**OPTIMIZING WHEAT BLENDS FOR
CUSTOMER VALUE CREATION:
A SPECIAL CASE OF SOLVENT RETENTION CAPACITY**

by

NIKOLAS C HAAS

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Major Professor
Vincent Amanor-Boadu

ABSTRACT

The intent of this thesis is to conduct a case study on the optimization of blending soft red winter wheat, prior to processing into flour, in order to meet specific solvent retention capacity, SRC, specifications, based on predetermined customer specifications. The thesis will provide the company with a greater understanding of how to effectively manage the customer's demands, and the costs associated with these activities in order to create greater customer value. If optimizing wheat blends is successful, the company will be able to provide similar SRC information to other customers as a value added service.

(Solvent retention capacity) is a test that provides analytical data that measures three specific physical components within soft wheat flour. Traditionally, wheat flour is sold according to moisture, ash, protein content, and basic dough characteristic data; though this information is important, SRC provides specific flour functionality information that will aid customers. SRC examines the: glutenin characteristics of the flour, pentosan content and gliadin characteristics, and the starch damage from the milling process. These values describe the functionality of the flour and provide information regarding the flour's ability to absorb water during the mixing process and the flour's ability to release that water during the baking process. SRC quality endpoints include: reduced mixing and baking times, reduced levels of breakage after baking, and greater overall ingredient consistency throughout all the customer's commercial bakeries.

This thesis develops a process that the company may use to meet SRC quality specifications determined by the customer. The company gains customer loyalty by supply a consistent product to the customer. This product in turn yields savings for the customer in the areas of lower water use, shorter baking time and consequently lower energy use.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I: INTRODUCTION

1.1: Situation

One of the largest commercial bakeries in the United States has recently asked all of its flour suppliers, of soft wheat flour, to provide Solvent Retention Capacity (SRC) data for all purchased flour for its cracker production facilities. The bakery feels that if flour quality is increased, more consistent based on SRC specifications, then their overall bakery operations, throughout the United States, will be more efficient and that their level of damaged product will decrease. The bakery is hoping to operate with consistent quality ingredients in order to be more effective and efficient at producing their products and operating their facilities.

Historically, the bakery has purchased flour based on the following attributes: moisture, protein, and ash; these are standard attributes that flour is sold by throughout the industry. SRC goes further by measuring and examining the physical components of the flour, therefore providing specific information relative to the flours functionality during the mixing and baking processes and as a finished baked product.

1.2: What is Solvent Retention Capacity

Solvent retention capacity is a test that provides analytical data that measures three specific physical components within the soft wheat flour. Traditionally, wheat flour is sold according to moisture, ash, and protein content; along with some basic dough characteristic data; though this information is important, SRC provides specific flour functionality information that will aid bakers. SRC examines the: glutenin characteristics of the flour, pentosan content and gliadin characteristics, and the starch damage from the

1

milling process. These values describe the functionality of the flour and provide

information regarding the flour's ability to absorb water during the mixing process and

the flour's ability to release that water during the baking process.

"SRC… [values are] expressed as percent of flour weight, on a 14 percent

moisture basis. Four solvents are independently used to produce four SRC values: water

SRC, 50 percent sucrose SRC, 5 percent sodium carbonate SRC, and 5 percent lactic acid

SRC. The combined pattern of the four SRC values establishes a practical flour

quality/functionality profile useful for predicting baking performance and specification

conformance. Generally, lactic acid SRC is associated with glutenin characteristics,

sodium carbonate SRC with levels of damaged starch, and sucrose SRC with pentosan

characteristics" (Solvent Retention Capacity Profile 2009). Water SRC is influenced by

the other three SRC values.

1.3: Problem Definition

A milling company seeks to enhance the value it creates for its customers to

increase its competitive advantage through the application of SRC. The challenge

confronting this is how to implement SRC testing and produce quality consistent flour

that meets the customer's specifications. Simply conducting SRC testing will not

produce quality flour. In order for the mill to meet the specifications required by the

bakery, SRC testing will need to be completed and kept up to date for all stored wheat

along with the amount of wheat available in storage, wheat blends will have to be

determined based on an optimization model and tested for SRC, and finished flour will

have to be tested to ensure that SRC specifications are met. In addition to this, the mill

will have to train employees on solvent retention capacity and why it is important, and invest in equipment to perform the tests.

SRC data is important to the customer because if flour quality is consistent across all of its bakeries then the organization could run more effectively. When flour is sold to the traditional protein specifications, there is still a lot of variation in the flour. The mill could be producing to the customer's specifications; however different wheat varieties and other characteristics within the wheat could influence the ability of the flour to perform consistently at the bakery throughout the year, crop season, or over the course of many years. It is very common for the milling company's technical service team to be called out to solve ingredient functionality issues at the customer's bakeries. Typically, the issue is that the flour is not absorbing water quick enough and a poor dough is developed that produces a poor quality cracker. To solve this, the bakery must always be adjusting processing times, or ingredient formulations. SRC data solves this problem for the bakery by forcing the mill to produce flour that meets fundamental functional specifications set by the customer. This allows the bakery to make fewer operational changes, therefore increasing operational effectiveness.

1.4: Solution Development

Flour is generally a commodity, and therefore is theoretically identical no matter who produces it, when it is milled to the standard specifications of: moisture, protein, and ash content- protein content being the most critical. The milling industry generally follows Figure 1.1 in its current production model, with specifications varying by customer based on applications. Different baked products require varying amounts of protein, e.g.,

crackers and cookies require low protein flour, while hearth breads and pizza dough require high protein flour.

Figure 1.1: Current Model

```
┌──────────┐   ┌──────────┐   ┌──────────┐   ┌──────────┐
│          │   │  Wheat   │   │          │   │          │
│ Wheat in │ ▶ │ Blended  │ ▶ │  Wheat   │ ▶ │ Flour to │
│ Storage  │   │for Protein│  │  Milled  │   │ Customer │
│          │   │ Content  │   │          │   │          │
└──────────┘   └──────────┘   └──────────┘   └──────────┘
```
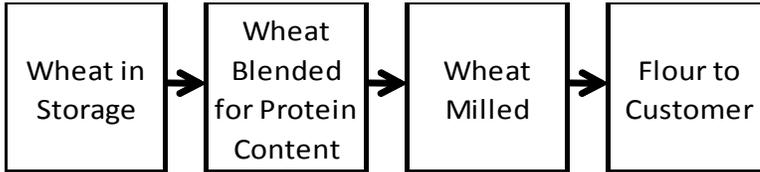
By providing SRC data and processing to SRC specification, the company's flour is transformed into an idiosyncratic value-added ingredient, providing information that contributes critical value to the success of the customer's operations. This move, illustrated in Figure 1.2 will position the organization for further future growth.

Figure 1.2: Proposed Model

```
┌──────────┐  ┌──────────┐  ┌──────────┐  ┌──────────┐  ┌──────────┐
│  Wheat   │  │  Wheat   │  │  Wheat   │  │          │  │          │
│Receiving │▶ │Tested for│▶ │ Blended  │▶ │  Wheat   │▶ │ Flour to │
│ to Mill  │  │   SRC    │  │ for SRC  │  │  Milled  │  │ Customer │
│ Elevator │  │Attributes│  │ Content  │  │          │  │          │
└──────────┘  └──────────┘  └──────────┘  └──────────┘  └──────────┘
     ▲             │
     │             ▼
┌─────────────────────────────────────────┐
│ SRC Data shared with Wheat Procurement   │
│ Team, to source the appropriate wheat to │
│      meet requried specifications.       │
└─────────────────────────────────────────┘
```
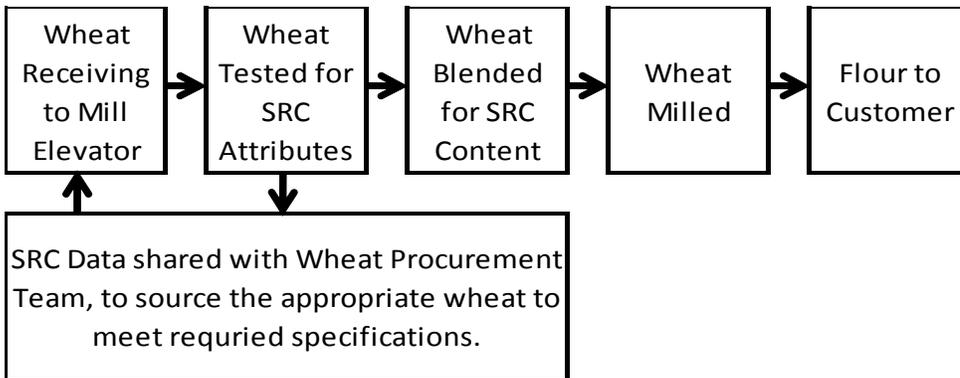
To do this, the mill will have to:

- Actively manage all wheat in storage by testing for solvent retention capacity.

- Optimize wheat mixes based on customer specification and wheat availability.

- Shift attention to testing for SRC content and, then, blending to achieve SRC

  specifications. The mill needs to focus on areas where it has control. Since all

the wheat is purchased from local grain elevators which do their own grain origination, it would not be to the mills advantage to source wheat directly from farmers- this would dramatically increase costs, but rather seek wheat from regions that the elevators pull from. For instance, the wheat procurement team should seek wheat from specific regions, i.e. specific elevators that are known to have wheat that presents the desired SRC attributes that the mill is seeking.

- Blend wheat based on an optimization model that will develop mill mix blends that will produce the desired SRC content required by the customer based on in house wheat inventory. Management at the mill will develop an optimization tool that is accurate, simple, and easy to understand. The optimization tool will give accurate information that will be used to blend wheat that meets SRC specifications. Creating a user friendly tool for all employees, to use and understand. The model will require accurate elevator bin inventory and corresponding SRC data for each bin. The optimization tool will generate SRC wheat blends that the operators will use. To ensure that the optimization tool is effective, accurate and up to date SRC testing will need to be completed; therefore the mill will develop effective SRC testing guidelines for testing frequency to guarantee the most accurate results.

The overall objective of the project is to develop a process to produce the most consistent flour that meets the customer's SRC specifications. This allows the company to address the customer's specific quality needs, thereby enhancing customer loyalty and increasing its competitiveness. Successfully achieving this objective will provide a

platform for the company to exploit the process at its other flour mills to further position itself as a preferred flour products supplier.

1.5: Implementation Plan

The mill has been testing the solvent retention capacity of its flour for a particular bakery for the last several months. However, it has just been testing the flour and has not actively sought to produce flour that meets the required SRC specifications. This is because management has not elevated SRC as a strategic opportunity to exploit. Consequently, management has not made the necessary investments to determine how to effectively manage wheat and flour to meet the specified SRC requirements requested by the customer.

The purpose of this project is to focus on how the mill can create greater customer value for the customer and then seek after opportunities to create value for other customers, existing and potential new ones, using the same process. Flour milling is an old industry; however, there are many potential opportunities to move the business from the commodity marketplace and into a new marketplace where new opportunities are available. Producing and testing for solvent retention capacity is one of those ways.

CHAPTER II: LITERATURE REVIEW

2.1: Solvent Retention Capacity

Literature relating to Solvent Retention Capacity (SRC) in soft wheat is limited to theory, grain breeding, and to the testing method. Data supporting the end uses of SRC testing are held as proprietary information by corporate bakeries that have found economic success by testing for SRC and using that information to optimize grain mixes to drive bakery efficiency. In fact, two of the individuals who developed the test, Harry Levine and Louise Slade, currently are private consultants to the bakery industry. They advise commercial bakeries on how to use SRC to drive greater efficiency and effectiveness.

In 1999 the American Association of Cereal Chemists (AACC) approved the SRC test as a new means of evaluating soft wheat quality, Method 56-11. The test was developed as a "predictive tests to assess the end-use quality of wheat and flour" (A. D. Bettge 2002, p.670) by Louise Slade from Nabisco in the 1980's. In 1994 Kraft-Nabisco worked with the University of Idaho Agricultural Experiment Station to develop new wheat varieties, with the goal to "help breeders and flour millers identify which components [in wheat were needed] to improve the functionality of [flour] in a dough" (Souza 1999) specifically for Nabisco. Bettge, et al. (2002) discusses how SRC testing came about as a way to save time and money on testing new wheat varieties instead of utilizing traditional milling and baking tests to determine wheat quality. They note that SRC testing allows for "[rapid] tests that are well-suited to estimate end-use quality of small samples of wheat or wheat meal" (A. D. Bettge 2002, p.670), which allowed "wheat [breeders] to eliminate lines with inferior quality and carry forward the remaining, more promising lines for more extensive testing" (A. D. Bettge 2002, p.670). As successful varieties of

wheat were released for farmers to plant, SRC testing has further been used as means to test for flour quality and consistency.

The official objective for SRC testing stated by the American Association of Cereal Chemists states that:

> SRC is the weight of solvent held by flour after centrifugation. It is expressed as percent of flour weight, on a 14 percent moisture basis. Four solvents are independently used to produce four SRC values: water SRC, 50 percent sucrose SRC, 5 percent sodium carbonate SRC, and 5 percent lactic acid SRC. The combined pattern of the four SRC values establishes a practical flour quality/functionality profile useful for predicting baking performance and specification conformance. Generally, lactic acid SRC is associated with glutenin characteristics, sodium carbonate SRC with levels of damaged starch, and sucrose SRC with pentosan characteristics. Water SRC is influenced by all of those flour constituents (Solvent Retention Capacity Profile 2009).

Glutenin and pentosan are characteristics of the actual wheat grain, while starch damage can be attributed to how the wheat was milled, but still is a measureable physical attribute within the wheat. "Soft wheats break [during the milling process] more irregularly, usually missing the starch granules, leaving them intact and causing lower water absorption" (Comis 2002) this will result in lower sodium carbonate SRC values. All four SRC values represent how the individual components absorb water during the mixing and baking process.

Guttieri and Souza (2003) discuss how variances occur in SRC values in different soft wheat populations. They conclude that the variations in SRC values are related to genetic, environmental, and processing factors. The authors state "greater levels of flour extraction often result in greater levels of damaged starch and bran fraction within the flour, which would elevate SRC values, particularly for sodium carbonate and sucrose" (a. E. Mary J. Guttieri 2003, p.1632). In addition to this, they address how millers and

bakers can use SRC data to know what varieties of wheat should be sought after for different bakery applications, i.e. cookies and crackers.

Guttieri (2001) discusses how the individual wheat characteristics that SRC tests for are affected by water and water absorption. She notes that "good cookie and cracker flours hold water poorly" (D. B. Mary J. Guttieri 2001, p.1054) and that "flours with excessive water retention require increased baking times in cookie and cracker manufacturing operations, which results in a less tender product and increased energy costs in bakeries". Typically soft wheat flour is sold to a bakery with limited analytical data that does not thoroughly state how water will affect the bakery's operations. SRC data provides that key information for a bakery, which the bakery can then use to setup its operations to run at an effective and efficient rate. When the miller knows the SRC specifications from the bakery, he or she can therefore select the proper wheat, optimize the wheat blend, and setup the milling operation to produce the required flour that best meets the bakery's needs. The article concluded that "the SRC [tests] may be of particular value in selection because it reflects the underlying macromolecular basis of quality independent of flour protein concentration" (D. B. Mary J. Guttieri 2001, p.1059). Instead of measuring flour functionality on the basis of protein, SRC data measures flour on a much more specific basis and flour functionality is directly related to bakery performance.

2.2: Wheat Blending

Flour millers have blended wheat for centuries as a means to manage quality and costs. Millers have been able to incorporate lower quality wheats, which costs significantly

less, into the wheat mix without affecting overall flour quality. Millers have used basic mathematics to determine wheat blends, however modern computers are allowing millers the opportunity to optimize wheat blends. This allows millers to incorporate multiple variables into the blending equation in order to determine the most advantageous blend. In the August 2001 *Journal of Food Process Engineering*, researcher Mehmet Hayta discussed how he used linear programming as a tool "to optimize the blending of wheat lots which [had] different quality characteristic and costs. Using best subsets regression, three quality tests (particle size index, dough volume and falling number value) were selected in relation to loaf volume of bread to be produced. The chosen criteria were set up in a linear programming format as a model for the computerized solution" (Mehmet Hayta 2001, p.179). He later noted that "The model's applicability was assessed in a commercial mill… [and as] a result of applying the model it was found possible to produce bread making flour with a reasonable quality and at a lower cost" (Mehmet Hayta 2001, p.179).

The variables used in the linear optimization model were measurements of some of the physical components of the wheat, as a result, it was possible to blend the wheat in proportion and achieve the desired optimum. This method can be utilized in other wheat blending scenarios too.

2.3: Ingredient Consistency

For the last few decades bakeries have struggled to find and maintain skilled personnel on their production floors. "As the reduced skilled labor pool continues to be a problem, bakers [are looking] to ingredient suppliers to provide them with products that are able to withstand inconsistent handling, as well as products that are less labor intensive"

(Gallo-Torres 1997, p.24). In her article *Innovations in Ingredients Addresses Bakers Needs*, (Gallo-Torres 1997) discusses how "Ingredient suppliers are finding new ways to help bakers, such as with education, assistance in product line development, and logistical advice on improving efficiency and reducing labor costs". These products and services provided by food ingredient manufactures are helping bakers maintain greater finished product integrity. Many businesses follow *Just-in-Time* production models in their operations and cannot afford the financial losses that are a result of inefficient production lines due to labor or ingredient performance. Consequently, "suppliers in the ingredient categories are responding to bakers' needs by rolling out products intended to help them cope with current issues and problems" (Gallo-Torres 1997, p.24) so the bakery can become more effective and efficient.

The goal of the ingredients manufacture is to become a preferred supplier, so that their products and services are irreplaceable by a competitor. Ingredient suppliers must be willing and able to respond to the individual needs of the customers that they service. Williamson (1991, p. 75) stated:

> Responsiveness to the customer is a fine ideal. Making it a reality is increasingly critical to gaining competitive advantage. In practice, it often means more variety at shorter notice. Faced with these challenges, companies must look to their suppliers for support. Instant market intelligence and flexible manufacturing are worth little if they face bottlenecks in getting the right supplies. Becoming customer responsive therefore starts with supplier strategy. Success requires better ways of managing the commercial links.

The competitive strategy of the flour mill should be to become the supplier of flour that performs consistently to the customer's specifications, and that responds quickly and effectively to customer needs and requests.

CHAPTER III: THEORY, METHODS, AND DATA

3.1: Operational Theory

For decades, flour millers have blended wheat in order to meet protein specifications required by customers. Different varieties of wheat are utilized in order to meet the required protein specifications of the customer. In addition to blending to protein content, millers process wheat into flour to ash specifications as well. Ash content affects the color of the flour, but has no functional value in baking or processing, it is simply a quality measurement. Other factor affecting flour quality include: falling number and moisture content.

Protein content in wheat is measured on a percent age basis; therefore millers have used simple mathematics to blend wheat to the desired protein content. For instance a customer's flour specification requires a protein content of 10.5%. If the miller does not have the wheat that will give him or her flour with 10.5 percent protein content, he or she can blend low protein wheat with higher protein wheat to get the desired result. The protein content of the blended wheat is simply based on the amount of wheat, from each bin, used in the blend. In this case, the miller can blend wheat that is 10.0 percent at 50 percent and wheat that is 11.0 percent at 50 percent and get the required protein content in the flour.

In addition to allowing millers to produce flour that meets customer specification, wheat blending gives millers greater control over a mill's overall operations. Milling operations greatly improve when the wheat on the mill is consistently the same. To achieve this, millers utilize blending techniques exactly like those used to meet customer protein requirements.

Milling flour to protein content is an effective way to manage product quality and consistency, however, two flours with identical protein levels can perform differently at the bakery. This especially affects large commercial bakeries that source flour from numerous suppliers. It is important to recognize that different wheat varieties and growing environments/conditions affect the quality of flour that is produced. Historically, commercial bakeries operated regionally, and sourced the flour needed for their operations from the regions where the bakery operated. With the continuing consolidation of the baking industry, large commercial bakeries are now operating on a national and/or global level. In order to effectively manage quality and baking performance additional flour quality data is needed.

Solvent retention capacity measures specific analytical components within wheat that can also be blended together, much like blending for protein. SRC provides bakeries with fundamental data that can be used to ensure flour consistency across all locations. This information will allow bakeries too increase operational effectiveness and efficiency.

For millers, instead of blending for one component, i.e., protein content, blending for SRC requires that wheat be blended to meet all four SRC requirements. In order to do this, an optimization tool will be needed.

3.1.1: Optimization Techniques

Optimization is a tool used throughout industries to increase the accuracy of making complex business decisions. Optimization tools seek to find "the most cost effective or highest achievable performance under the given constraints, by maximizing desired factors and minimizing undesired ones, …optimization is restricted by

the lack of full information, and the lack of time to evaluate what information is available"
(Business Dictionary 2011). Optimization allows managers to make accurate business

decisions based on solid facts. At the mill, an optimization model will be used to develop

the SRC wheat mixes using the data collected through testing and wheat management. The

optimization tool will provide a model that the miller can use to blend wheat to meet

customer specifications. The model will determine which wheat varieties, based on protein

content, need to be included in the SRC wheat mix based on: the physical wheat inventory

in the elevator- per bin, and the SRC attributes of the wheat in the elevator- per bin. The

model will produce a recipe for a wheat mix that meets set specifications, this recipe will

tell the miller how much of each type of wheat to use in the mix. The optimization tool

will provide a structured framework for the miller to make accurate decisions. For the

optimization tool to work correctly, it is essential that accurate data be collected on a

regular basis, and that grain management practices are followed.

3.1.2: Wheat Blending

Wheat blending is the process by which different varieties of wheat or wheat with

different quality characteristics are blended to achieve a particular outcome. Blending has

traditionally been used by millers to achieve particular protein content in the flour. For

instance, 50 bushels of 12 percent protein wheat blended with 50 bushels of 10 percent

protein wheat, yields 100 bushels of wheat with 11 percent protein content. Commercial

mills traditionally use multiple wheat sources to produce different products.

Because SRC is a measurement of specific physical characteristics of wheat, it is

possible to blend wheat according to SRC requirements. However, instead of blending

wheat for one or two attributes, it will be necessary to blend wheat according to the four physical characteristics that SRC measures- lactic acid SRC, sucrose SRC, sodium carbonate SRC, and water SRC. Because blending wheat based on multiple attributes it will be necessary for the miller to utilize the optimization model to achieve the optimum wheat blend that meets specification based on the amount of wheat available.

3.1.3: Wheat Management

Wheat management describes the handling and storage procedures that a flour mill uses to manage wheat for quality control and economic opportunities. Flour millers are primarily interested in wheat quality- the physical attributes and characteristics of the wheat. High quality wheat, wheat that has been stored and handled correctly generates higher production yields and has lower amounts of infestation and microbial activity- fewer damaged kernels. Flour millers blend the wheat that is stored in the elevator into a mill-mix that is processed into flour. Therefore millers must rely on accurate wheat data to determine the varieties and quality of wheat to use in their mill mixes. Inaccurate data will produce products that do not meet customer expectations. In addition, millers must know how much wheat they have on hand in order to process; this is achieved by maintaining an accurate physical wheat inventory to know what is currently available.

Solvent retention capacity will require the mill to do additional testing on wheat stored in the elevator. To do this effectively, the mill will have to test the wheat in each elevator bin to determine the SRC attributes of the wheat contained therein. This will provide critical data that the miller will use to determine wheat blends.

3.2: Methods

In order to blend for solvent retention capacity it is necessary that the miller know beforehand what the SRC values are for the wheat that is available. For the purposes of this thesis, eight elevator bins were selected and a ten pound representative sample was collected from each bin, and tested for SRC. The four SRC values were measured for each sample and incorporated into an Excel spreadsheet, see Table 3.1.

An optimization model was developed to determine the quantity of wheat from each bin, X_j, needed to produce a given quantity of wheat, Z, that when milled into flour meets the customer's SRC specifications. The problem is defined in Equation (1).

$$
\begin{aligned}
\max_{\{X \geq 0\}} Z &= \sum_{i=1}^{4} \gamma_{ij} X_j \\
s.t.\ B_j^{\max} &\geq \sum_{i=1}^{} \lambda_{ij} X_j \geq B_j^{\min} \\
Y_j &\geq X_j \\
X_j &\geq 0
\end{aligned}
\tag{1}
$$

In Equation (1), the parameter γ_{ij} in the objective function (line 1) refers to bin SRCs, where i is from 1 to 4 and represents: water SRC, lactic acid SRC, sucrose SRC and sodium carbonate SRC respectively and j refers to each bin, numbered 1 to 8. Line 2 defines the constraint that the measured SRCs must fall within the customer's specified bounds, B_j maximum and minimum if the blend is going to meet the specifications. The parameter λ_{ij} is the bin-specific SRC. Line 3 in Equation (1) defines the constraint that the quantity of grain from each bin included in the blend cannot exceed the available grain in that bin, and line 4 defines the non-negativity constraint, i.e., the quantity of grain cannot be negative. Microsoft Excel's Solver macro was used to solve for the optimum wheat blend.

The foregoing presents the technical optimum for the blend. It is conceivable that grain with specific SRC characteristics would command a different price and that flour produced to meet customer specific SRC characteristics would attract a premium price over traditional flour. These conceivable realities and the fact that testing for SRC presents real cost to the milling company suggests that the technical optimum may differ from the economic optimum. The economic optimum is defined in Equation (2).

$$\max_{\{X\}} \pi = \sum_{i=1}^{4} p_j X_j$$
$$s.t. \ B_j^{\max} \geq \sum_{i=1}^{4} \lambda_{ij}^* X_j \geq B_j^{\min}$$
$$Y_j \geq X_j$$
$$X_j \geq 0$$

(2)

In Equation (2), the problem is to maximize net returns from blending the grain from the different bins, defined by π. The other constraints are as defined from above in Equation 1. The net price, estimated as the price of the flour from the blended grain after adjusting for the cost of grain in each bin and the SRC testing costs. Therefore, the net price, p_j, is summarized in Equation (3).

$$p_j = P - C_j - \sum_{i=1}^{4} \alpha_i t_{ij}$$

(3)

Where P is the flour price received, C_j is the cost of grain in each bin, α_{ij} is the unit test cost for each of the SRC tests: water, lactic acid, sucrose and sodium carbonate, and t_{ij} is the number of tests conducted on each bin of grain and after blending and milling. This thesis assumes that there is no difference between the bins with respect to the cost of grain; therefore the cost of grain becomes a constant in Equation (3).

The intent of this thesis is to explore the feasibility of blending the available wheat at the flour mill in order to meet the customer's SRC specifications. The mill must utilize the wheat that is available; it would not be advantageous for the mill to source wheat on a moment's notice in order to meet the customer's requirements. Therefore, the miller must find a way in which to test and blend the wheat that is available. Price considerations are critical to the profitability of the mill; however for this thesis the intent is only to consider the possibility of using the resources available to the mill, current wheat on site, and still be able to produce a quality product that meets the customer's SRC requirements.

3.3: Data

The primary data for the research was obtained from samples taken from each of the eight elevator bins available at the flour mill. Each sample was subjected to SRC testing and recorded, see Table 3.1. The tests provided insights into the reality and challenges that confront the mill as it seeks to pursue the strategy of milling to SRC specifications for the customer. The data shows that water SRC ranges from 55.35 to 63.45, lactic acid SRC ranges from 84.25 to 97.87, sucrose SRC ranges from 96.13 to 106.80, and sodium carbonate SRC ranges from 78.36 to 91.65. The average values of the four SRC are: 58.79, 92.33, 101.08, and 83.77, these are the SRC values that would result if equal proportions of grain from each of the eight bins were blended together into a wheat mix. The standard deviations are: 2.96, 4.96, 4.30, and 4.48, thus, if the specified SRC values are within the bounds of these measures, i.e., mean ySRC $\pm$ SD (where y = water, lactic acid, sucrose, and sodium carbonate), then it would be possible to produce flour that meets the customer's expectations by blending equal proportions of wheat from each bin.

However, this is not the case, making this research important and critical to the flour industry as the idea of solvent retention capacity takes hold.

Table 3.1: SRC Bin Data

Bin	Water SRC	Lactic Acid SRC	Sucrose SRC	Sodium Carbonate SRC
1	56.03	95.64	99.14	79.52
2	63.45	94.45	106.80	91.65
3	61.88	87.20	106.70	87.03
4	57.20	96.22	97.60	84.53
5	55.35	97.87	96.13	78.36
6	60.94	88.51	103.24	86.44
7	56.95	84.25	96.75	80.66
8	58.49	94.49	102.27	81.97
MIN	55.35	84.25	96.13	78.36
MAX	63.45	97.87	106.80	91.65
MEAN	58.79	92.33	101.08	83.77
SD	2.96	4.96	4.30	4.48

The grain in each bin was purchased from numerous sources and at different times. Consequently, it is impossible to know the cost of grain in each bin used in this research. To this end, it was assumed that the cost of grain, C_j, as specified in Equation (3) above is the same across all bins. Additionally, the experiment focused on the mill's ability to blend available wheat to meet customer specifications and did not, therefore, seek to address the economic optimum solution as specified in Equation (2). This was because while it is clear that meeting customer specifications has value to the customer, that value may be in terms of customer loyalty and not necessarily in higher prices. This is difficult to measure accurately. While that value could have been simulated to determine the extent of its effect on the economic optimum, it is here assumed that achieving an optimum SRC-based blend would help the mill develop a different and superior conversation with its customer to enhance its profitability.

CHAPTER IV: ANAYLSIS

4.1: Blending for SRC Effectiveness

As indicated, the specifications required by customers are hardly obtained by blending equal portions of grain from all the bins. Indeed, the uncertainty about how to get the right wheat mix makes the problem quite complex. The bin SRC results, see Table 3.1, provides an idea for what the mill has to work with. For example, it will be impossible for the mill to generate water SRC in excess of 63.45, see Bin 2, because that it is the highest water SRC available. Similarly, there cannot be a blend of grain that will produce sodium carbonate SRC of less than 78.36, see Bin 5, because this is the minimum sodium carbonate SRC in the sample. This is the challenge confronting the flour mill when choosing to pursue the strategy of blending and milling to the SRC specifications of the customer: if the customer specifications are outside of what the mill has available in regards to SRC characteristics on the wheat stored in the elevator, it is therefore impossible to meet the customer's needs.

The foregoing would mean that the miller would have to think carefully through this strategy and know the specifications of the customer, purchasing grain in ways that facilitate meeting these specifications through blending strategies that are being explored in this thesis. This blue ocean strategy implies that millers cannot purchase grain solely on price but on the desired characteristics that would allow them to create value for their customers through careful understanding of customer needs and effective incorporation of that understanding in their raw material sourcing decisions.

For this research, it is assumed that the customer's SRC specifications are as defined in Table 4.1. The table indicates that water SRC should fall between 52 and 58 while lactic acid SRC must be between 95 and 105.

Table 4.1: Customer's SRC Specifications

	Water	Lactic Acid	Sucrose	Sodium Carbonate
Min	52.00	95.00	90.00	66.00
Max	58.00	105.00	100.00	72.00

A number of trials were conducted in search of the combinations that could be done to meet the customer's SRC specifications. There is no theoretical foundation to expect that the relationships among the four SRC specifications are linear, and therefore, the search was conducted using the Generalized Reduced Gradient (GRG) algorithm embedded in Microsoft Excel Solver. It assumes that the constraint surface is nonlinear, implying that there could be numerous feasible regions where all the constraints are satisfied. While this eliminates the constraint of "forcing" linearity among the SRCs, it creates multiple optimum solutions. There is no way to determine which of the solutions generated, with each iteration, is the tallest peak, since they all satisfy the target objective. Nonlinear optimization methods, in general, do not provide any guarantees that the results are the true optimum. Therefore, there may be false peaks, known as saddle points, resulting from using this solution engine. Yet, for the purposes of this research, where the focus is on exploring the opportunities and feasibility of blending grain to achieve customer SRC specifications, this is seen as a good attempt. It will show the possibility and the challenges associated with pursuing a strategy of building a specification-based supply

relationship with customers. The results of the search for alternative combinations are

presented and discussed in the following sections.

4.1.1: Trial #1

Table 4.2 shows the results for the first trial for blending to SRC specifications

using the optimization tool developed. The green highlighted cells represent values that are

within the customers SRC specifications. For instance, the lactic acid SRC value for Bin 8

is 99.84 and within the range of 95.0 to 105.0. The minimum and maximum SRC values

for each SRC variable are highlighted and are located at the bottom of the table. Towards

the bottom of the table are the target SRC values for each variable based on the

optimization model, and the actual SRC values for the wheat blend after it was blended

together. The solver model was set to generate a wheat mix of 1000 grams; this was the

target value that the model solved for. The table also shows the percent of wheat from each

bin in the wheat mix, this value totals to 100 percent of 1000 grams. Since none of the

wheat available in the elevator met the sodium carbonate specifications it was impossible to

therefore blend to that specification. The *Amount in Bin* column represents the sample size

used for the trial, a 1000 gram sample was taken from each of the original 10 pound

samples collected from each elevator bin. The model specifies that the amount of wheat

taken from each bin cannot exceed the 1000 grams available, and that negative amounts of

wheat from each elevator bin cannot occur.

Table 4.2: Trial #1 - SRC Wheat Blending

Bin	Amount in Bin	Water	Lactic Acid	Sucrose	Sodium Carbonate	% of Mix	Amount in Mix
1	1000	56.03	95.64	99.14	79.52	50%	500
2	1000	63.45	94.45	106.80	91.65	0%	0
3	1000	61.88	87.20	106.70	87.03	0%	0
4	1000	57.20	96.22	97.60	84.53	0%	0
5	1000	55.35	97.87	96.13	78.36	50%	500
6	1000	58.83	99.84	101.41	84.71	0%	0
7	1000	56.95	84.25	96.75	80.66	0%	0
8	1000	58.49	94.49	102.27	81.97	0%	0
TOTAL		**55.69**	**96.76**	**97.64**	**78.94**	**100%**	**1000**

	Water	Lactic Acid	Sucrose	Sodium Carbonate
Target	55.69	96.76	97.64	78.94
Actual	55.95	97.32	96.17	78.67
Min	52.00	95.00	90.00	66.00
Max	58.00	105.00	100.00	72.00

The results from Trial #1 show a mill mix using 500 grams out of Bin 1 and 500 grams out of Bin 5, for a total of 1000 grams. The resulting mix, theoretically according to the solve model, would have the following SRC values: water SRC of 55.69, lactic acid SRC of 97.76, sucrose SRC of 97.64, and sodium carbonate SRC of 78.94. When the mix was tested the actual SRC results were: water SRC of 55.95, lactic acid SRC of 97.32, sucrose SRC of 96.17, and sodium carbonate SRC of 78.67. The actual values were within the customer's specifications and about 1.5 percent of the target values based on the model with the exception of sodium carbonate.

4.1.2: Trial #2

Table 4.3 shows the results for Trail #2. It involved running the Solver again in
search of alternative nonlinear combinations among the grains to achieve the specified SRC
constraints. The solution met three of the four SRC targets except the sodium carbonate
value was not met because there was no wheat available that met the sodium carbonate
specification given by the customer. The actual results, from testing the wheat mix
recommended by the model, produced results that were within 2 percent of the targeted
SRC results from the model.

Table 4.3: Trial #2 - SRC Wheat Blending

Bin	Amount in Bin	Water	Lactic Acid	Sucrose	Sodium Carbonate	% of Mix	Amount in Mix
1	1000	56.03	95.64	99.14	79.52	31%	311
2	1000	63.45	94.45	106.80	91.65	0%	0
3	1000	61.88	87.20	106.70	87.03	0%	0
4	1000	57.20	96.22	97.60	84.53	26%	258
5	1000	55.35	97.87	96.13	78.36	28%	281
6	1000	60.94	88.51	103.24	86.44	15%	150
7	1000	56.95	84.25	96.75	80.66	0%	0
8	1000	58.49	94.49	102.27	81.97	0%	0
TOTAL		56.88	95.35	98.51	81.52	100%	1000

	Water	Lactic Acid	Sucrose	Sodium Carbonate
Target	56.88	95.35	98.51	81.52
Actual	56.87	97.20	99.89	81.16
Min	52.00	95.00	90.00	66.00
Max	58.00	105.00	100.00	72.00

The foregoing results show that while the model proved to be effective in meeting
the customer's specifications, millers cannot meet all specifications if they do not have the
right grain available to them. In this case, the only way the mill can meet the sodium

carbonate specification is to source wheat that has lower sodium carbonate SRC in sufficient quantity to make a blend that yields lower SRC than is currently available in its bins.

4.1.3: Trial #2

Table 4.4 shows the results from Trial #3. This was the last trial where the actual mix recommended by the optimization model was actually tested to validate the model's effectiveness at generating a wheat mix that met the customer's SRC specifications. As in the previous trials, the sodium carbonate SRC specification was not met due to the wheat available.

Table 4.4: Trial #3 - SRC Wheat Blending

Bin	Amount in Bin	Water	Lactic Acid	Sucrose	Sodium Carbonate	% of Mix	Amount in Mix
1	1000	56.03	95.64	99.14	79.52	43%	425
2	1000	63.45	94.45	106.80	91.65	9%	85
3	1000	61.88	87.20	106.70	87.03	0%	0
4	1000	57.20	96.22	97.60	84.53	5%	50
5	1000	55.35	97.87	96.13	78.36	29%	290
6	1000	60.94	88.51	103.24	86.44	15%	150
7	1000	56.95	84.25	96.75	80.66	0%	0
8	1000	58.49	94.49	102.27	81.97	0%	0
TOTAL		57.26	95.15	99.46	81.50	100%	1000

	Water	Lactic Acid	Sucrose	Sodium Carbonate
Target	57.26	95.15	99.46	81.50
Actual	57.32	97.03	97.84	80.20
Min	52.00	95.00	90.00	66.00
Max	58.00	105.00	100.00	72.00

4.1.4: Summary of Trial Results

The foregoing analyses showed that it is possible to blend grain to meet customer specifications if the mill has the *right* grain available to start with. The results also show the possibility of developing internal supply chains to ensure that grain procurement is done to meet the desired SRC specifications of customers. The results also point to logistics and logistics management for grain as they are purchased, moved and brought in to be stored in different bins. The possibility of creating new value for customers increases significantly from the results shown in this study. The results and their margins of deviation from the specifications are summarized in Table 4.5.

Table 4.5 shows the SRC situation, comparing actual to target in each of the three trials. The largest deviation of 1.98 percent occurred for lactic acid SRC in Trial #3. Overall, the differences between the targeted SRC values (those values from the optimization model), and the actual SRC values (those values from the actual blended wheat resulting from the optimization solution) varied only slightly. Even the sodium carbonate value, the one SRC specification that was not met, never exceeded a 2 percent difference between the targeted value and the actual value obtained after blending.

Table 4.5: Results Summation and percent Difference between Target and Actual

Trial		Water		Lactic Acid		Sucrose		Sodium Carbonate	
1	Target	55.69	0.47%	96.76	0.58%	97.64	1.51%	78.94	0.34%
	Actual	55.95		97.32		96.17		78.67	
2	Target	56.88	0.02%	95.35	1.94%	98.51	1.40%	81.52	0.44%
	Actual	56.87		97.20		99.89		81.16	
3	Target	57.26	0.10%	95.15	1.98%	99.46	1.63%	81.50	1.60%
	Actual	57.32		97.03		97.84		80.20	

4.2: Theoretical SRC Optimization

In the foregoing analysis, it was assumed that the quantity of grain in each bin was the same. However, this is hardly the situation in any mill for most of the time. The reality is that bins would have different quantities of wheat in them because of their inherent characteristics and use patterns. Additionally, as new wheat come in, they may be stored in different bins, altering their quantities even within the day. This would suggest that adopting a customer SRC specification milling protocol would create the demand for a careful management of bins – what goes in where and how much. It will also require significant testing and retesting as new grain is added to bins to ensure that the mill is constantly aware of the true SRC situation in the bins to optimize the blending for the customers.

In this section, a small portion of this complex re-organization of the mill's operations was simulated to assess its implications on the optimum solution. The focus of this analysis was to look at different quantities of grain in each bin. These quantities, therefore, became constraints in the model. Additionally, the target output was increased from 1000 grams to 2000 grams, based on the assumption that the customer required a greater quantity of flour from the mill. The model was, then, solved using the Simplex LP algorithm in Microsoft Excel Solver. This algorithm ensures that a single optimum solution is obtained from the analysis that satisfied all the constraints. All other constraints remained as specified in the previous trials.

Table 4.6 displays the results from a theoretical trial of the SRC optimization model. The optimization model was able to create a mix that met all SRC specifications, and met all constraints within the solver tool. The wheat mix generated from this trial was

not tested to see how its SRCs compared with the actual SRC results.[1] The effectiveness of

the tests from the three trials would lead to a high confidence in these results being within

the customer's specifications.

Table 4.6: Theoretical - SRC Wheat Blending

Bin	Amount in Bin	Water	Lactic Acid	Sucrose	Sodium Carbonate	% of Mix	Amount in Mix
1	500	56.03	95.64	99.14	79.52	25%	500
2	250	63.45	94.45	106.80	91.65	13%	250
3	1000	61.88	87.20	106.70	87.03	0%	0
4	750	57.20	96.22	97.60	84.53	21%	423
5	750	55.35	97.87	96.13	78.36	19%	389
6	100	60.94	88.51	103.24	86.44	1%	11
7	500	56.95	84.25	96.75	80.66	5%	99
8	350	58.49	94.49	102.27	81.97	16%	328
TOTAL		57.55	95.25	99.60	82.37	100%	2000

	Water	Lactic Acid	Sucrose	Sodium Carbonate
Target	57.55	95.25	99.60	82.37
Actual	n/a	n/a	n/a	n/a
Min	52.00	95.00	90.00	66.00
Max	58.00	105.00	100.00	72.00

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[1] This was primarily a result of the author changing jobs before completing this research and losing access to the laboratory where these tests could be conducted easily.

CHAPTER V: CONCLUSION

5.1: Wheat Blending to Solvent Retention Capacity

The results from the blending trials indicate that SRC attributes can be attained by blending wheat to the correct proportion based on the optimization model's recommendations to meet customer specifications. The SRC specification that was not met during the experiment was due to the unavailability of wheat meeting the sodium carbonate specification. In this case, it would be necessary to work with the customer on changing the sodium carbonate SRC specification, or the mill could actively work on sourcing wheat that would provide the necessary specifications, the latter option is recommended.

In order for the mill to correctly source wheat that would meet the sodium carbonate specification, it would have to rely heavily on crop data from either a wheat testing laboratory—CII Laboratory Services for example—or from regional wheat growers' association. It is becoming increasing common for grower associations to provide these data to grain merchandisers when requested. However, the industry is currently not using this data to make purchasing decisions. SRC data would allow mills' procurement departments to purchase wheat that would meet the SRC specifications. The optimization model could be utilized to ensure that the right quantities of wheat are being purchased at all times to allow the mill to meet its blending obligations.

Running an economic optimum would allow the internal supply chain – from grain merchandisers to mill managers and flour marketers – to coordinate their activities to ensure that the blending operations achieve optimum profitability for the mill as a whole, and not just for meeting the blending specifications. For example, the cost of wheat in each elevator bin would need to be assessed as would the price obtained for each flour batch

produced. The practical constraints associated with these data made it impossible to pursue this analysis in this research. Rather, the focus was to determine the feasibility of optimum blending to achieve SRC targets. However, it well understood that the technical optimum does not necessarily lead to economic optimum, and this would have to be investigated.

5.2: Value to Customer

With the mill being able to blend wheat in order to meet the solvent retention capacity specifications for the customer, the customer is now able to have a continuous supply of consistent flour. The variability in the customer's flour to meet its bakery needs is thus eliminated or significantly reduced. SRC reflects the fundamental physical requirements of the flour. With that locked in, the customer can then focus on how to maximize performance within the bakery without worrying about how to manage flour quality.

The specific value to the customer coming from the flour consistency based on SRC is multidimensional. For example, SRC-based flour consistency would allow the customer to:

- Use less water in dough formulas
- Decrease baking times due to less water baked off during the baking cycle
- Allow the bakery to have more consistent oven control settings
- Reduce energy consumption as a result of reduced baking times
- Reduce shrinkage of product during cooling process
- Reduce produce breakage

These are tangible benefits that can be priced and included in the flour pricing. However, it is important to note that most bakeries are not thinking in this manner yet. Therefore, this analysis is suggested for future research on this topic. Thus, in finding the economic optimum blend to achieve the customer SRC specification, the flour mill must investigate what embedded value receiving the SRC specific flour would create for the customer through in-depth interviews and even measurements in the customer's bakeries. For example, how much water and energy are saved as a result of using the SRC-specific flour? How much time is saved in the baking process and how much shelf life extension is gained? The value of these saving may then be estimated to provide an indication of how to develop a premium price for the flour for the mill. The mill could then compare the premium price it could receive with the cost of sourcing the right wheat and storing them and blending them to provide the right product for the customer.

5.3: Value to Company

A mill would pursue this strategy of blending to meet SRC specifications because it has inherent value in it. First, it allows the mill to move out of the commodity space in which flour generally exists into a unique and idiosyncratic space because the flour it produces is always to the specifications of the customer. The flexibility of reorganizing blends allows the mill to ensure that changes in customer specifications can be accommodated within reason and reward. This creates significant opportunity to strengthen the mill's relationship with its customer.

The cost of testing for SRC is not very high, about $0.12/cwt, cost per 100 pounds of flour. Therefore, it would seem that the value that SRC-specific blending provides to the

bakery far exceeds the costs of conducting the tests. The costs of meeting SRC-specific

blending could be high if search and procurement costs are included in the analysis. Yet, it

is possible for these to be structured in ways that still provide value, in that total cost of

producing the SRC-specific flour is less than the value that the customer gets from using

the SRC-specific flour. As long as the company can organize its internal supply chain to

minimize cost of producing the SRC-specific flour and ensures that the customer is getting

a consistent product that yields the value dimensions described above, the mill can use this

to secure its relationship and possibly get a few cents per pound of flour sold.

Apart from meeting customer needs, the mill could use the optimization tools

developed in this research to better manage flour quality for different customers. It can

work closely with these customers to show them how they can profit from its unique

blending solutions that produce flour that is more consistent for their use. Guarding its

blending formula as trade secret could position the mill to be a preferred supplier for its

premium customers, allowing it reduce selling costs and increase internal efficiencies.

5.4: Conclusions

This research sought to determine the feasibility of constructing an optimum blend

to meet solvent retention capacities of wheat to satisfy the specific needs of a customer.

The optimization method used showed that it is not only feasible to do this but it does make

sense to work towards incorporating this approach in milling to the needs of customers.

The study provides insights into new opportunities for mills as they search for ways to

avoid the red ocean competitive markets they are swimming in and move to blue oceans

where they are able to define themselves to their customers in different ways to maximize

the value of their relationships.

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