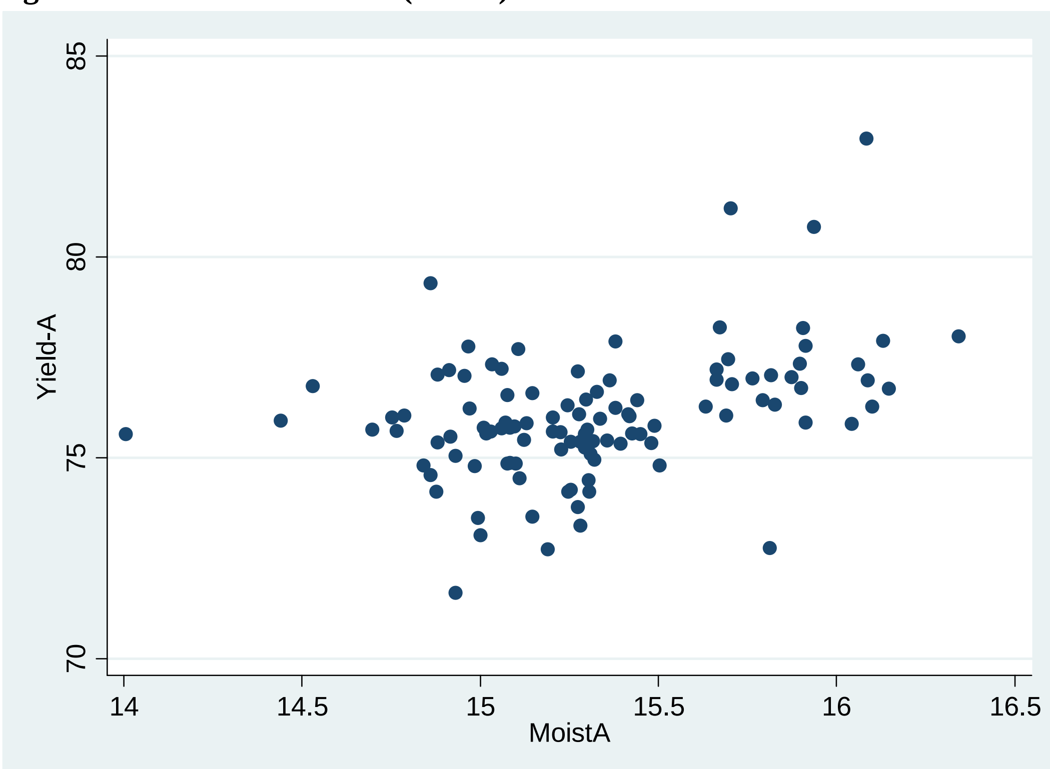
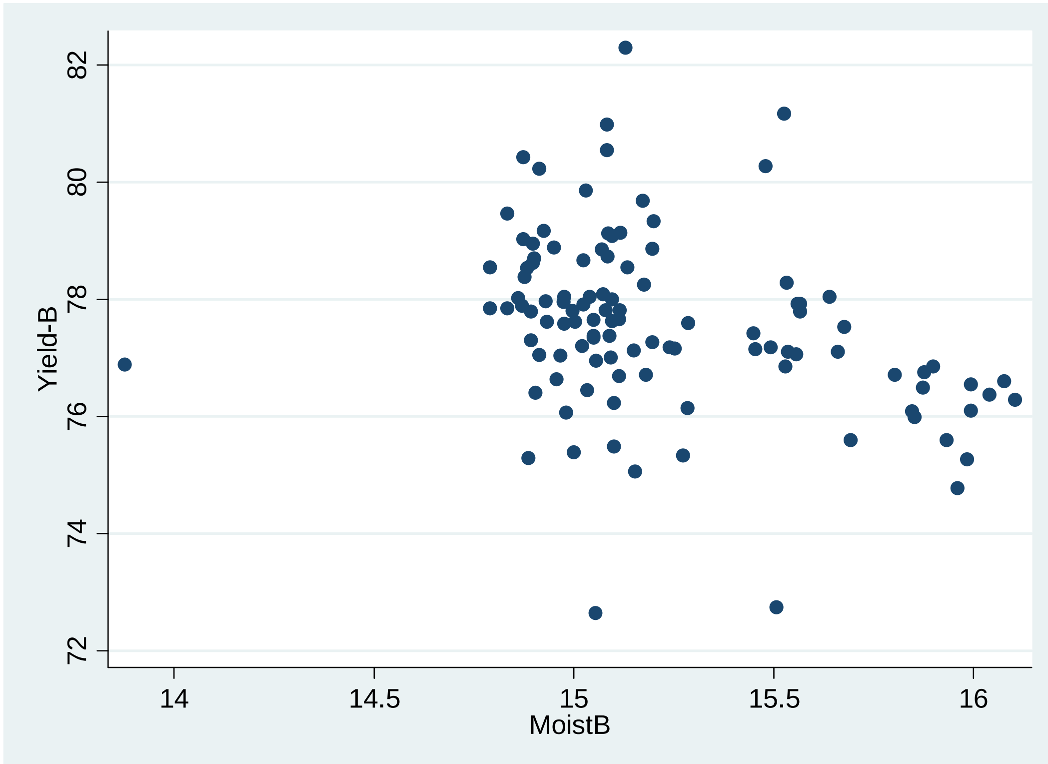


Figure 3.2: Yield vs Moisture (B Mill)



The effect of *Thousand Kernel Weight* is also not consistent across the two mills – being positive for Mill A and negative for Mill B. Given these estimates, the null hypotheses, Ho: $B_{TKW} \leq 0$, cannot be rejected. In other words, we do not have evidence that higher TKW values result in greater milling efficiency.

As expected, the effect of downtime is consistently negative for both mills, but the only statistically significant coefficient estimate is for the variable *D2* in Mill B. The estimated coefficient of minus 2.07 indicates that, *ceteris paribus*, yield is 2.07% lower on a day when two shifts experience downtime compared to a day when no shift experiences downtime. To put that number in perspective, assume that a mill grinds 21,000 bu of wheat per day and that average yield is 77% yielding 970,200 lbs. of flour and 289,800 lbs. of by-product. If wheat cost $7.60/bu ($0.13/lb.) the cost of wheat is $159,600. If the prices of flour and by-product are $0.22/lb. and $0.08/lb., total revenue is $236,628 and gross margin for the day is $77,028. Now assume that the mill experiences one hour of downtime on two shifts, reducing both the total amount of wheat ground (by a factor of 1/12) and milling efficiency from 77% to 74.93%. The total amount of wheat ground falls to 19,250 bu at a cost of $146,300. The total amount of flour produced is 865,442 lbs. which, with by-product, results in total revenue of $213,562. The gross margin for the day falls by $9,776. In the sample data, only around 3.5% of days had two shifts with downtime, which would translate to approximately 13 days per year. Eliminating the downtime events on those 13 days would increase the annual margin by $126,960.

Temperature is the only variable that is statistically significant in both linear models and the estimated coefficient is similar for both mills at -0.060 for Mill A and -0.044 for Mill B. The null hypotheses, Ho: $B_{\text{Temp}} \geq 0$, is rejected and we conclude that higher temperatures reduce milling efficiency. Using a value of -0.05, the approximate average of the coefficients in the linear models for A Mill and B Mill, we can investigate the economic significance of the effect of temperature. Assume, as above, that a mill grinds 21,000 bu/day with average yield of 77 % resulting in a daily gross margin of $77,028. In our data, the average daily temperature was approximately 88F with a minimum of approximately 70F. Reducing the average ambient temperature from the 88F to 70F is estimated to increase yield by 18*0.05 = 0.90%, from say 77% to 77.9%. Using the same prices as above, that increase in yield is calculated to increase daily gross margin by $1,588. Over 365 days, the total impact amounts to almost $580,000.

Adding quadratic terms for temperature did not appear to generate a significant improvement in model fit. While overall Adj R-Sq does increase when quadratic terms for moisture, temperature and relative humidity are added, both the linear and quadratic terms on temperature are statistically insignificant in the models for both mills, and, as with moisture, the curvature implied by the coefficient signs is different for each mill. Figures 3.3 and 3.4 plot yield against temperature and neither provide strong evidence in favor of a quadratic specification.

Figure 3.3: Yield vs Temperature (A Mill)

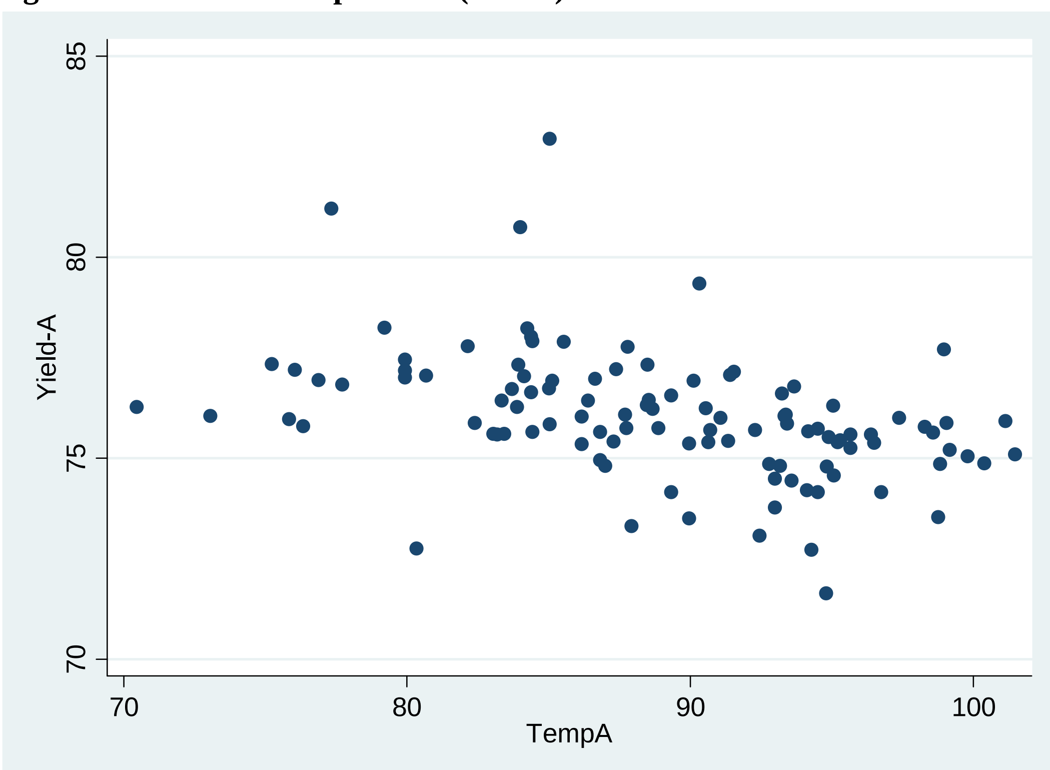
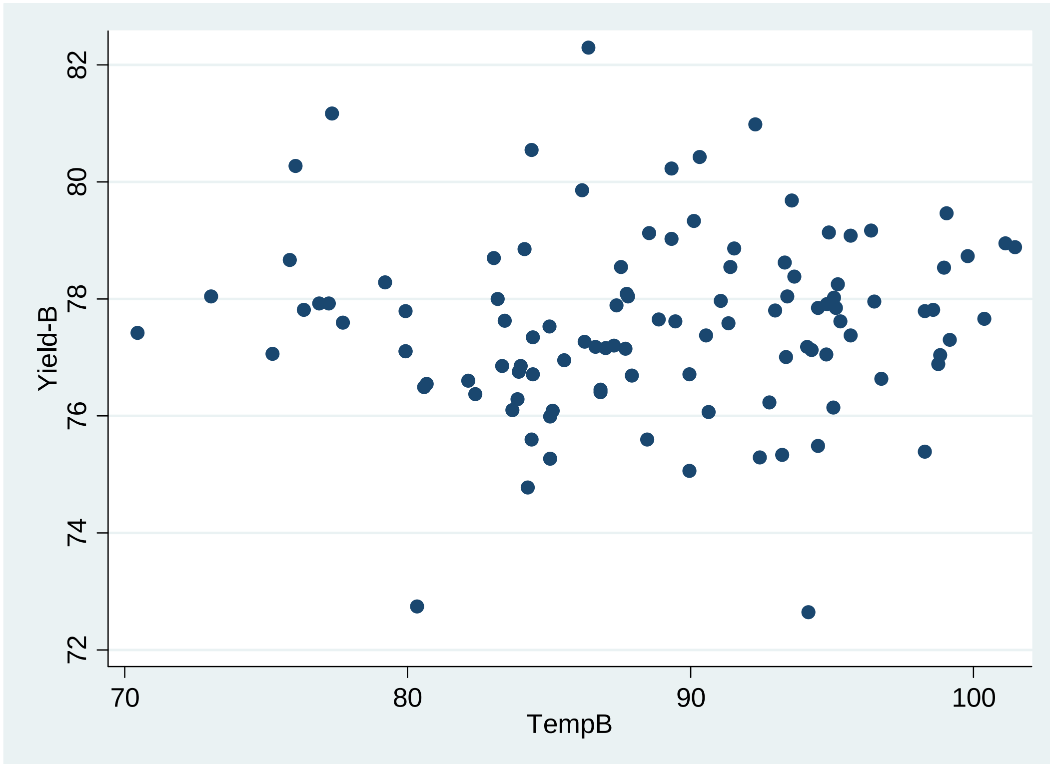


Figure 3.4: Yield vs Temperature (B Mill)



The effect of relative humidity was not statistically significant in the linear models for both mills. The coefficients were statistically significant at the 5% level in the quadratic specification for Mill A – however, the signs were unexpected in that they suggested a point where yield was minimized rather than maximized. Coefficients in the quadratic model for Mill B were not statistically significant. Since the data (see Figures 3.5 and 3.6) and analysis fail to indicate a consistent effect of relative humidity on yield, no economic analysis is performed for this variable.

Figure 3.5: Yield vs Relative Humidity (A Mill)

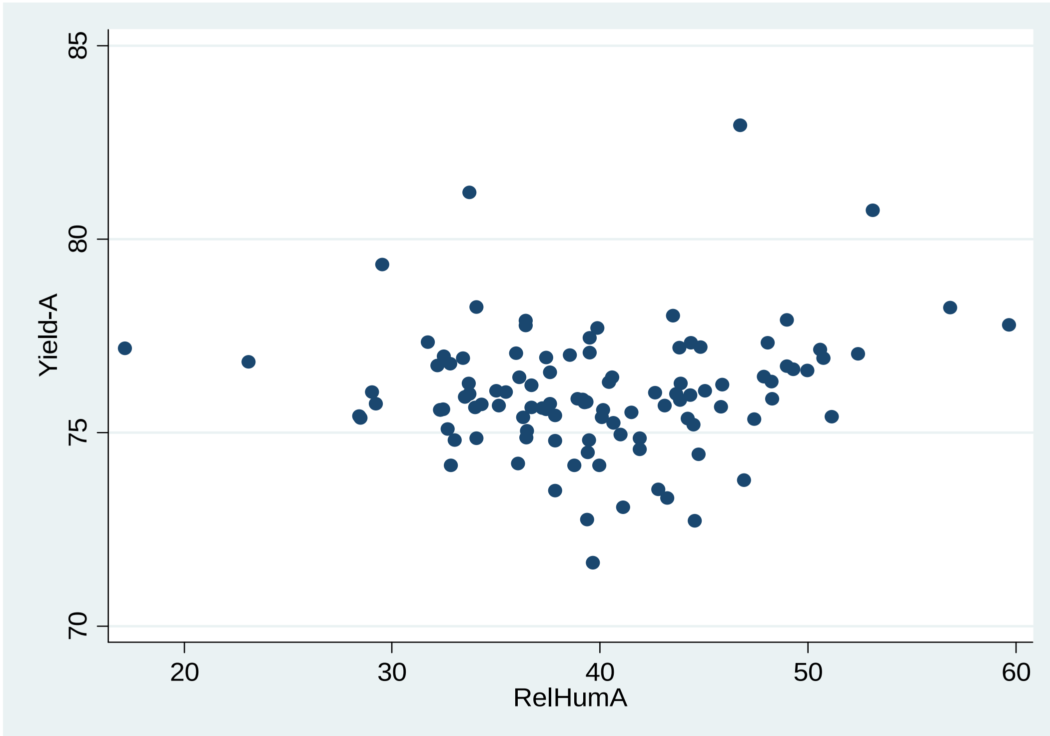
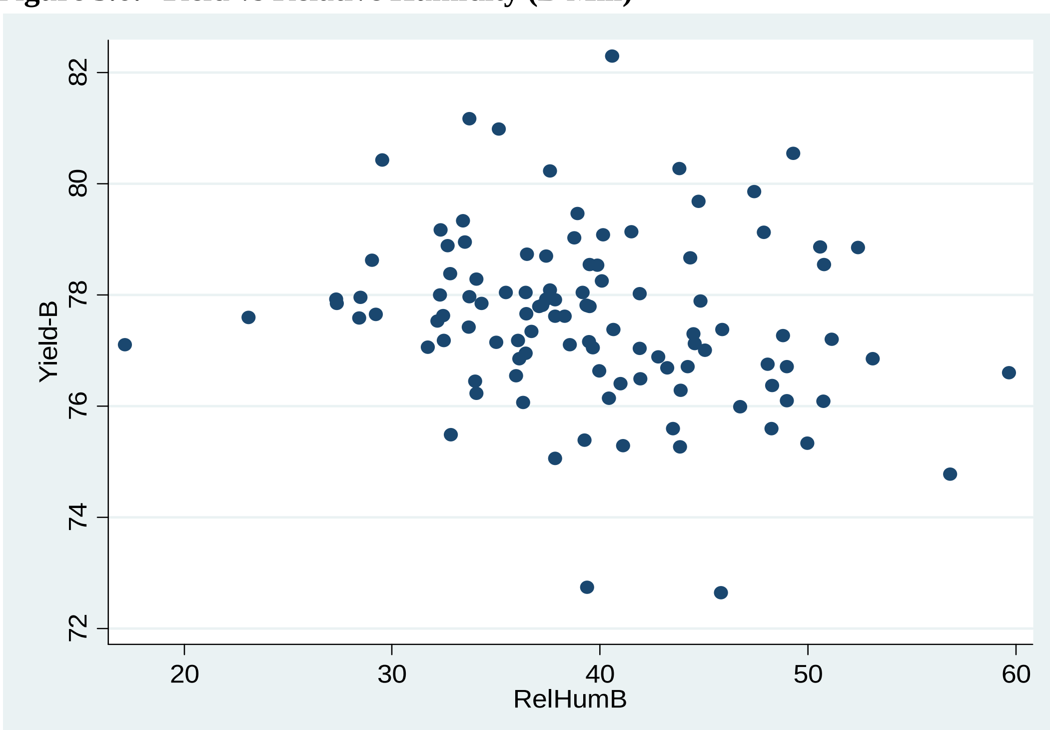


Figure 3.6: Yield vs Relative Humidity (B Mill)



3.4.1 Comparing Mill Efficiency

The summary statistics (Tables 3.1 and 3.2) suggest that B Mill, with an average yield of 77.57%, operates more efficiently than A Mill, where the average yields is 76.04%. However, such a comparison based on simple averages can be misleading given that milling efficiency is influenced by several variables, the levels of which may not be equal for both mills. Furthermore, the regression results in Tables 3.3 and 3.4 do not allow for any inference about comparative efficiency since they are estimated separately for both mills. However, if the data from both mills is pooled, a model can be estimated that allows for an inference about relative efficiency holding other variables constant. The model to be estimated is as follows:

$$(3)\quad \text{Yield} = \alpha + \beta_1\, \textit{Moisture} + \beta_2\, \textit{TKW} + \beta_3\, \textit{D1} + \beta_4\, \textit{D2} + \beta_5\, \textit{Temp} + \beta_6\, \textit{RH} + \beta_7\, A + \varepsilon$$

In this model, the variable *A* is a dummy variable that takes a value of 1 if an observation is from A Mill, zero otherwise. The estimated coefficient on *A* is an estimate of the difference in efficiency between A Mill and B Mill, holding constant the values of the other variables in the model. Thus, if the estimated value for β_7 is negative it suggests that A Mill operates less efficiently than B Mill. The regression model estimates for equation (3) are presented in Table 3.5.

Table 3.5: Pooled model for wheat yield

Variable	Coefficient	t-stat
Constant	87.333	
Moisture	-0.179	-0.49
TKW	-0.081	-1.32
Temp	-0.045**	-2.22
Rel.Hum.	-0.004	-0.26
D1	-0.372	-1.4
D2	-1.605***	-2.89
A Mill	-1.495***	-7.00
R-Sq	0.264	
Adj R-Sq	0.239	
N	216	

*, **, *** indicate statistical significance at the 10%, 5%, and 1% levels.

The coefficient on *A Mill* is negative and highly significant, indicating that A Mill operates less efficiently than B Mill. The estimated coefficient indicates that, when moisture, TKW, downtime, temperature and humidity are all held equal, the yield from A Mill is predicted to be 1.495% lower than that of B Mill. The daily revenue loss associated with that yield reduction is estimated to be $2,637 for a mill grinding 21,000 bu of wheat per day and assuming values of $0.22/lb. and $0.08/lb. for flour and by-product. Over 365 days, the loss in revenue amounts to $962,571.

CHAPTER IV: CONCLUSIONS AND RECOMMENDATIONS

The goal of this project was to estimate the effects of different variables on flour yield in two commercial wheat mills. This was done by collecting a sample of data from two mills, and using a linear regression model to provide estimates of the effect on daily flour yield of each variable. The economic significance of each variable was estimated using coefficients from the regression models and assuming prices for wheat, flour, and wheat milling by-product. Results indicate that mill temperature and downtime have significant effects on flour yield. The effects of moisture, TKW, and relative humidity were not statistically significant. Higher mill temperatures were associated with reductions in flour yield. A pooled regression model investigated comparative efficiency of the two mills in the sample. One mill was found to operate less efficiently that the other with an estimated difference in yield of approximately 1.5% holding constant the other variables in the model.

4.1 Recommendations

4.1.1 A Mill vs. B Mill. A significant economic benefit would be obtained by increasing the efficiency of A Mill to the level currently attained by B Mill. The annual reduction in gross margin due to inefficiency in A Mill is estimated at $962,571. A comparison of the two mills' flow sheets should be completed, including roll, sifter, and purifier surfaces. Plans should be considered to make A Mill's flow similar to B Mill's flow. Equipment changes may also have to be considered to improve A Mill's yield.

4.1.2 Downtime. The occurrence of downtime was estimated to have a negative impact on flour yield. The effect was statistically significant in B Mill when a day experienced two or more shifts with downtime. Compared to a day with no downtime, the occurrence of downtime on two or more shifts was estimated to reduce daily gross margin by $9,766. The annual cost for days experiencing downtime on two or more shifts was estimated at $126,960. These calculations include production losses associated with the mill not being in operation (assuming each downtime event shuts production down for one hour) in addition to yield losses. Downtime can be prevented by identifying and developing preventive and predictive maintenance. Part of each miller's training should include downtime education and a system of communication so that maintenance and performance issues can be addressed before they result in unscheduled downtime.

4.1.3 Temperature on the roll floor. Higher temperatures in the mill were found to have a negative impact on yield. The effect was statistically significant for both mills. Reducing mill temperature from 88F, the average temperature in the data sample, to 70F was estimated to increase daily gross margin by $1,588 in a mill grinding 21,000 bushel per day. Installation of a climate control system in a commercial mill represents a substantial capital investment but the potential gains identified in this project suggest that additional investigation of the costs and benefits of that investment is warranted.

4.2 Future considerations

Data were not available to analyze flour yield on a shift by shift basis for this project. It is recommended that such an analysis be performed before any management actions are implemented on the basis of findings from this project. Analyzing yield on a shift by shift basis allows for the investigation of effects on yield associated with: a) individual millers and b) individual shifts.

4.2.1 Shift effects

Shifts can be organized either in a rotating, a continuous or a discontinuous fashion. Shift work in general disrupts biological rhythms, sleep and social life. In addition, it can lead to a number of clinical and non-clinical problems. It retards human performance and increases the likelihood of industrial accidents (Pati, Chandrawanshi, and Reinberg; 2001). Although human performance is decreased, shift work is still the most economical way to run a flour mill. Most commercial mills run 24 hours a day, allowing machine cost to be spread out over more units.

It is possible that flour yield varies systematically by shift. For example, night time shifts may consistently produce lower yields than daytime shifts. Why might that occur? One factor is that the day shift has management present and more resources available to help and monitor production efficiency. Consideration could be given to adding management supervision to each shift or tying the shift miller's pay to the performance on the shift. Worker fatigue is another factor. Millers rotate shifts every two weeks and studies show that the human body is negatively affected by this disruption to the biological rhythms of the human body. Consideration could be given to not rotate shifts and permanently assign shifts with incentives tied to performance, or shift rotations could be shortened and the direction of rotation changed. Pati, Chandrawanshi and Reinberg (2001) reported that shift rotations of 3-4 days and the direction of rotation being 1^{st}-2^{nd}-3^{rd} can lessen worker fatigue.

4.2.2 Miller effects

It is also possible that individual millers may have a significant effect on yield, perhaps due to skill, training or experience. If the skill level of an individual miller proves to have an impact on yield, then training for all millers with the goal of improving performance and making yield more consistent between millers would be beneficial. A mentoring program may help get less skilled and experienced millers to perform better. Education classes on milling, distance learning in milling, and incentive programs could be considered to raise the awareness of how critical yield is to the profitability of the plant.

Effects on yield due to shift effects or to the effect of individual millers may help explain some of the results obtained in this study such as the difference in yield between the two mills. If shift and miller effects are relevant, they need to be regarded as omitted variables in this analysis, thus raising the possibility of bias in the resulting coefficient estimates. For that reason it is recommended that the study be repeated using data from individual shifts before any changes are implemented on the basis of the current analysis.

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