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PROCUREMENT STRATEGIES TO MEET FUNCTIONAL REQUIREMENTS IN WHEAT SHIPMENTS

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ABSTRACT

Consistency of functional characteristics in wheat is a concern confronting buyers and sellers. This research analyzes the cost and risk of different procurement strategies for importers. A stochastic simulation model is used to determine the probability of a functional characteristic being satisfied subject to quality targets. Joint probabilities of meeting specifications and costs were determined for alternative functional characteristics. Results indicate that, as more specific characteristics are incorporated into a contract, the probabilities of meeting end-use requirements increase. Specific characteristics come with a higher cost, due to increased testing costs related to identity preservation. The results are summarized as cost/risk tradeoffs confronting buyers in wheat procurement.

Key Words: buying strategies, location, variety, functional characteristic tests, costs, risks

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William W. Wilson, Del Albert Peterson and Bruce Dahl*

INTRODUCTION

Consistency of functional characteristics (absorption, peaktime, loaf volume, and stability) in hard red spring (HRS) wheat is a problem confronting buyers and sellers. Quality uncertainty usually refers to variability in functional performance and arises from a combination of varietal differences, agronomic practices, environmental conditions, and handling and marketing practices. Guaranteeing quality for functional characteristics is problematic because most are not easily measurable. Some require laboratory testing and, therefore, are not commonly used in procurement contracts. The changing competition among wheat buyers, largely due to the increased privatization of wheat importing functions, has led to increased demand for high-quality U.S. wheat. Wheat suppliers, on the other hand, are subject to a more diverse supply of wheat varieties and production processes.

The purpose of this study is to analyze the cost and risk of alternative procurement strategies that can be used by international wheat end-users to mitigate quality inconsistency. We develop a model to quantify costs and risks for different procurement strategies and apply it to the case of HRS. The model poses procurement strategies inclusive of grade and protein, targeted varieties, and locations and several functional trait tests. The first section below provides a background discussion. Subsequent sections describe the quality, price, and cost statistics used in the analysis; the empirical model is specified and results are presented. A final section draws some implications for buyers and sellers.

BACKGROUND AND PREVIOUS STUDIES

Wheat-Quality Consistency Problems

Dahl and Wilson (1998) defined three elements of quality consistency. One is quality variability due to sampling and grading errors. Second is the variability of grain characteristics in shipments taken from different regions and climatic areas. Among these characteristics are those easily measurable (e.g., protein and damage) and other characteristics with greater measurement error. For characteristics that are susceptible to greater measurement error, there are greater risks. The third aspect relates to functional performance (i.e., mixing and baking characteristics). End-users see this inconsistency as a major hurdle which is reflected in the relationship between functional performance and measurable characteristics. Buyers normally specify easily measurable characteristics which are correlated with desirable functional characteristics. Low correlations result in greater uncertainty in functional performance, or greater inconsistency.

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Dahl and Wilson (1998) documented the variability of quality for HRS wheat at different points throughout the production and marketing system and found that quality variability decreased as it moved from farm-level production to export locations. The variability of wheat and functional characteristics were examined to determine the contribution of variety, location, and environment to the variation in individual quality characteristics. For many wheat and functional characteristics, variability was impacted most by year to year effects (i.e., environment), followed by location and variety effects. Variability in the mix tolerance index (MTI) and wet gluten were affected most by location and variety; whereas, mix time was affected most by environment and variety. Therefore, buyers may increase consistency of purchases for MTI, wet gluten, and mix time by focusing on location and/or varieties.

Dahl and Wilson (1999) examined the effect of quality variability on three alternative methods of calculating value of wheat to millers. These included buying on a "net wheat" price, valuing wheat lots based on a millable wheat index, and valuing lots based on the net profit (value added) in milling. Simulation models were utilized to evaluate the effects of variability for wheat characteristics on the estimated value for the three alternative measures.

Wilson and Preszler (1992), utilized the input characteristic model (ICM) to analyze effects of price and quality on competition in the U.K. wheat import market. The U.K. market was targeted for this analysis because it illustrates the fierce competition between the U.S. and Canadian export markets, and the U.K. is characteristic of numerous markets in which higher-protein U.S. and Canadian wheat compete for use in blends with lower-quality native wheat. For most characteristics, the expected values of functional characteristic performance for U.S. wheat had variances which exceeded those of Canada. The Canadian varieties possessing the lower variances in quality characteristics lowered the overall costs because a greater proportion of cheaper wheat could be used in the blending process. This occurrence resulted in shifting from U.S. to Canadian wheat. However, the impact of quality characteristics cannot be assessed without considering the impact of price on these purchasing practices as well as functional quality. Thus, both quality characteristics and price impact the distribution of market shares and are strategic variables for sellers.

Procurement Strategies and Practices

International competition in wheat is quickly having to focus on consistency. The market will get more sophisticated in segregating for quality in the next few years. More demanding buyers generally request increased contract specifications (Oades, 2001a).

Procurement strategies utilized by wheat end-users range from simple spot market transactions to elaborate vertical integration techniques. Strategies that fall in between these extremes are numerous and often considered the norm. Examples of these strategies include contracting, testing and segregation practices, targeting of origins and varieties, contracting production practices, and identity preservation (IP) (Figure 1) (Wilson and Dahl, 2002).

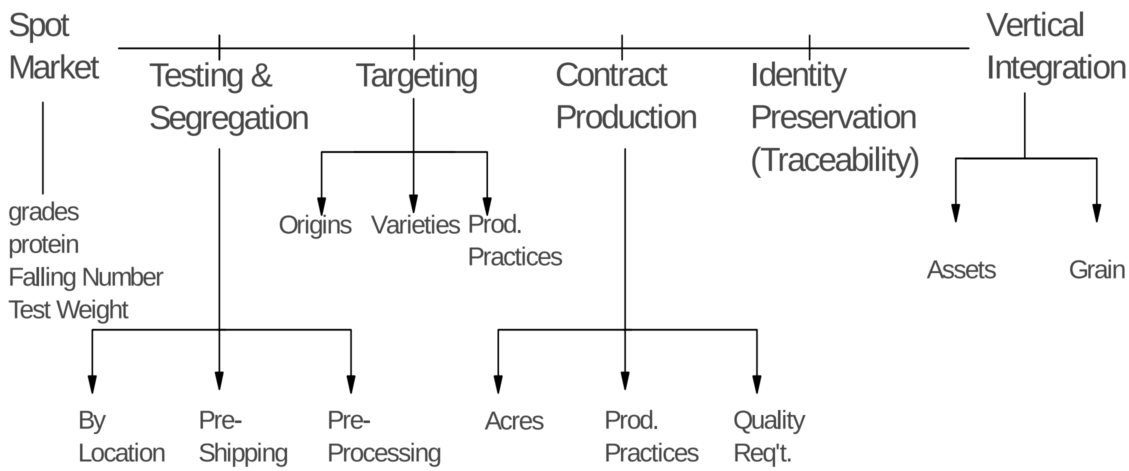

Figure 1. Spectrum of Procurement Strategies

Testing and segregation practices by end-users often entail location segregation techniques accompanied by either pre-shipment or pre-processing testing processes or a combination. Targeting origins and varieties consists of purchasing wheat from a given county or region, and purchasing a particular variety. Specific production practices involve contracting a desirable acreage to be produced, overseeing the production practices on that area, and requiring the final product to meet desirable quality requirements. IP requirements include preserving wheat characteristics throughout the entire production and transportation process (Wilson and Dahl, 2002).

Contract terms can define minimum acceptable quality of a shipment. There is a direct relationship between price and risk in international wheat contracting. The seller assumes risks that include producing specified quality, making on-time deliveries, and controlling costs. Use of quality specifications that are uncommon or which are stated in parameters not commonly used creates uncertainty and risk throughout the system. Thus, contracts should use only the purchase quality specifications that enhance milling and flour functional performance and economic return (U.S. Wheat Associates, 2001). Buyers should also use quality parameters common to the international origin which they are sourcing (Oades, 2001b). Use of accurate quality specifications in contracts improves the likelihood that customers will be satisfied.

Wheat is usually marketed on a grade basis. Specifications are a part of the purchase contract and affect price. Grain grading and inspection agencies are required to certify various quality specifications to insure that the buyer and seller both know that the buyer is receiving what he agreed to purchase. Quality factors routinely certified on all export cargoes are numerical grade, class, moisture content, protein content, and dockage content. Certification of additional quality factors can also be specified in the contract and be performed and certified by the USDA's Federal Grain Inspection Service or a private company (U.S. Wheat Associates, 2001).

Some U.S. end-users have begun the process of contracting the production of selected wheat varieties. Variety-specific procurement strategies help end-users meet both economic and functional quality requirements which they are unable to achieve through normal commodity market channels (Dahl and Wilson, 1998). Producers, in turn, receive a premium for producing those wheats, which may compensate for weakened yield potential. Premiums awarded to producers may also compensate them for possible risks associated with conditions, which may inhibit them from meeting minimum contract specifications. Examples of end-users using variety-specific strategies include, but are not limited to, General Mills (described below), Warburtons, and ConAgra/AgriPro.

Identity Preservation (IP) Procurement Strategies

In light of recent changes, the U.S. Department of Agriculture (USDA) sought public comment on how the USDA can continue to facilitate the marketing of grains and like products (Shipman, 2001). Comments received formed a consensus in two major areas, the need for standardized testing methods and the need to foster the development of quality assurance processes. While the U.S. commodity system is efficient in moving vast amounts of grains from the farmer to the end-user, commingling minimizes the ability of the system to extract the value of any specific quality (Shipman, 2001). IP is seen as a necessary tool in order to minimize the likelihood of commingling throughout the logistical system.

The IP revolution involves identifying desirable quality attributes which are not widely available due to inadequate varieties present in today's market. It is believed that incentives to the IP system should provoke expansion to the point that those qualities will become common, displacing varieties that do not offer desirable characteristics. The IP system could then become the market's natural vehicle enabling the development of a new grain marketing world (Drynan, 1997).

General Mills is in the process of converting all of its cereal plants to IP handling of wheat and oats (Willis, 2001). The primary reasons for this are the expected improvements in product quality, consistency, productivity, and human health benefits. General Mills specifies varieties in its contract which can increase processing plant efficiency and product shelf life. The main components in General Mill's IP system include supply of certified seed, field scout with certified crop advisors, premium incentives to producers, closed loop contracts, defined marketing plans, producer accountability, and product traceability (Willis, 2001). Auditing is applied to both producers and grain handlers.

In Canada, only varieties with acceptable end-use quality characteristics can be registered for commercial production. Kernel visual distinguishability requires that all wheat varieties from a given class be visually distinguishable from varieties of other classes. Wheat is segregated in terms of functional quality at the plant breeding stage of the supply chain. Any wheat variety that is of inferior functional quality is not allowed to be released at this early stage. The requirement of kernel visual distinguishability enables wheat buyers to predict the class and functional performance by merely looking at it (Kennett et al., 1998). Recent discussions in Canada have explored changing regulations from kernel visual distinguishability to a system with variety eligibility declarations as the method of determining segregations (Canadian Grain Commission, 2003).

Warburtons Ltd. is an example of a bread processor with quality specifications that cannot be guaranteed through the Canadian grain grading system without greater control over the supply chain for milling wheat quality. Warburtons Ltd. is Great Britain's largest independent bakery and has been in the business of baking and selling bread since 1876 (Kennett et al., 1998). The company's focus on the high-quality end of the market means that a Warburton loaf is often twice the price of a regular loaf. Despite its relatively high price, recent evidence suggests that sales of Warburton's bread are on the increase.

A contributing factor to the quality of Warburtons' bread is the company's insistence on using the best quality wheat available. Traditionally, Warburtons Ltd. purchased Canadian Western Red Spring (CWRS) wheat according to grade and protein content. As the number of varieties within the CWRS class increased, Warburtons noticed variability in functional characteristics within and between shipments. Its research identified which varieties performed best and concluded that a blend of varieties were preferred. These varieties included Teal, Pasqua, and Columbus (Kennett et al., 1998).

Warburtons Ltd. introduced a system of wheat procurement using IP wheat contracts with producers from western Manitoba. The contracts outline the obligations of the producer and the grain handling company. The producer agrees to devote a specific acreage to the production of a particular variety. Crops are grown from certified seed, and the producer is required to submit a report to the grain company concerning weather conditions, inputs, and crop yield, along with a representative sample of wheat (Kennett et al., 1998).

Warburtons specifies the quantities of the varieties that are required for its processing needs. The Manitoba Pool Elevators (MPE) ensures that all wheat produced under contract and destined for Warburtons is segregated and identity preserved through the grain handling system. Warburtons purchases its wheat directly from the Canadian Wheat Board (CWB) and is charged a price higher than the CWRS wheat market price for a comparable grade. Warburtons also pays a management fee to the MPE for administering production contracts and for IP services. All acceptable contracted grain is purchased by the MPE at the agreed price. In the first year of the contracting program, producers were paid a $30 per ton premium over the regular CWB price for the identical grain (Kennett et al., 1998).

Warburtons' second year of the contracting program brought changes. In an attempt to spread out supplier risk, Warburtons commissioned a second grain company, N.M. Paterson and Sons Ltd. Paterson sources grain through supply contracts with producers, much like the MPE, and has the same responsibility to preserve the identity of the contracted wheat through the grain handling system (Kennett et al., 1998). Warburtons has been greatly successful with regards to its contracting endeavors and plans to continue. As other companies look to procurement strategies similar to Warburtons' IP supply chain, their need for more specific contract terms will undoubtedly increase.

EMPIRICAL MODEL

Not conforming to end-use requirements has important implications for wheat buyers. These implications include the risk of not conforming to contract specifications, greater costs associated with higher quality purchases, and/or the effects of increased operating costs associated with likely stock-out costs due to nonconformance (Wilson et al., 2000). Wheat quality characteristics (e.g., protein and test weight) that are easily measurable in a timely manner are typically used for contracting. Functional characteristics (e.g., stability and peaktime) are not easily measurable, but statistical relationships exist between wheat quality and functional characteristics. Though it has not been conventional to use functional characteristics in contracting for wheat procurement, buyers and end-users are ultimately concerned with these characteristics.

In this study, stochastic simulation was used to analyze costs and risks of alternative procurement strategies. These strategies include buying based on wheat protein levels, varieties, locations, and functional characteristics. The simulation models are used to estimate procurement costs and determine the probability that shipments would meet end-user requirements for the alternative procurement strategies. Costs for procuring wheat are estimated inclusive of purchase costs, shipping, and tests required for each of the strategies. Statistical relationships between wheat and functional characteristics were estimated and utilized to derive probability distributions for meeting functional conformance for each of the alternative purchase strategies. Stochastic variables include basis values and functional characteristics.

Mathematical Specification and Definitions

Simulations were conducted to determine the cost of delivering HRS and the probability of functional characteristics conforming to target values. Prices were defined given inter-market competition. Specifically, the costs of delivering HRS to each market *i* from each location *j* were defined as:

$$P_{ij} = F + \mathrm{Max}(B_{1j}-T_{1j},B_{2j}-T_{2j},B_{3j}-T_{3j}) + T_{ij} + X_i \qquad (1)$$

where P_{ij} is the price of HRS at market *i* (1=PNW, 2=Gulf, and 3=Minneapolis) from origin *j* (*j*=1-20, representing 20 crop reporting districts within the HRS production area); F is the futures price; B_{ij} is the basis value for market *i* from origin *j*; T_{ij} is the shipping cost to market *i* from origin *j*; and X_i is the testing/verification cost for market *i*.

The probability of characteristic *k* conforming to a requirement was defined as:

$$\mathrm{Prob}\ (Y_k = 1), \qquad (2)$$

and the joint probability for the wheat lot as:

$$\mathrm{Prob}\ (\prod Y_k = 1), \qquad (3)$$

where Y_k= 1 if the quality target for the functional characteristic *k* is satisfied, $\prod Y_k$= 1 if the joint probability of quality specifications for all functional characteristics is satisfied, and *k*= 1…….n, representing absorption, peaktime, stability, loaf volume, flour protein, flour ash, and flour extraction.

Data Sources and Distributions

Wheat quality functional characteristic requirements are shown in Table 1 and were obtained from industry representatives. Ultimately, these are the requirements in the model and would vary across end-uses, countries, and processing technologies. Those in Table 1 are fairly typical of products (e.g., frozen dough, blends, variety breads) produced from HRS.

Table 1. Wheat and Functional Characteristic Requirements

Wheat and Functional Characteristic	Target Value
Wheat Characteristics	
Wheat Protein (%)	14.2
Test Weight (lbs/bushel)	60
Moisture (%)	12.5
Falling Number (sec)	400
1000 Kernel Weight (g)	30
Functional Characteristics	
Absorption (%)	63
Peaktime (min)	7
Stability (min)	14
Loaf Vol. (cc/100g Loaf)	1000
Flour Characteristics	
Flour protein (%)	12
Extraction (%)	68
Ash (% dry basis)	0.47

Twenty origins defined as Crop Reporting Districts (CRDs) throughout the HRS wheat-producing region were used. Prices at each origin (CRD) are determined through inter-market competition between three markets: Minneapolis (MPLS), the Pacific Northwest (PNW), and the Gulf of Mexico. Basis differentials and freight rate relationships cause the purchasing costs to vary geographically, generally increasing in the westerly CRDs. Average costs and probabilities of conforming to requirements were determined for supplying the PNW market from each CRD.

Since the futures value would affect all strategies similarly, a fixed value was assumed. The futures value used was obtained from the Minneapolis Grain Exchange for July 27, 2002. Distributions for basis values were assumed normal with mean values equal to those present on July 27, 2002 (35 c/bu for MPLS and 78 c/bu for PNW). Standard deviations for basis distributions were 34 c/bu for MPLS and 38 c/bu for PNW, which are representative of monthly observations for MPLS and PNW 14 percent HRS basis from August 1991 to July 2002 (USDA-AMS). The estimated correlation of basis values from 1991-2002 was .92 and was incorporated in the simulation model. Shipping costs were 52 car rates taken from the Burlington Northern Sante Fe Railroad for each CRD on July 27, 2002.

Testing costs for location and variety were obtained from CII Laboratories (2002) and functional characteristic testing costs from the Canadian Grain Commission (2002) were used. Costs were $100/sample for a location monitoring test (e.g., auditing), $300/sample for an electrophoresis variety test, $40/sample for a farinograph test, $30/sample for a loaf volume test, and $17/sample for a flour protein test. Each sample was assumed representative of every two grain cars (i.e., every 6,600 bushels). The farinograph, loaf volume and flour protein tests were incorporated using a hypogeometric function at a 95 percent accuracy level. Some testing costs were elusive, as they are not yet extensively used. Therefore, approximate costs were used in the simulations to measure their probabilities.

Wheat Quality Characteristics

All wheat and functional characteristic data were obtained from a Spring Wheat Baker's (SWB) data set for the 1999 and 2000 harvest years. It includes functional and wheat characteristics representative of the entire HRS producing region. The data set is comprised of 316 samples, including 154 from 1999 and 162 from 2000. Simple statistics and correlations for each variable, including wheat protein, moisture level, falling number, test weight, thousand kernel weight, stability, peaktime, ash content, loaf volume, absorption, extraction, and flour protein, are shown in Tables 2 through 4.

Distributions for each were derived using distribution fitting capabilities in *@Risk* (Palisade, 1997) and are shown in Table 3. Results indicate that normal distributions were always one of the top three distributions for fitting data on individual characteristics. Thus, normal distributions were used to represent all variables in the simulations.

Table 2. Statistics for Wheat and End-Use Characteristics

Variable	N	Mean	Std Dev	Minimum	Maximum
Wheat Protein	306	14.42	0.83	11.88	17.22
Moisture level	316	12.32	0.93	9.79	16.32
Falling Number	308	437.51	54.73	185.07	571.72
Test Weight	316	60.25	1.43	55.72	63.72
1000 KW	313	30.74	2.55	23.86	41.35
Stability	242	17.66	6.21	5.54	28.51
Peaktime	242	8.91	2.11	4.71	20.28
Ash	145	0.51	0.04	0.05	0.52
Volume	314	11.96	2.88	5.01	20.06
Absorption	243	62.89	1.98	55.91	68.71
Extraction	312	69.39	4.44	20.81	81.21
Flour Protein	145	12.71	0.76	10.71	14.71

Table 3. Distributions for Wheat and Functional Characteristics

Variable	Distribution	Mean	Std Dev
Wheat Protein (%)	Normal	14.42	0.87
Test Weight (lbs/bushel)	Normal	60.21	1.49
Moisture (%)	Normal	12.35	0.96
Falling Number (sec)	Normal	437.52	54.72
1000 Kernel Weight (g)	Logistic	30.65	1.36
Absorption (%)	Normal	62.83	1.93
Peaktime (min)	Ext. Value	8.01	1.62
Stability (min)	Normal	17.61	6.29
Extraction (%)	Logistic	69.65	1.46
Loaf Vol. (cc/100g Loaf)	Logistic	11.71	1.62
Flour protein (%)	Logistic	12.71	0.39
Ash (% dry basis)	Normal	0.46	0.04

The correlation matrix used in all simulations for each functional characteristic is:

Table 4. Correlation Matrix

	Absorption	Peaktime	Ash	Stability	Extraction	Volume	Flour Protein
Absorption	1.00	-0.16	0.13	-0.24	0.01	0.15	0.31
Peaktime		1.00	-0.33	0.52	-0.04	0.05	0.04
Ash			1.00	-0.06	-0.12	0.06	0.07
Stability				1.00	-0.18	0.23	-0.16
Extraction					1.00	-0.01	-0.01
Loaf Volume						1.00	0.25
Flour Protein							1.00

Separate regression models were estimated for each functional characteristic and interaction terms for location and variety were included to reflect differences associated with these parameters. The base model was specified as:

$$Y_i = f_1(X_t) + \varepsilon \,, \tag{4}$$

where Y_i is a vector of functional characteristics (i.e., absorption, stability, peaktime, loaf volume, ash content, and flour extraction), X_t is a vector of wheat characteristics [i.e., wheat protein (%), test weight (lbs/bu), falling number (seconds), 1000 kernel weight (g), and moisture level (%)], and ε is the error term. Other specifications included:

$$Y_{i=} f_2(X_t, V_{ik}) + \varepsilon \,, \tag{5}$$

where $V_{i,k}$ is variety *k* in sample *i*,

$$Y_i = f_3(X_t, O_{ij}) + \varepsilon \,, \tag{6}$$

where O_{ij} is origin *i* delivered to market *j*, and

$$Y_i = f_4(X_t, O_{ij}, V_{ik}) + \varepsilon \,. \tag{7}$$

Significant t-statistics at a 5 percent level were considered in choosing which characteristics were significant. Insignificant variables were excluded. Table 5 shows selected results and those for all regressions are in Appendix A. Figures 2 and 3 show the relationship of wheat protein with absorption and stability.

Table 5. Regression Results (Adj. R^2 and RMSE)

	Variables						
Model	Flour Protein	Flour Extraction	Flour Ash	Absorption	Stability	Loaf Volume	Peaktime
				R^2			
Model 1	0.55	0.11	0.05	0.33	0.22	0.16	0.04
Model 2	0.59	0.28	0.06	0.48	0.27	0.28	0.08
Model 3	0.59	0.24	0.08	0.39	0.23	0.15	0.16
Model 4	0.62	0.35	0.05	0.50	0.28	0.33	0.14
				RMSE			
Model 1	0.49	2.02	0.04	1.53	5.67	2.65	2.12
Model 2	0.47	1.82	0.04	1.35	5.55	2.43	2.07
Model 3	0.47	1.87	0.04	1.46	5.60	2.72	2.02
Model 4	0.45	1.73	0.05	1.32	5.39	2.35	2.04

Model 1 is Base model, Model 2 includes variety, Model 3 includes locations, and Model 4 includes varieties and locations.

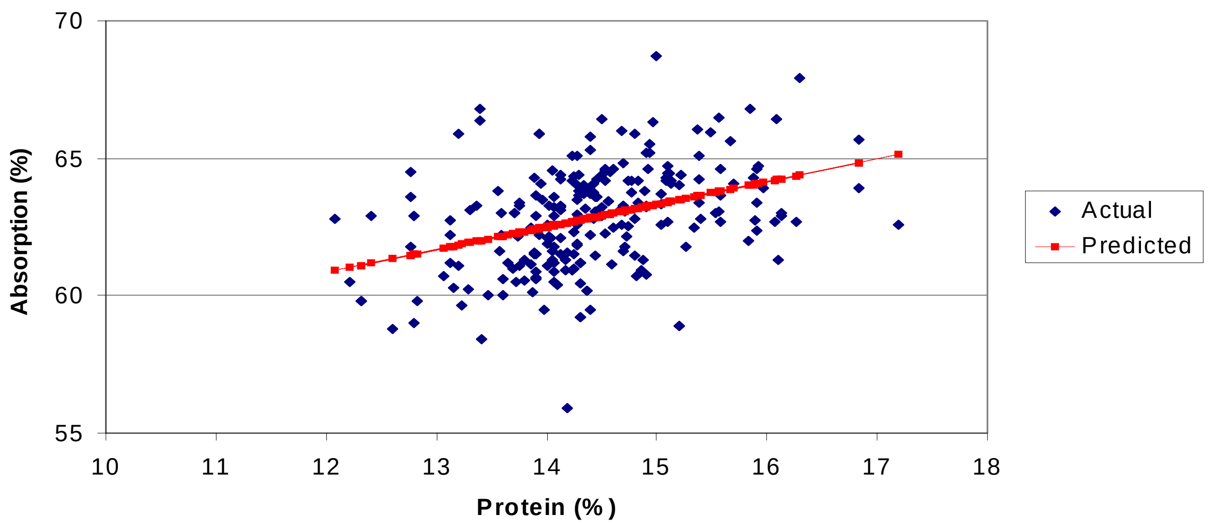

Figure 2. Relationship Between Absorption and Wheat Protein.

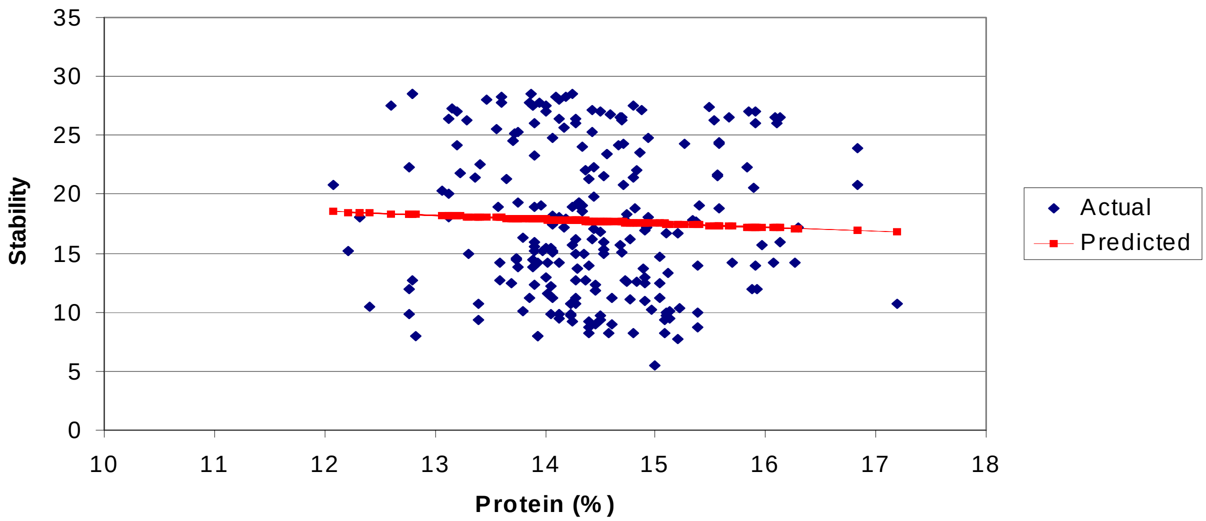

Figure 3. Relationship Between Stability and Wheat Protein.

Simulation Procedures

Stochastic simulation was used to determine procurement costs and risks of alternative strategies to the PNW. The simulation determined the procurement costs from each individual CRD, and the probability of meeting individual and joint end-user requirements. The model was simulated using *@Risk* (Palisade, 1997). One thousand iterations of each model were run, at which time acceptable stopping criteria were reached. The simulation incorporated correlations between functional characteristics within the model. The RMSE was the measure of uncertainty for each functional characteristic constructing the RHS variables. Risk is measured by the joint probability of meeting the desired end-use requirements. Sensitivities for delivery to alternative markets were examined.

Six separate procurement strategies were simulated. All regressions included functional characteristics (e.g., peaktime) as dependent variables while independent variables (e.g., wheat characteristics, location dummy variables, and variety dummy variables) were altered to allow different effects to be imposed on the functional characteristics. Strategies simulated included wheat characteristics (e.g., protein and test weight), adding variety specification (e.g., McNeal), a CRD location dummy (e.g., MN-1), adding both a variety and location dummy, and adding functional characteristic tests. These converged to contract strategies using wheat specification only, and specifications including variety, location, variety and location, and functional specifications. Seven dependent functional characteristics were evaluated, including ash (% dry basis), flour protein (%), extraction (%), absorption (%), loaf volume (cc per 100 gram loaf), peaktime (minutes), and stability (minutes).

RESULTS AND SENSITIVITIES

Base Case Results: Wheat Characteristics

Results from these simulations were used to determine the probability that each requirement is met. Two separate models were simulated and the probability of all characteristics being met was derived. The first model derived probabilities of conforming to quality requirements throughout the HRS wheat growing region based on wheat characteristics. The second model considered buying HRS wheat based on wheat characteristics and protein levels. As protein levels increase, the likelihood of conforming to requirements increases, but procurement cost increases as well.

The probabilities of meeting functional requirements based on wheat characteristics are shown in Table 6. There is a .95 probability that absorption will be greater than or equal to 60 percent, and a probability of .59 that all functional characteristics meet their target values based on a joint probability of absorption, peaktime, stability, and loaf volume. The functional characteristic that is most difficult to satisfy is stability.

Table 6. Probability of Meeting Requirements
(Wheat Characteristics Model)

Functional Characteristic	Prob. of Meeting Requirements
Absorption	.95
Peaktime	.98
Stability	.71
Loaf Volume	.90
Joint Probability	.59
Flour Characteristics Ash	.99
Flour Protein	.90
Flour Extraction	.82
Average Cost (c/bu)	478

One way to improve quality is to specify a greater protein level. The wheat protein model varied protein levels from 13.0 percent to 15.0 percent by increments of 0.5 percent and results derived for each (Table 7 and Figure 4). Stability was the only variable that showed a decrease in probability due to a negative relationship with protein. Results show that end-users can improve end-use conformance by specifying higher protein levels. Costs, however, increase as protein premiums increase.

Table 7. Probability of Meeting Requirements (Wheat Protein Sensitivity Model)

	Wheat Protein				
Functional Characteristic	13.0%	13.5%	14.0%	14.5%	15.0%
Absorption	.88	.91	.93	.96	.98
Peaktime	.91	.98	.98	.99	.99
Stability	.75	.74	.72	.70	.67
Loaf Volume	.67	.69	.87	.91	.93
Joint Probability	.25	.41	.53	.60	.62
Average Cost (c/bu)	469	473	477	481	485

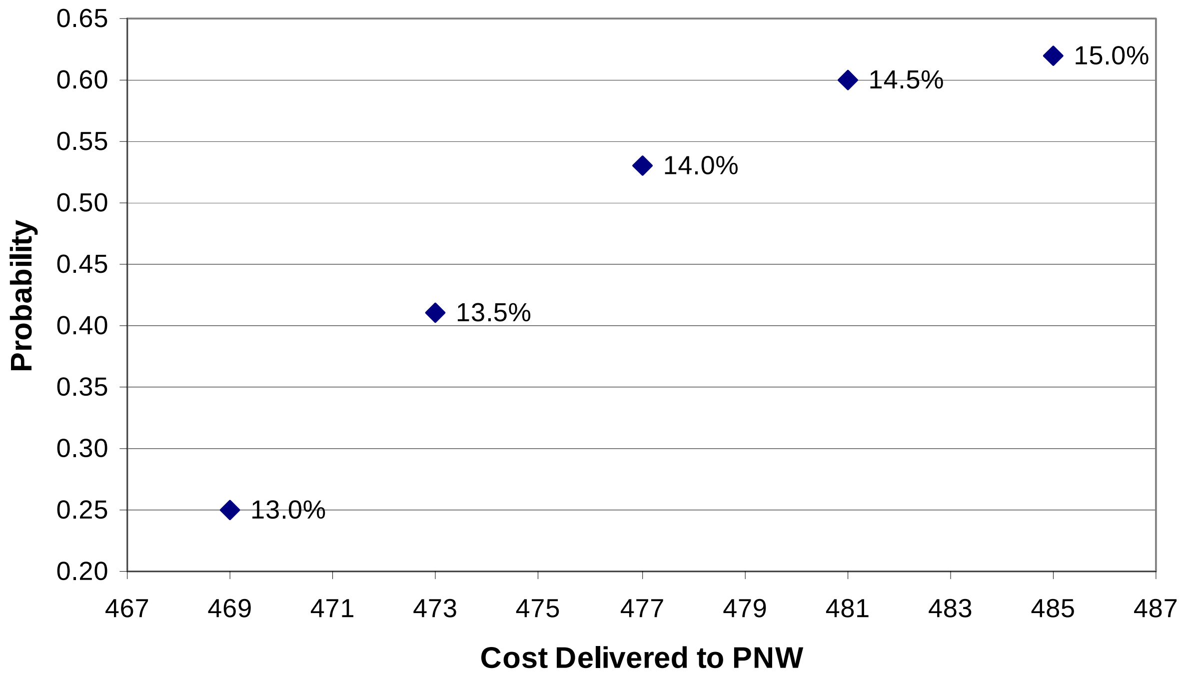

Figure 4. Relationship Between Joint Probability and Average Cost (PNW) (Wheat Protein Model).

Variety and Location Results

Three separate variety and location models were used to determine the cost and probability of meeting functional requirements for HRS wheat. The first included specifying one of the more popular varieties in recent years. The second included specification for targeted locations defined as crop reporting districts (CRDs). The third included combinations of varieties and CRDs. A total of 115 separate location/variety combinations were analyzed.

Strategy 1.1: Wheat Characteristics and Varieties

This model incorporated the effect of variety on functional characteristics. The eight varieties analyzed included the more popular varieties in recent years (2375, Ernest, Forge, Gunnar, Ingot, McNeal, Oxen, and Russ). The RMSE for each equation varied from the initial model which impacted the probability of meeting requirements. The first model included variety specifications along with these wheat characteristics: protein, test weight, thousand kernel weight, falling number, and moisture. A testing cost of $300/sample (assuming five samples for every ten grain cars) for an electrophoresis test was added to the average procurement cost per bushel to allow for targeting varieties.

Average cost for each variety is calculated for the CRDs in which each variety is grown (Table 8). The increase in cost is due to a variety testing cost and the added cost of the location in which a variety is grown. Varieties grown in the eastern HRS producing region (e.g., 2375) are higher cost going west than varieties grown in the western region (e.g., McNeal) when delivered to the PNW.

Table 8. Probability of Meeting Requirements (Wheat Characteristics and Variety Model)

	Variety						
Functional Characteristic	2375	Forge	Gunnar	Ingot	McNeal	Oxen	Russ
Absorption	.95	.95	.94	.95	.95	.96	.99
Peaktime	.72	.92	.61	.78	.71	.86	.79
Stability	.54	.89	.39	.85	.80	.84	.61
Volume	.56	.68	.70	.94	.99	.82	.79
Joint Probability	.32	.53	.39	.63	.62	.57	.45
Average Cost (c/bu)							
PNW	492	496	487	496	468	496	493
MPLS	427	423	435	430	479	426	430

The variety Ingot shows the highest probability of meeting all functional requirements and is followed by McNeal. Varieties 2375 and Gunnar have the lowest probability of meeting all functional requirements. Average costs are all similar except for McNeal, which is grown primarily in the Montana CRDs, where delivered wheat prices are lower when shipped to the PNW. The least cost variety strategy for delivery to the Minneapolis market is Forge.

Strategy 1.2: Wheat Characteristics and Location

The effect of buying based on wheat characteristics and location was examined. Wheat was purchased by location, a location verification test cost of $100/sample was applied, and it was assumed that 5 samples were taken for every 10 grain cars. A location specification cost was added for monitoring IP at each location. This test is envisioned as a cost of auditing, which is common in IP transactions.

The greatest probability of meeting all functional requirements are MT2, ND9, and SD3 CRDs, respectively (Table 9). The lowest probabilities of meeting functional requirements are found in the MT8, MT9, and ND5 CRDs. Stability resulted in lower probabilities in all three CRDs. Without including stability, MT8 and MT9 would yield higher overall probabilities compared to most other CRDs. Low loaf volume probabilities reduced MT3 and MT5. If loaf volume had not been included, both of these CRDs would have fared well compared to other CRDs. Finally, depending on the procurement practices, end-users may only consider one or a few functional characteristics when making a purchase.

The minimum cost strategy, while meeting all requirements with a probability of at least 0.4, is to buy from either CRDs, MT2 or ND7. Montana varieties have a much lower cost than ND9 when shipped to the PNW, but these costs are reversed when shipping to MPLS. A greater than 0.6 probability of meeting minimum requirements would eliminate all CRDs except for MT2 and MT5 from procurement.

Table 9. Probability of Meeting Requirements (Wheat Characteristics and Location Model)

Functional Characteristic	Location										
	MN1	MN4	MT2	MT3	MT5	MT7	MT8	MT9	ND1	ND2	ND3
Absorption	0.91	0.86	0.89	0.99	0.99	0.99	0.98	0.77	0.96	0.99	0.93
Peaktime	0.82	0.79	0.88	0.91	0.99	0.90	0.41	0.85	0.80	0.81	0.77
Stability	0.76	0.71	0.90	0.80	0.80	0.64	0.46	0.49	0.64	0.67	0.56
Volume	0.75	0.72	0.87	0.86	0.75	0.67	0.87	0.53	0.76	0.74	0.66
Joint Probability	0.45	0.39	0.67	0.59	0.62	0.55	0.34	0.37	0.46	0.49	0.44
Average Cost (c/bu)											
PNW	498	506	463	463	463	463	463	463	470	477	494
MPLS	420	420	487	487	473	487	473	473	473	450	420

	ND4	ND5	ND6	ND7	ND8	ND9	SD2	SD3	SD5
Absorption	0.99	0.95	0.94	0.96	0.96	0.93	0.95	0.66	0.97
Peaktime	0.88	0.63	0.82	0.88	0.94	0.85	0.83	0.85	0.70
Stability	0.72	0.46	0.64	0.75	0.85	0.80	0.81	0.89	0.66
Volume	0.81	0.55	0.69	0.65	0.49	0.84	0.86	0.93	0.85
Joint Probability	0.46	0.35	0.43	0.48	0.40	0.52	0.55	0.51	0.42
Average Cost (c/bu)									
PNW	475	488	500	466	479	501	477	490	493
MPLS	446	420	420	430	420	420	420	420	420

Figures 5 and 6 show the relationship between average cost for shipments to the PNW and MPLS, respectively, and the probability of meeting requirements. Western North Dakota and Montana are the cheapest locations for procurement and have some of the highest probabilities of meeting requirements and should be targeted locations for procurement when delivering to the PNW. Other locations are either higher cost and/or lower probability of conforming. When delivering to the MPLS market (Figure 6), buyers are faced with a clear cost/risk tradeoff: there is a high cost and high probability of conformance at MT and a low cost and low probability of conformance at MN. For example, MT2 had the highest probability of conforming (.67), but is also the highest cost CRD for delivery to MPLS (4.87). In contrast, most of the ND and MN locations are lowest cost (420), but have lesser probabilities of conforming (.35 - .55).

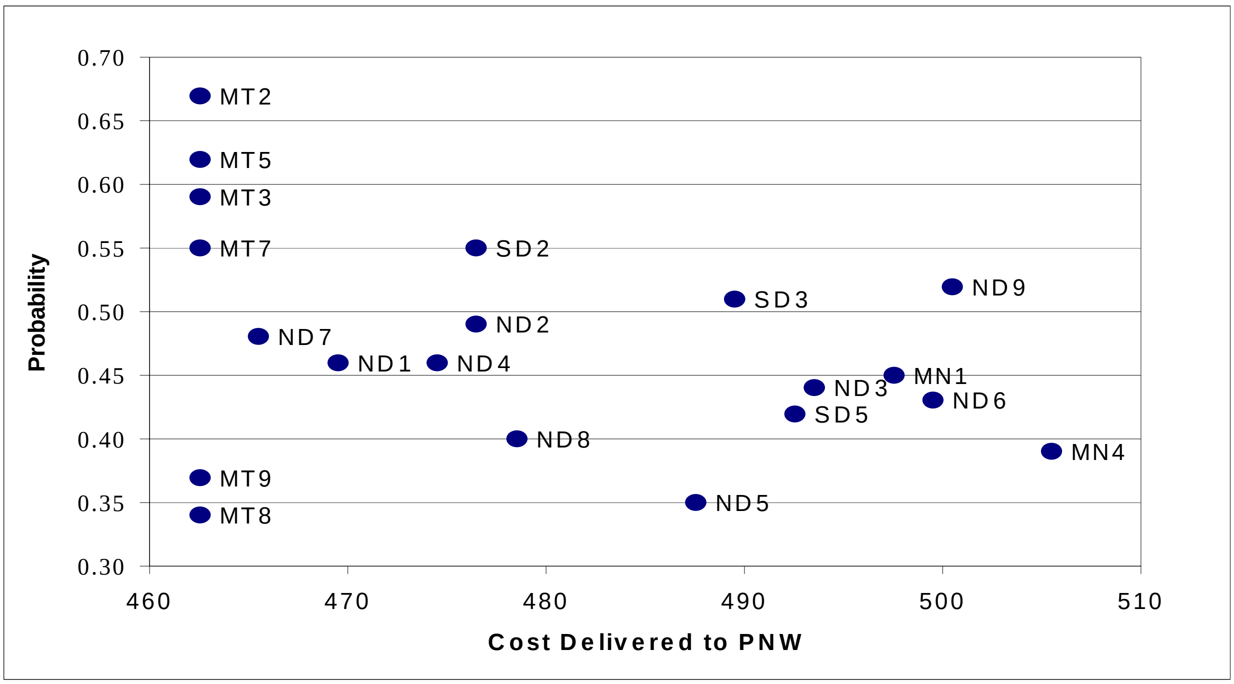

Figure 5. Relationship Between Joint Probability and Average Cost (PNW) (Wheat Characteristics and Location Model).

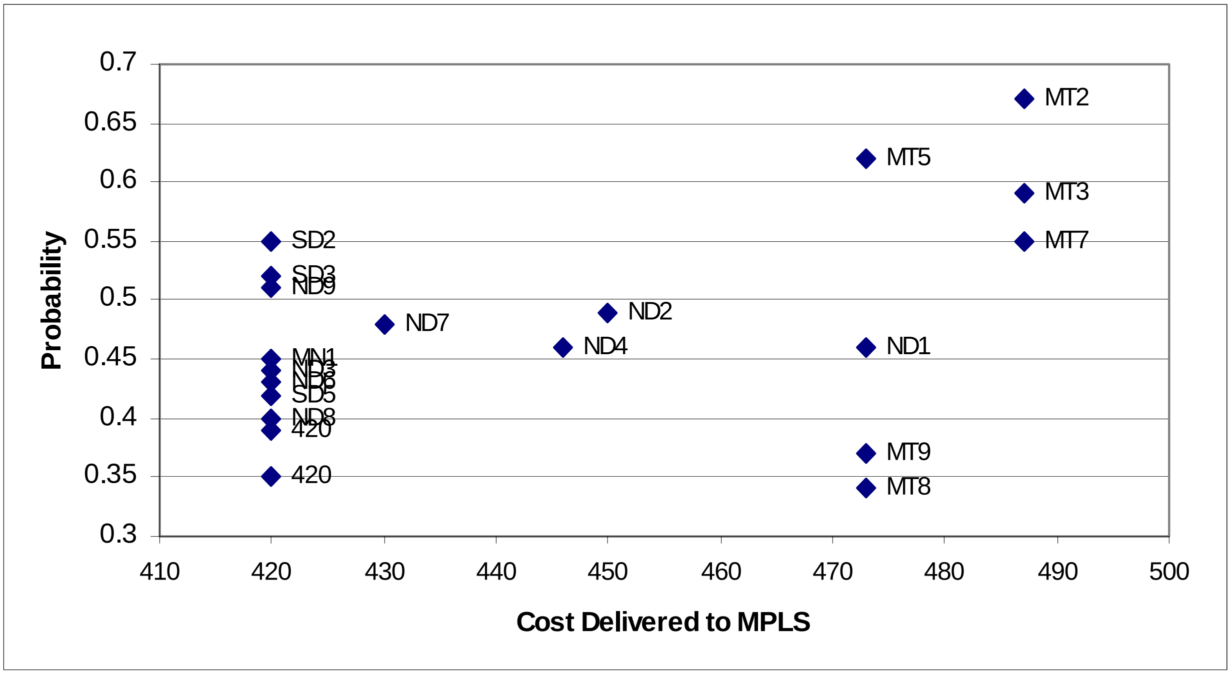

Figure 6. Relationship Between Joint Probability and Average Cost (MPLS) (Wheat Characteristics and Location Model).

Strategy 1.3: Wheat Characteristics and Variety and Location

This model incorporated the joint specification and effect of variety and location on functional characteristics. A total of 115 separate location/variety combinations were analyzed. Both variety and location test costs are included. Tables 10-12 show results based on wheat characteristics, location, and variety (for seven different varieties). Average cost delivered to the PNW was calculated for each location. The results presented are the most interesting. See Appendix B for a complete set of results.

Results show that the MT9 and SD2 CRDs should be targeted regions. Ingot and McNeal are the preferred varieties; however, McNeal is grown primarily in Montana and has a lower procurement cost for delivery to the PNW from MT9 than does Ingot from SD2.

Minnesota, eastern North Dakota, and South Dakota were the highest cost CRDs for the PNW. Varieties 2375 and Gunnar scored the lowest probability of meeting end-user needs, and costs were higher for both varieties than most of their competing varieties.

Ingot was the best performing variety in North Dakota and Minnesota, yielding a high probability of conformance in every CRD grown. The minimum cost strategy to meet requirements with a probability of 0.4 is to buy Forge, Ernest, Oxen, Russ, Ingot, or McNeal from any CRD, but avoid Gunnar and 2375 at all locations. When the minimum probability of conforming to requirements is increased from 0.4 to 0.5 and then to 0.6, varietal choice switches to Ingot and McNeal with location choices moving farther west and north in the HRS producing region. MT2 and McNeal are the best choice when considering cost/risk tradeoffs delivered to the PNW, whereas ND6 and Ingot are the best choice considering cost/risk tradeoffs delivered to MPLS.

Table 10. Probability of Meeting Requirements MN1 and MT9 (Wheat Characteristics, Location, and Variety Model)

Functional	MN1Variety						MT9 Variety	
Characteristic	2375	Forge	Gunnar	Ingot	Oxen	Russ	Ernest	McNeal
Absorption	.97	.92	.99	.94	.95	.99	.78	.99
Peaktime	.48	.86	.47	.75	.80	.69	.99	.84
Stability	.53	.90	.43	.83	.82	.58	.89	.79
Loaf Volume	.83	.83	.93	.98	.91	.91	.40	.99
Joint Probability	.37	.47	.41	.69	.56	.48	.38	.69
Average Cost (c/bu)								
PNW	503	503	503	503	503	503	467	467
MPLS	424	424	424	424	424	424	491	491

Table 11. Probability of Meeting Requirements ND6 (Wheat Characteristics, Location, and Variety Model)

Functional	Variety					
Characteristic	2375	Forge	Gunnar	Ingot	Oxen	Russ
Absorption	.99	.95	.99	.97	.98	.99
Peaktime	.54	.89	.52	.79	.84	.74
Stability	.44	.85	.34	.77	.75	.48
Loaf Volume	.79	.79	.90	.97	.88	.88
Joint Probability	.34	.60	.35	.68	.64	.47
Average Cost (c/bu)						
PNW	504	504	504	504	504	504
MPLS	424	424	424	424	424	424

Table 12. Probability of Meeting Requirements SD2 (Wheat Characteristics, Location, and Variety Model)

Functional	Variety			
Characteristic	Forge	Ingot	Oxen	Russ
Absorption	.94	.96	.97	.99
Peaktime	.91	.82	.86	.77
Stability	.95	.91	.90	.72
Loaf Volume	.93	.99	.97	.97
Joint Probability	.64	.73	.57	.50
Average Cost (c/bu)				
PNW	481	481	481	481
MPLS	424	424	424	424

The probability of meeting requirements increases with location and variety models compared to the base case (Table 13). The variety and location model provides the highest probability of conformance; whereas, the location model provides the lowest cost. Base case costs are higher because cost is aggregated across CRDs as no locations or varieties were specified. Therefore, when varieties and locations are specified, the lowest cost varieties and locations that meet requirements should be targeted.

Table 13. Probability of Meeting Requirements (Comparison Between Base Case and Location, Variety Models)

Functional Characteristic	Base Case	Varieties	Locations	Varieties & Locations
		McNeal	MT2	McNeal in MT9
Absorption	0.95	0.95	0.89	0.99
Peaktime	0.98	0.71	0.88	0.84
Stability	0.71	0.80	0.90	0.79
Loaf Volume	0.90	0.99	0.87	0.99
Joint Probability	0.59	0.62	0.67	0.69
Average Cost (c/bu)				
PNW	478	468.3	462.5	467.0

Wheat Characteristics and Functional Characteristics

This model analyzed the effect of specifying functional characteristics which were tested for verification. Tests were conducted at costs of $40/sample for a farinograph test and $30/sample for a loaf volume test. All tests are 95 percent accurate, and 5 samples for every 10 grain cars were tested. The farinograph and loaf volume tests were incorporated using a hypogeometric function at a 95 percent accuracy level to derive individual and joint probabilities. If the characteristic is not met with the test, it is rejected. Two models were analyzed. The first included tests for absorption, peaktime, and stability using a farinograph test. The second included testing for absorption, peaktime, stability, and loaf volume. All probabilities are based on wheat and functional characteristic requirements. Average procurement costs delivered to the PNW are also derived.

The joint probability of meeting requirements is .75 when the farinograph test is conducted (Table 14). Probabilities of meeting absorption, peaktime, and stability requirements all increased to .95, and procurement cost increased by 2 cents per bushel. The results indicate that testing for loaf volume, although it does not have as much impact on the results as the farinograph test, improves the likelihood of conforming to end-user requirements. The largest increase in conformance for a characteristic comes from inclusion of loaf volume which results in an increase from .88 to .95. This also resulted in an increase in the joint probability of meeting all requirements from .75 to .81. Average cost increased 1 cent per bushel.

Table 14. Probability of Meeting Requirements (Comparison Between Base Case and Functional Models)

Functional Characteristic	Base Case	Farinograph	Loaf Volume
Absorption	0.95	0.95	0.95
Peaktime	0.98	0.95	0.95
Stability	0.71	0.95	0.95
Loaf Volume	0.90	0.88	0.95
Joint Probability	0.59	0.75	0.81
Average Cost (c/bu)			
PNW	478	480	481

The probability of meeting requirements increases considerably when functional characteristic tests are performed with minimal cost compared to the base case.

Sensitivities were conducted to evaluate change in costs/risks for different levels of requirements for functional characteristics. Tables 15 through 17 show the probability of meeting functional requirements based on wheat characteristics while varying different target values of functional characteristics. The results indicate that, as functional specifications increase, they become more difficult to satisfy and the probability of meeting requirements declines. Absorption shows the largest decline when the minimum specification is increased from 60 percent to 64 percent. Probabilities of peaktime and stability meeting requirements show a less dramatic decline when minimum specifications are increased. Stability, however, drops from 71 percent to a 44 percent chance of meeting requirements when its minimum value is increased from 14 minutes to 18 minutes.

Table 15. Probability of Meeting Requirements (Wheat Characteristics and Absorption = 56%, 60%, and 64%)

	Absorption		
Functional Characteristic	56%	60%	64%
Absorption	.99	.95	.15
Peaktime	.99	.99	.99
Ash	.99	.99	.99
Stability	.71	.71	.71
Flour Extraction	.81	.82	.81
Loaf Volume	.72	.72	.72
Flour Protein	.90	.90	.90
Joint Probability	.39	.36	.06

Table 16. Probability of Meeting Requirements (Wheat Characteristics and Peaktime = 4 minutes, 7 minutes, and 10 minutes)

Functional Characteristic	Peaktime		
	4 Min.	7 Min.	10 Min.
Absorption	.95	.95	.94
Peaktime	.99	.98	.77
Ash	.99	.99	.99
Stability	.71	.71	.71
Flour Extraction	.82	.81	.81
Loaf Volume	.72	.72	.72
Flour Protein	.90	.90	.89
Joint Probability	.39	.36	.33

Table 17. Probability of Meeting Requirements (Wheat Characteristics and Stability = 10 minutes, 14 minutes, and 18 minutes)

Functional Characteristic	Stability		
	10 Min.	14 Min.	18 Min.
Absorption	.94	.94	.94
Peaktime	.98	.98	.98
Ash	.99	.99	.99
Stability	.90	.71	.44
Flour Extraction	.81	.81	.81
Loaf Volume	.72	.72	.72
Flour Protein	.90	.89	.89
Joint Probability	.47	.37	.23

SUMMARY

Consistency for functional characteristics in wheat is a major problem faced in the relationship between suppliers and end-users. Variability in quality for functional characteristics has implications for food processors including the risk of not conforming to requirements, greater costs associated with higher quality purchasing, and increased operating costs associated with likely stock-out costs due to nonconformance. A common procurement strategy designed to alleviate this problem is to purchase based on wheat protein levels. Less common alternative strategies include vertical integration, targeting of origins, and pre-shipment samples. End-users use these procurement strategies as a means to improve quality in their final product. However, changes in varieties planted, along with variable growing conditions, have led to increased conformance uncertainties.

Procurement strategies were modeled using stochastic simulation to estimate procurement costs and risks. Procurement strategies included purchase by variety, location, variety and location, and strategies with tests for functional characteristics. Procurement costs delivered to PNW and MPLS markets, and the probability of meeting buyer requirements, were estimated. The models utilized estimated functional relationships and correlations between wheat characteristics and functional characteristics to determine probabilities of meeting buyer requirements. Testing costs for varieties and functional characteristics were included in sensitivities involving these requirements.

The probability of meeting functional targets increases as purchase strategies increase in specificity from purchase by protein to incorporation of functional characteristics (Table 18). Costs increase as well. The base case involves procuring HRS based solely on protein levels; whereas, the variety model bases its purchases on specific varieties. End-users face the choice of either a higher probability of conformance through variety purchases with higher costs, or a lower probability of conformance through protein purchases with lower costs.[1] Functional testing yields the highest joint probability of conformance but at a higher cost. The location and variety models are less costly than the high protein strategies and yield similar results, providing evidence that these strategies are optimal.

Table 18. Comparison of Strategies

Strategy*	Probability of Conformance (Joint)	Cost Delivered PNW (c/bu)
Base Case	0.59	478
Wheat and Protein 13%	0.25	469
Wheat and Protein 14%	0.53	477
Wheat and Protein 15%	0.62	485
Location	0.67	463
Variety	0.62	468
Location and Variety	0.69	467
Functional Tests	0.81	481

*All strategies include requirements for protein.

The results quantified costs and risks of these alternative procurement strategies in the case of HRS shipments to the U.S. West Coast. The results indicate that there is substantial risk of not meeting functional trait requirements using conventional contracts. These risks can be mitigated by specifying either targeted variety, locations, or both, though at higher costs. Use of functional trait specifications in contracts, even at higher costs, is a much more cost-effective means of reducing these risks.

HRS suppliers and end-users can utilize contract requirements to improve quality. The wheat protein model, which is used extensively by end-users, involves modest cost increases (protein premiums), and protein levels are easy to measure. More specific strategies, such as location and/or variety involve greater communication between producers and end-users. Long-term relationships could likely develop to facilitate such a contract.

[1] Issues of dominance of strategies are examined in a companion piece (Wilson and Dahl, *forthcoming*).

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APPENDIX A

Table A.1. Regression Results: Absorption

Variables	Mod. 1		Mod. 2		Mod. 3		Mod. 4		Mod. 5		Mod. 6		Mod. 7	
	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.
Intercept	35.711	6.5	29.041	4.8	32.728	5.3	29.167	4.4	32.045	3.7	33.551	3.6	34.376	3.5
Wheat Protein	0.947	7.5	0.898	7.0	0.807	5.3	0.772	5.0	0.626	2.5	0.641	2.5	0.624	2.4
Moisture	-0.442	-4.0	-0.338	-3.0	-0.294	-1.6	-0.251	-1.5	-0.333	-2.3	-0.362	-2.5	-0.380	-2.5
Falling Number	0.002	1.0	-0.001	-0.7	0.002	1.2	0.001	-0.3	0.001	-0.3	0.000	-0.1	0.001	-0.2
Test Weight	0.232	3.1	0.383	4.7	0.259	3.1	0.372	4.0	0.236	1.9	0.254	1.9	0.246	1.8
1000 Kernel Weight	0.136	3.0	0.083	1.8	0.137	2.8	0.086	1.7	0.180	2.6	0.147	2.0	0.151	2.0
d2375			-0.210	-0.6			-0.207	-0.6						
Forge			-1.212	-2.7			-0.897	-1.9						
Gunnar			0.310	0.8			0.344	0.8						
Ingot			-0.937	-2.0			-0.511	-1.0						
McNeal			2.289	4.9			2.028	4.0						
Oxen			-0.768	-2.3			-0.462	-1.2						
Russ			1.422	4.4			1.567	4.4						
MN1					0.699	1.0	0.350	0.5						
MN4					0.363	0.5	0.204	0.3						
MT2					1.409	1.6	0.990	1.2						
MT3					2.459	3.0	1.480	1.9						
MT5					2.459	2.5	1.842	2.0						
MT7					2.319	1.8	2.373	2.0						
MT8					2.162	1.7	1.125	0.9						
MT9					0.414	0.4	-0.499	-0.5						
ND1					1.551	1.9	0.823	1.1						
ND2					2.985	2.8	2.341	2.4						
ND3					1.120	1.4	0.551	0.8						
ND4					2.265	2.7	1.603	2.1						
ND5					1.387	1.7	0.665	0.9						
ND6					1.187	1.6	0.731	1.0						
ND7					1.580	2.2	1.235	1.8						
ND8					1.434	1.4	0.820	0.9						
ND9					1.058	1.3	0.540	0.7						
SD2					1.381	1.6	0.609	0.8						
SD3					-0.623	-0.6	-0.475	-0.5						
SD5					1.479	1.6	0.545	0.7						
Flour Protein									0.506	1.7	0.463	1.5	0.448	1.4
Absorption														
Stability											-0.006	-0.2	-0.010	-0.3
Peaktime											-0.091	-1.3	-0.091	-1.3
Loaf Volume													0.028	0.3
Adj. Rsquare	0.328		0.475		0.387		0.500		0.330		0.330		0.324	
RMSE	1.525		1.350		1.460		1.320		1.509		1.537		1.543	

PE is the parameter estimate, t-val. is the estimated t-statistic for the estimated parameter and RMSE is the root mean square error.

Table A.2. Regression Results: Stability

Variables	Mod. 1		Mod. 2		Mod. 3		Mod. 4		Mod. 5		Mod. 6		Mod. 7	
	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.
Intercept	129.20	6.3	101.81	4.3	108.05	4.6	101.38	3.8	121.94	4.2	116.47	4.1	129.41	4.7
Wheat Protein	-0.75	-1.6	0.16	0.3	-0.69	-1.2	0.14	0.2	0.61	0.7	0.54	0.7	-0.02	0.0
Moisture	-0.74	1.8	-0.11	-0.2	0.83	1.2	1.06	1.5	-0.67	-1.4	-0.45	-1.0	-0.95	-2.1
Falling Number	0.03	3.8	0.03	4.0	0.02	2.0	0.02	2.2	0.04	4.7	0.04	4.8	0.03	3.6
Test Weight	-1.69	-6.1	-1.58	-4.8	-1.63	-5.1	-1.78	-4.7	-1.45	-3.5	-1.68	-4.3	-1.71	-4.6
1000 Kernel Weight	-0.07	-0.4	-0.12	-0.6	0.00	0.0	-0.01	0.0	-0.14	-0.6	0.18	0.8	0.28	1.3
d2375			-2.58	-2.0			-1.73	-1.3						
Forge			3.51	1.9										
Gunnar			-4.95	-3.1			-3.36	-2.0						
Ingot			1.34	0.7			2.34	1.2						
McNeal			1.22	0.7			1.92	0.9						
Oxen			2.17	1.6			2.34	1.5						
Russ			-1.71	-1.3			-1.22	-0.8						
MN1					-0.66	-0.2	-1.10	-0.4						
MN4					-0.66	-0.2	-1.67	-0.6						
MT2					5.56	1.7	3.49	1.0						
MT3					2.84	0.9	2.63	0.8						
MT5					4.23	1.1	3.06	0.8						
MT7					1.25	0.3	1.48	0.3						
MT8					-1.27	-0.3	-2.98	-0.6						
MT9					0.46	0.1	0.02	0.0						
ND1					-1.34	-0.4	-1.46	-0.5						
ND2					-1.97	-0.5	-0.71	-0.2						
ND3					-3.20	-1.1	-3.03	-1.0						
ND4					0.05	0.0	-0.17	-0.1						
ND5					-4.56	-1.5	-4.38	-1.4						
ND6					-1.91	-0.7	-2.30	-0.8						
ND7					2.51	0.9	2.94	1.1						
ND8					3.01	0.8	3.26	0.9						
ND9					1.21	0.4	0.42	0.1						
SD2					1.93	0.6	0.97	0.3						
SD3					4.02	1.1	1.58	0.4						
SD5					0.10	0.0	0.76	0.2						
Flour Protein									-2.25	-2.2	-1.94	-2.0	-2.15	-2.4
Absorption											-0.06	-0.2	-0.08	-0.3
Stability														
Peaktime											0.87	4.4	0.78	4.1
Loaf Volume													0.84	3.6
Adj. Rsquare	0.22		0.27		0.23		0.28		0.24		0.35		0.42	
RMSE	5.67		5.39		5.55		5.36		5.19		4.80		4.54	

Table A.3. Regression Results: Ash

Variables	Mod. 1		Mod. 2		Mod. 3		Mod. 4		Mod. 5		Mod. 6		Mod. 7	
	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.
Intercept	0.428	2.2	0.289	1.1	0.325	1.5	0.227	0.8	0.468	2.2	0.096	0.4	0.085	0.3
Wheat Protein	0.009	2.2	0.013	2.6	0.009	1.9	0.012	2.1	0.012	2.0	0.010	1.4	0.010	1.4
Moisture	0.008	2.3	0.006	1.4	0.004	0.7	0.001	0.2	0.008	2.1	0.011	2.7	0.011	2.5
Falling Number	0.000	-0.2	0.000	-0.2	0.000	-0.3	0.000	-0.4	0.000	-0.2	0.000	-0.7	0.000	-0.6
Test Weight	-0.004	-1.4	-0.002	-0.7	-0.003	-0.9	-0.001	-0.4	-0.004	-1.5	0.001	-0.2	0.001	-0.2
1000 Kernel Weight	0.001	0.9	0.002	1.0	0.003	1.7	0.003	1.7	0.001	0.8	-0.002	-1.1	-0.002	-1.1
d2375			0.030	2.0			0.035	2.2						
Forge			0.025	1.5			0.022	1.3						
Gunnar			0.005	0.3			0.009	0.5						
Ingot			-0.004	-0.2			0.001	0.0						
McNeal			-0.009	-0.5			0.001	0.0						
Oxen			0.015	0.9			0.010	0.6						
Russ			0.025	1.8			0.025	1.7						
MN1					0.056	3.0	0.064	3.3						
MT3					0.022	0.9	0.030	1.1						
MT5					0.076	2.8	0.083	2.9						
MT7					0.044	1.5	0.048	1.6						
MT8					0.014	0.4	0.027	0.7						
MT9					0.032	1.0	0.035	1.1						
ND1					0.028	1.2	0.034	1.4						
ND2					0.074	2.5	0.070	2.2						
ND3					0.057	2.7	0.062	2.9						
ND4					0.048	2.2	0.048	2.2						
ND5					0.061	2.7	0.064	2.7						
ND6					0.056	2.8	0.061	3.0						
ND7					0.041	2.0	0.044	2.1						
ND8					0.056	2.2	0.054	2.0						
ND9					0.072	3.3	0.072	3.3						
SD2					0.068	2.9	0.071	3.0						
SD3					0.070	2.6	0.072	2.6						
SD5					0.068	2.5	0.069	2.5						
Flour Protein									-0.004	-0.6	-0.008	-1.0	-0.008	-0.9
Absorption											0.006	2.1	0.006	2.1
Stability											0.001	1.0	0.001	1.0
Peaktime											-0.006	-3.2	-0.006	-3.2
Loaf Volume													0.000	-0.2
Adj. Rsquare	0.053		0.061		0.081		0.086		0.049		0.159		0.150	
RMSE	0.042		0.042		0.042		0.046		0.042		0.043		0.043	

Table A.4. Regression Results: Peaktime

Variables	Mod. 1		Mod. 2		Mod. 3		Mod. 4		Mod. 5		Mod. 6		Mod. 7	
	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.
Intercept	21.501	2.8	8.095	0.9	16.481	1.9	7.645	0.8	8.435	0.6	-7.632	-0.5	-7.779	-0.5
Wheat Protein	0.019	0.1	0.261	1.3	-0.119	-0.6	0.030	0.1	0.123	0.3	0.129	0.4	0.131	0.4
Moisture	-0.170	-1.1	0.048	0.3	0.628	2.5	0.717	2.8	-0.281	-1.3	-0.221	-1.1	-0.218	-1.0
Falling Number	0.000	0.2	0.003	1.0	-0.004	-1.4	0.000	-0.1	0.002	0.5	-0.005	-1.3	-0.005	-1.3
Test Weight	-0.095	-0.9	0.028	0.2	-0.091	-0.8	-0.032	-0.2	0.285	1.5	0.589	3.2	0.590	3.1
1000 Kernel Weight	-0.170	-2.7	-0.197	-2.8	-0.190	-2.7	-0.178	-2.3	-0.355	-3.3	-0.297	-3.0	-0.298	-2.9
d2375			-1.195	-2.4			-0.893	-1.7						
Forge			0.378	0.5			0.970	1.4						
Gunnar			-1.948	-3.2			-1.209	-1.9						
Ingot			-1.041	-1.5			-0.213	-0.3						
McNeal			-1.133	-1.6			-1.441	-1.9						
Oxen			-0.080	-0.2			0.424	0.7						
Russ			-0.595	-1.2			-0.003	0.0						
MN1					-1.396	-1.4	-1.279	-1.3						
MN4					-1.275	-1.1	-1.226	-1.1						
MT2					1.403	1.2	1.566	1.2						
MT3					0.859	0.8	1.245	1.1						
MT5					3.297	2.4	3.514	2.5						
MT7					1.585	0.9	1.594	0.9						
MT8					-2.063	-1.2	-1.284	-0.7						
MT9					1.553	1.0	2.126	1.3						
ND1					-0.907	-0.8	-0.444	-0.4						
ND2					-1.281	-0.9	-0.351	-0.2						
ND3														
ND4					-0.173	-0.2	0.189	0.2						
ND5					-2.313	-2.0	-1.829	-1.6						
ND6					-1.061	-1.0	-0.952	-0.9						
ND7					0.936	0.9	1.107	1.1						
ND8					0.705	0.5	0.903	0.6						
ND9					-0.700	-0.6	-0.722	-0.6						
SD2					-0.627	-0.5	-0.764	-0.6						
SD3					-0.339	-0.2	-0.856	-0.6						
SD5					-1.251	-1.0	-1.325	-1.0						
Flour Protein									-0.323	-0.7	0.174	0.4	0.177	0.4
Absorption											-0.183	-1.3	-0.183	-1.3
Stability											0.180	4.4	0.181	4.1
Peaktime														
Loaf Volume													-0.005	0.0
Adj. Rsquare	0.037		0.084		0.158		0.134		0.065		0.215		0.269	
RMSE	2.123		2.073		2.044		2.015		2.376		2.178		2.189	

Table A.5. Regression Results: Flour Protein

Variables	Mod. 1		Mod. 2		Mod. 3		Mod. 4		Mod. 5		Mod. 6		Mod. 7	
	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.
Intercept	9.052	4.0	13.273	4.7	8.590	3.4	12.848	4.1	8.590	3.4	8.644	2.9	9.594	3.1
Wheat Protein	0.574	11.8	0.462	8.2	0.499	9.1	0.387	6.1	0.499	9.1	0.545	8.7	0.514	7.8
Moisture	-0.105	-2.5	-0.123	-2.7	-0.111	-1.8	-0.141	-2.2	-0.111	-1.8	-0.080	-1.7	-0.102	-2.1
Falling Number	0.000	-0.2	0.000	0.1	0.000	0.5	0.001	1.0	0.000	0.5	0.001	1.0	0.001	0.7
1000 Kernel Weight	-0.022	-1.3	-0.030	-1.8	-0.023	-1.3	-0.031	-1.7	-0.023	-1.3	-0.049	-2.2	-0.043	-1.9
d2375			-0.040	-0.2			-0.161	-1.0						
Forge			-0.545	-3.1			-0.513	-2.9						
Gunnar			0.392	1.9			0.364	1.8						
Ingot			0.166	0.8			0.203	0.9						
McNeal			-0.021	-0.1			-0.203	-0.9						
Oxen			-0.449	-2.5			-0.375	-2.1						
Russ			-0.085	-0.5			-0.019	-0.1						
MN1					-0.038	-0.2	-0.035	-0.2						
MN4					-0.126	-0.5	-0.103	-0.4						
MT2					0.072	0.3	0.091	0.4						
MT3					-0.162	-0.6	-0.122	-0.4						
MT5					0.309	1.0	0.324	1.0						
MT7					-0.051	-0.2	0.031	0.1						
MT8					0.435	1.1	0.359	0.9						
MT9					0.046	0.1	0.082	0.2						
ND1					0.245	0.9	0.255	0.9						
ND2					0.443	1.3	0.439	1.3						
ND3					-0.012	-0.1	0.034	0.2						
ND4					0.124	0.5	0.192	0.8						
ND5					0.085	0.3	0.095	0.4						
ND6					0.541	2.4	0.577	2.6						
ND7					0.140	0.6	0.107	0.5						
ND8					0.455	1.6	0.427	1.5						
ND9					0.173	0.7	0.222	0.9						
SD2					-0.216	-0.8	-0.159	-0.6						
SD5					-0.620	-2.0	-0.627	-2.1						
Flour Protein														
Absorption											0.046	1.5	0.044	1.4
Stability											-0.020	-2.0	-0.024	-2.4
Peaktime											0.009	0.4	0.009	0.4
Loaf Volume													0.036	1.4
Adj. Rsquare	0.553		0.589		0.588		0.621		0.588		0.585		0.588	
RMSE	0.489		0.471		0.470		0.452		0.470		0.484		0.482	

Table A.6. Regression Results: Flour Extraction

Variables	Mod. 1		Mod. 2		Mod. 3		Mod. 4		Mod. 5		Mod. 6		Mod. 7	
	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.
Intercept	61.199	9.7	71.878	10.3	77.123	11.3	80.229	10.7	73.530	8.1	94.468	8.1	86.538	7.4
Wheat Protein	-0.335	-2.3	-0.372	-2.4	-0.218	-1.3	-0.349	-2.0	-0.626	-2.4	-0.169	-0.6	-0.020	-0.1
Moisture	-0.092	-0.7	-0.479	-3.5	-1.080	-5.4	-1.120	-5.9	-0.210	-1.3	-0.372	-2.1	-0.203	-1.1
Falling Number	-0.008	-3.3	-0.004	-1.8	-0.006	-2.3	-0.001	-0.5	-0.008	-2.6	-0.008	-2.4	-0.006	-2.0
Test Weight	0.232	2.8	0.078	0.9	0.121	1.3	0.040	0.4	-0.037	-0.3	-0.035	-0.2	0.032	0.2
1000 Kernel Weight	0.120	2.4	0.188	3.9	0.131	2.6	0.187	3.7	0.166	2.7	0.245	2.8	0.208	2.4
d2375			1.061	2.6			0.694	1.7						
Forge			-0.005	0.0			-0.271	-0.5						
Gunnar			0.811	1.7			0.509	1.1						
Ingot			1.412	2.7			1.138	2.1						
McNeal			-2.659	-5.2			-2.569	-4.7						
Oxen			2.109	5.2			1.813	4.3						
MN1					1.118	1.5	1.299	1.9						
MN4					0.989	1.2	0.666	0.9						
MT2					-2.038	-2.3	-1.006	-1.2						
MT3					-1.871	-2.2	-0.660	-0.8						
MT5					-3.175	-3.0	-2.006	-2.0						
MT7					-1.297	-1.1	-1.092	-1.0						
MT8					-1.723	-1.3	0.231	0.2						
MT9					-2.738	-2.2	-1.100	-0.9						
ND1					-0.692	-0.8	0.322	0.4						
ND2					-0.680	-0.6	0.021	0.0						
ND3					1.160	1.5	1.585	2.1						
ND4					-0.515	-0.6	-0.253	-0.3						
ND5					1.382	1.6	1.741	2.2						
ND6					1.860	2.4	1.899	2.6						
ND7					-0.783	-1.0	-0.449	-0.6						
ND8					-1.003	-1.0	-0.755	-0.8						
ND9					0.165	0.2	0.151	0.2						
SD2					0.391	0.5	0.486	0.6						
SD3					1.661	1.8	1.307	1.5						
SD5					-0.008	0.0	-0.079	-0.1						
Flour Protein									0.586	1.8	0.435	1.2	0.565	1.6
Absorption											-0.388	-3.3	-0.378	-3.4
Stability											-0.039	-1.0	-0.005	-0.1
Peaktime											-0.081	-1.0	-0.081	-1.0
Loaf Volume													-0.256	-2.7
Adj. Rsquare	0.114		0.280		0.242		0.353		0.120		0.191		0.237	
RMSE	2.020		1.821		1.871		1.728		1.839		1.802		1.749	

Table A.7. Regression Results: Loaf Volume

Variables	Mod. 1		Mod. 2		Mod. 3		Mod. 4		Mod. 5		Mod. 6		Mod. 7	
	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.	PE	t-val.
Intercept	16.382	1.9	14.941	1.6	2.786	0.3	13.625	1.3	-14.759	-1.5	-30.804	-2.7	-30.804	-2.7
Wheat Protein	0.529	2.7	0.597	2.9	0.692	2.9	0.577	2.4	0.501	1.7	0.583	1.9	0.583	1.9
Moisture	-0.250	-1.4	-0.108	-0.6	0.159	0.6	0.122	0.5	0.672	3.9	0.660	3.8	0.660	3.8
Falling Number	0.006	2.1	0.003	0.9	0.004	1.2	-0.002	-0.5	0.011	3.3	0.006	2.0	0.006	2.0
Test Weight	-0.108	-1.0	-0.131	-1.1	-0.035	-0.3	-0.149	-1.1	-0.004	0.0	0.261	1.6	0.261	1.6
1000 Kernel Weight	-0.168	-2.5	-0.136	-2.1	-0.116	-1.6	-0.102	-1.5	-0.053	-0.8	-0.143	-1.7	-0.143	-1.7
d2375			-0.487	-0.9			-0.100	-0.2						
Forge			0.293	0.4			-0.069	-0.1						
Gunnar			0.454	0.7			1.123	1.7						
Ingot			2.496	3.6			2.452	3.4						
McNeal			4.979	7.3			5.626	7.6						
Oxen			1.352	2.5			0.856	1.5						
Russ			1.074	2.2			0.873	1.7						
MN1					0.787	0.7	0.565	0.6						
MN4					0.722	0.6	0.391	0.4						
MT2					2.595	2.1	2.165	1.9						
MT3					2.489	2.0	1.149	1.0						
MT5					1.823	1.2	0.802	0.6						
MT7					0.655	0.4	1.035	0.7						
MT8					3.321	1.7	0.140	0.1						
MT9					0.503	0.3	-1.864	-1.2						
ND2					0.772	0.5	-0.003	0.0						
ND3					0.145	0.1	0.139	0.1						
ND4					1.692	1.4	1.143	1.0						
ND5					-0.451	-0.4	-1.012	-0.9						
ND6					0.452	0.4	0.227	0.2						
ND7					0.905	0.8	1.446	1.4						
ND8					-0.555	-0.4	-0.241	-0.2						
ND9					1.904	1.6	1.629	1.5						
SD2					2.236	1.8	1.825	1.7						
SD3					3.434	2.6	2.903	2.4						
SD5					2.389	1.8	2.208	1.8						
Flour Protein									0.610	1.7	0.503	1.4	0.503	1.4
Absorption											0.038	0.3	0.038	0.3
Stability											0.133	3.6	0.133	3.6
Peaktime											-0.003	0.0	-0.003	0.0
Loaf Volume														
Adj. Rsquare	0.160		0.282		0.147		0.329		0.218		0.329		0.329	
RMSE	2.720		2.433		2.651		2.354		2.015		1.803		1.803	

APPENDIX B

Table B.1. Probability of Meeting Requirements, MN4

Functional Characteristic		MN4	Variety		
	2375	Forge	Ingot	Oxen	Russ
Absorption	0.97	0.90	0.93	0.95	1.00
Peaktime	0.46	0.85	0.73	0.78	0.67
Ash	0.99	0.93	1.00	0.97	1.00
Stability	0.48	0.87	0.80	0.78	0.52
Flour Extraction	0.97	0.90	0.99	0.99	0.91
Loaf Volume	0.81	0.81	0.97	0.90	0.90
Flour Protein	0.80	0.51	0.95	0.63	0.87
Probability meeting all	0.20	0.27	0.54	0.38	0.30
Average Cost (c/bu)					
PNW	504.0	504.0	504.0	504.0	504.0

Table B.2. Probability of Meeting Requirements, MT2

Functional Characteristic	MT2	Variety
	Ernest	McNeal
Absorption	0.96	1.00
Peaktime	1.00	0.85
Ash	0.98	1.00
Stability	0.98	0.94
Flour Extraction	0.84	0.15
Loaf Volume	0.92	0.99
Flour Protein	0.88	0.88
Probability meeting all	0.65	0.10
Average Cost (c/bu)		
PNW	461.0	461.0

Table B.3. Probability of Meeting Requirements, MT3

Functional Characteristic	MT3 Ernest	Variety McNeal
Absorption	0.98	0.99
Peaktime	1.00	0.80
Ash	0.99	1.00
Stability	0.97	0.92
Flour Extraction	0.88	0.20
Loaf Volume	0.84	0.99
Flour Protein	0.76	0.76
Probability meeting all	0.55	0.11
Average Cost (c/bu)		
PNW	461.0	461.0

Table B.4. Probability of Meeting Requirements, MT5

Functional Characteristic	MT5 Ernest	Variety McNeal
Absorption	0.99	1.00
Peaktime	1.00	0.98
Ash	1.00	0.96
Stability	0.97	0.93
Flour Extraction	0.66	0.06
Loaf Volume	0.80	1.00
Flour Protein	0.96	0.96
Probability meeting all	0.50	0.05
Average Cost (c/bu)		
PNW	461.0	461.0

Table B.5. Probability of Meeting Requirements, MT8

Functional Characteristic	MT8 Ernest	Variety McNeal
Absorption	0.96	1.00
Peaktime	1.00	0.41
Ash	1.00	0.99
Stability	0.81	0.68
Flour Extraction	0.96	0.67
Loaf Volume	0.71	1.00
Flour Protein	0.96	0.96
Probability meeting all	0.52	0.25
Average Cost (c/bu)		
PNW	461.0	461.0

Table B.6. Probability of Meeting Requirements, ND1

Functional Characteristic		ND1	Variety	
	Ernest	Gunnar	Ingot	McNeal
Absorption	0.93	1.00	0.98	1.00
Peaktime	1.00	0.61	0.85	0.64
Ash	1.00	0.97	1.00	0.99
Stability	0.89	0.39	0.81	0.78
Flour Extraction	0.97	0.94	0.97	0.43
Loaf Volume	0.70	0.90	0.97	1.00
Flour Protein	0.93	1.00	0.99	0.93
Probability meeting all	0.56	0.29	0.67	0.22
Average Cost (c/bu)				
PNW	468.0	468.0	468.0	468.0

Table B.7. Probability of Meeting Requirements, ND2

Functional Characteristic	ND2	Variety
	Gunnar	Russ
Absorption	1.00	0.99
Peaktime	0.70	0.87
Ash	1.00	1.00
Stability	0.47	0.62
Flour Extraction	0.93	0.85
Loaf Volume	0.88	0.86
Flour Protein	1.00	0.99
Probability meeting all	0.34	0.45
Average Cost (c/bu)		
PNW	475.0	475.0

Table B.8. Probability of Meeting Requirements, ND3

Functional Characteristic		ND3	Variety	
	2375	Forge	Gunnar	Russ
Absorption	0.98	0.94	0.99	1.00
Peaktime	0.48	0.86	0.46	0.69
Ash	1.00	1.00	1.00	0.97
Stability	0.38	0.81	0.29	0.43
Flour Extraction	0.99	0.97	0.99	0.97
Loaf Volume	0.78	0.78	0.90	0.88
Flour Protein	0.87	0.62	0.99	0.92
Probability meeting all	0.19	0.35	0.18	0.30
Average Cost (c/bu)				
PNW	492.0	492.0	492.0	492.0

Table B.9. Probability of Meeting Requirements, ND4

Functional Characteristic	ND4 Variety				
	2375	Gunnar	McNeal	Oxen	Russ
Absorption	1.00	1.00	0.99	1.00	0.99
Peaktime	0.75	0.74	0.76	0.94	0.89
Ash	1.00	0.98	0.96	1.00	0.99
Stability	0.30	0.22	0.61	0.62	0.34
Flour Extraction	0.91	0.89	0.31	0.98	0.80
Loaf Volume	0.88	0.95	1.00	0.94	0.94
Flour Protein	0.93	1.00	0.91	0.83	0.96
Probability meeting all	0.20	0.17	0.13	0.46	0.23
Average Cost (c/bu)					
PNW	473.0	473.0	473.0	473.0	473.0

Table B.10. Probability of Meeting Requirements, ND5

Functional Characteristic	ND5 Variety				
	2375	Gunnar	Ingot	Oxen	Russ
Absorption	0.99	0.99	0.96	0.97	1.00
Peaktime	0.39	0.37	0.66	0.72	0.60
Ash	1.00	1.00	0.97	0.96	1.00
Stability	0.30	0.22	0.64	0.62	0.35
Flour Extraction	0.99	0.99	1.00	1.00	0.98
Loaf Volume	0.60	0.78	0.91	0.74	0.75
Flour Protein	0.89	0.99	0.98	0.76	0.93
Probability meeting all	0.11	0.11	0.43	0.32	0.20
Average Cost (c/bu)					
PNW	486.0	486.0	486.0	486.0	486.0

Table B.11. Probability of Meeting Requirements, ND7

Functional Characteristic	ND7	Variety	
	2375	Ernest	Gunnar
Absorption	1.00	0.96	1.00
Peaktime	0.88	0.99	0.87
Ash	0.97	0.99	1.00
Stability	0.79	0.98	0.71
Flour Extraction	0.89	0.92	0.87
Loaf Volume	0.91	0.86	0.97
Flour Protein	0.90	0.87	0.99
Probability meeting all	0.54	0.67	0.55
Average Cost (c/bu)			
PNW	464.0	464.0	464.0

Table B.12. Probability of Meeting Requirements, ND8

Functional Characteristic	ND8	Variety	
	2375	Gunnar	Russ
Absorption	0.99	1.00	1.00
Peaktime	0.87	0.86	0.95
Ash	0.96	1.00	1.00
Stability	0.81	0.74	0.84
Flour Extraction	0.85	0.83	0.71
Loaf Volume	0.72	0.86	0.84
Flour Protein	0.98	1.00	0.99
Probability meeting all	0.46	0.49	0.48
Average Cost (c/bu)			
PNW	477.0	477.0	477.0

Table B.13. Probability of Meeting Requirements, ND9

Functional Characteristic			ND9	Variety		
	2375	Forge	Gunnar	Ingot	Oxen	Russ
Absorption	0.98	0.94	0.99	0.96	0.97	0.98
Peaktime	0.58	0.91	0.57	0.82	0.86	0.78
Ash	1.00	1.00	0.94	1.00	1.00	0.92
Stability	0.64	0.94	0.53	0.89	0.88	0.68
Flour Extraction	0.94	0.84	0.93	0.97	0.99	0.86
Loaf Volume	0.92	0.92	0.97	0.99	0.96	0.96
Flour Protein	0.94	0.76	1.00	0.99	0.85	0.97
Probability meeting all	0.37	0.50	0.34	0.69	0.62	0.47
Average Cost (c/bu)						
PNW	499.0	499.0	499.0	499.0	499.0	499.0

Table B.14. Probability of Meeting Requirements, SD3

Functional Characteristic	SD3 Variety			
	Forge	Ingot	Oxen	Russ
Absorption	0.77	0.83	0.86	1.00
Peaktime	0.90	0.81	0.86	0.77
Ash	0.99	0.99	1.00	1.00
Stability	0.96	0.93	0.92	0.76
Flour Extraction	0.95	0.99	1.00	0.96
Loaf Volume	0.97	1.00	0.99	0.99
Flour Protein	0.59	0.97	0.71	0.91
Probability meeting all	0.40	0.61	0.51	0.55
Average Cost (c/bu)				
PNW	488.0	488.0	488.0	488.0

Table B.15. Probability of Meeting Requirements, SD5

Functional Characteristic	SD5 Variety		
	Forge	Oxen	Russ
Absorption	0.93	0.97	1.00
Peaktime	0.87	0.81	0.71
Ash	0.99	0.99	0.99
Stability	0.95	0.90	0.72
Flour Extraction	0.81	0.98	0.83
Loaf Volume	0.95	0.98	0.98
Flour Protein	0.12	0.19	0.47
Probability meeting all	0.08	0.13	0.20
Average Cost (c/bu)			
PNW	491.0	491.0	491.0