Optimizing wheat mix composition to maximize customer satisfaction

by

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ABSTRACT

Imagine a flour miller with several customers producing different products. Each of them demands a unique flour to meet their customers' needs. The miller receives wheat from numerous sources, each presenting very different compositions of protein, ash, and moisture holding capacity. It is the unique composition of these three components of flour that gives it its useability across numerous products. That is, different customers for the miller require flour that has idiosyncratic combinations of the foregoing attributes. The miller's task is to meet each customer's demand by offering flour that is exactly or close to what they need at a price they are willing to pay. Therefore, the miller's challenge is not just to minimize cost of producing each specific flour but to get the highest possible margin from each customer.

The purpose of this thesis was to optimize the cost of producing flour to the unique specification of each of the miller's multiple customers and compare the profitability of each customer based on their offer prices and customers' rheological specifications. The research used five customers as a case study based on a flour mill's inventory of five types of flour. The results showed that customers' rheological needs had a direct impact on the cost of the wheat required to produce the flour they needed. The results showed that while one customer's (Customer 1) needs could be satisfied with a single type of wheat, Customer 3's needs could only be satisfied using a blend of four types of wheat. Incidentally, the larger number of types of wheat needed did not imply higher cost. Customer 4 and Customer 5 needed three types of wheat to produce their rheological

specification and Customer 5 had the highest cost per bushel of needed to produce their flour.

The results revealed the wheat type that was not needed in any customer’s mix. This would suggest that if these were the total customer list of the miller, then wheat they were not needed to meet the lowest cost mix for any customer should not be procured. Therefore, this project could direct the procurement team to match their activities with the manufacturing team in sourcing and procuring only wheat they are needed in customer products. The research also noted the potential for future work that could segment customers into product groups to facilitate scale and in so doing enhance the profitability from specific mixes by not only reducing cost of producing particular mixes but to expand volume and revenues in order to maximize profits.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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CHAPTER I: INTRODUCTION

1.1 Background

Bay State Milling Company (BSMC) is a large family owned milling company that is in the fifth generation of ownership passed down for over 125 years. The company was started by Bernard J. Rothwell, and is headquartered in Quincy, Massachusetts. Its strategic goal to produce a grade of flour that few, if any, competitors can match. Over the years the company has grown from the first acquisition of its flagship mill in Winona, MN in 1899, to expanding into specialty grains in a new state of the art facility in Woodland, CA as recently as 2018. The business has changed from a primarily white flour producing operation to having three different business units including varietal solutions, organic, and white flour production, and co-packaging and blending ancient grains.

1.2 Situation

With the increased investment in multiple business units, BSMC's leadership is looking for ways to cut costs while keeping its unwavering commitment to customer satisfaction. This is theorized to be most effective if the company can align national brand specifications at its six different locations. Alignment of the flour specifications is usually determined by the right combination of Moisture, Ash, and Protein (MAP). The MAP property of any flour is determined by the wheat going into its production, and the properties of wheat are a function of their origin. Therefore, the regions from which the wheat is sourced become important in the alignment of flour specifications at BSMC. The other part of the equation are rheological properties, including but not limited to Absorption, Mixing Tolerance Index (MTI), Peak, Stability, Falling Number Value (FNV) and Modified Amylograph. These technical terms are explained in the literature section of the thesis.

Currently, BSMC's supply chain gets feedback from individual mills and each of these mills, based on their location, focuses on different technical factors – MAP, MTI, and FNV. With an objective to align its national brands has emerged need to ensure that the different mills are receiving wheat that will produce the most consistent rheological results. The way to minimize cost while allowing for the alignment of all mills in the network to the quality standards of the flour a customer receives has become the million-dollar question for the company.

1.3 Research Problem, Question, and Objectives

In an ideal world, a baker can add the same amount of water to the same quantity of flour, mix them for the same amount of time, add the exact amount of additional ingredients at the mix and end up with the exact bread loaf, pizza crust, or pastry. With the quality of wheat affected by numerous environmental factors, meeting customer demand with regard to final flour rheology is the critical problem facing all millers with customer satisfaction as their business objective. As such, milling companies work to satisfy their customers by focusing on providing them with consistent flour that requires those customers to make no to only minimal adjustments given the different batches of flour they receive.

Successfully milling the right flour with the appropriate rheology is not costless. The cost may explain why millers do not undertake the exercise of milling to customer specification. Instead, they attempt to deliver a generic flour with a generally acceptable rheology that meets the needs of most customers. However, there are always customers whose needs differ from the average, and who need special attention to address the needs of their own customers. The purpose of this research, then, is to determine the optimal cost of specific flours identified by customers to meet specific customer needs. We can think of these flours as coming from a number of customers or a single customer with different end customer needs. The question motivating the research, then, is this: Given the inventory of wheat available at the mill, what is the least cost of milling flour to meet the specific needs defined by a customer?

The primary input into flour milling is wheat, and millers often combine wheat from different sources to achieve the desired flour characteristics and cost. It is often the case that there is not enough of the different types of wheat needed to mill a particular flour with the desired rheology. But the most likely situation is that different wheat sourced from different locations need to be mixed in the flour milling process to achieve the desired rheology. The proportions of the different types of wheat affect the final cost of the wheat input going into the flour. The selection of the different proportions of the different types of wheat to achieve the double objective of cost and flour characteristics is the miller's challenge. The research question, therefore, is this: Constrained by the rheological specifications of customers and the availability of wheat with different characteristics at the millers, how do millers meet customers specifications at the least cost? Against this background, the overall objective of this research estimates the lowest cost combination of different types of wheat to meet the rheological specifications for flour defined by specific customers. The specific objectives of this research are as follows:

1. Describe rheology and its importance to customers in meeting their own customers needed; and
2. Estimate the optimal cost of producing the specific rheological-defined flour for a select number of customers.

The results from achieving the foregoing objectives provide not only the state of flour milling strategy and the rationale for such strategy but offer an explanation why millers do or do not attempt to optimize their production of customized flour for their customers. The results would also provide information on how to segment markets to identify customers who can exploit specific flour with unique rheology to enable their users to create novel opportunities for themselves and their customers.

1.4 Outline of the Thesis

The current chapter has provided a rationale for this study, defined its problem, stated its problem, and specified its objectives. The rest of the thesis is organized as follows. First, an overview of the flour manufacturing industry is presented. Its purpose is to provide a context for understanding the challenges facing the industry and its evolving market. This is presented in the next chapter. Within the second chapter is also an overview of the literature of the science of flour production. Chapter 3 uses historical data of the industry and the market to provide some indications of the nature of the market. We will identify three principal product markers for flour: breads and cakes; pizza crust; and pastry. For example, while pizza flour requires much less water than bread flour for hydration, and pizza flour needs oil to hydrate properly, pastry flour requires lower protein (and hence lower gluten formation potential). Therefore, the destination market for the flour causes the selection of wheat and milling processes to meet customer needs. Chapter 4 will present the description of the optimization process used to estimate the least cost profiles of the specified flours and evaluate their competitiveness within current market conditions. The discussion of the results will reveal the reasons behind the strategic choices many flour miller make. It will also allow use to assess the economic feasibility of BSMC's stated objectives to meet the specific needs of its customers. It will help BSMC to ask whether it is targeting the right market if indeed it determines that its focus on the higher quality product comes with a higher cost of production. The final chapter summarizes the study and provides insights into future research that may be pursued.

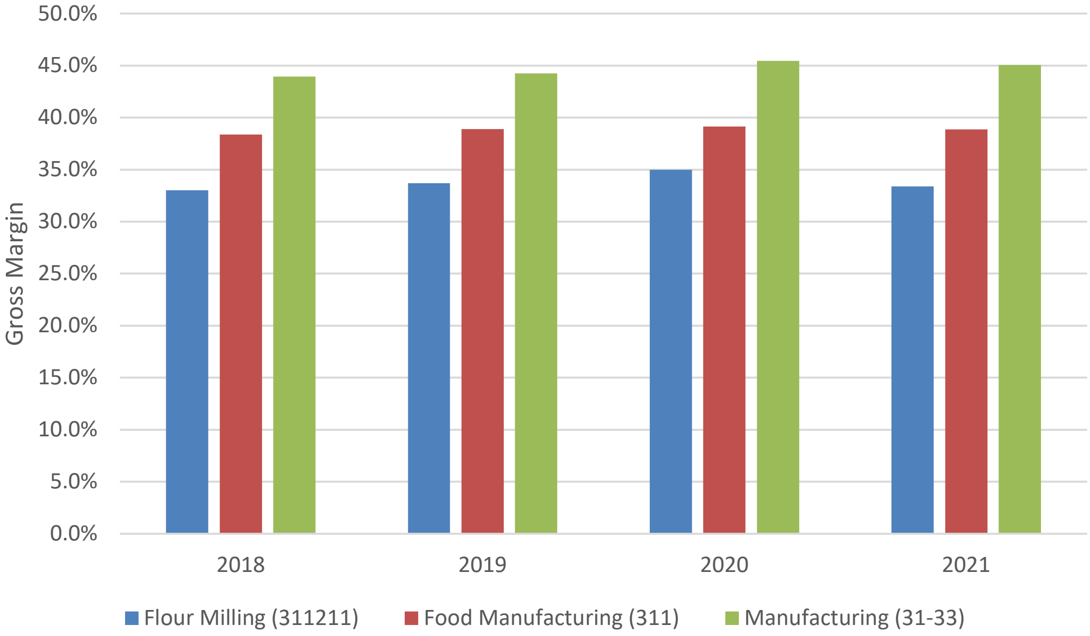
CHAPTER II: LITERATURE REVIEW

This chapter covers two main components of the research. The first is that it provides an overview of the flour milling industry in the U.S. and its evolution and performance over the past several years. It shows that flour, like most agri-food products, has a derived demand profile driving the evolution of manufacturing and input supply. The second component presents an overview of the rheology of flour to frame the need for its consideration in assessing quality and value of the final products emanating from such flour.

2.1 The Flour Milling Industry in the U.S.

Flour mills are defined under the North American Industry Classification System (NAICS) as belonging to 311211. It is classed within the same four-digit NAICS as rice milling and malting. The flour milling industry's value of shipments or revenue increased from about $12.4 billion in 2018 to $14.7 billion in 2021. Its payroll increased from $750.5 million to $852.5 million over the same period. Thus, while revenues increased by 19% and annual payroll increased by 14%, the number of employees increased by only 2% - from 12,879 to 13,079 between 2018 and 2021. The flour milling industry's total cost of materials was about $9.8 billion in 2021 compared to $8.3 billion in 2018, which comprised about $9.0 billion and $7.8 billion, respectively in cost of materials (wheat, etc.) and packaging. The industry's gross margin was 33.0% in 2018, increased to 35.0% in 2020 – the year of COVID-19 – and has returned to approximately 33.4% by 2021. This contrasts with food manufacturing and all manufacturing during the same period (Figure 2.1). The figure shows that flour milling industry's gross margin was lower than that of the food manufacturing industry and all manufacturing industry in each of the four years considered. The figure also shows that all manufacturing, food manufacturing, and flour milling all presented their best gross margin in 2020, the first year of the COVID-19 pandemic.

Figure 2.1: Gross Margin for the Flour Milling Industry Compared with Food Manufacturing and All Manufacturing



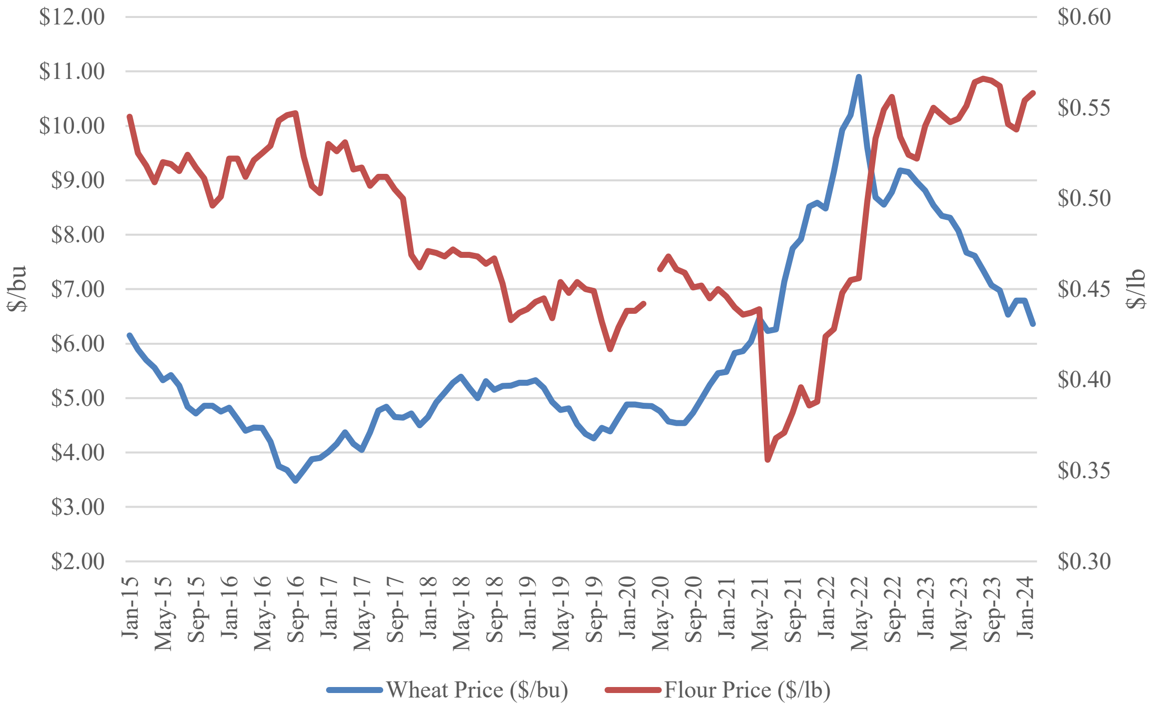
Source: U.S. Census Bureau Annual Survey of Manufacturers Summary Statistics Available at ASM-2018-21.

The flour milling industry has faced some challenges in the past several years with respect to increased diagnoses of celiac disease and other gluten-intolerance diseases across the country. The Centers for Diseases Control and Prevention (CDC) reports that between 0.5% and 1% of the general population in the United States is affected by celiac disease. Bradauskiene, et al. (2023) report a strong correlation between wheat product consumption and celiac disease (r = 0.88) across the western world. However, the correlation coefficient was not statistically significant within countries. This notwithstanding, it has been noted that a single celiac patient in any household makes the whole household go off wheat and gluten products to ensure the safety of the gluten-intolerant person. However, there is also evidence that a large number of people are adhering to gluten-free or gluten-restricted diets that are unnecessary (Sabença, et al. 2021). In addition to celiac disease, other autoimmune disorders related to wheat are gluten ataxia, affecting a maximum of 6% of the population, and dermatitis herpetiformis, which affect between 0.4 and 2.6 per 100,000 people. Then, there are those allergic to wheat and those who are non-allergic and non-autoimmune but merely have a sensitivity to wheat and wheat products. This group, accounting for up to 13% of the population, are those who are often miscounted into the autoimmune group (Sabença, et al. 2021).

U.S. flour production totaled 430.3 million cwt, in 2022, up 9.1 million cwt (2.2%) from the previous year, the largest since flour production jumped 15.4 million cwt in 2007 (World Grain 2023). The increased production has also created significant challenges across the supply chain for wheat. Executives of the six Class I railroads in North America participated in a conversation on March 17, 2024, at the 128th National Grain and Feed Association conference in Orlando FL. The executives identified interest rates and shipping disruptions in the Red Sea as some of the challenges they are dealing with. They noted that the record corn crop in 2023 kept trains busy, but the shift in a major railroad company's strategy could have the biggest effect on rail transportation in the industry. Norfolk Southern announced scrapping its "service over profits" strategy and focusing on maximizing profits as a result of activist investor Ancora Holdings Group's efforts. That, the executives argued, could create challenges for some of the lines in the domestic transportation chain, whether getting wheat to milling plants or getting flour out to customers. But BNSF reported having seen grain movement double over previous year as a result of the resolution to labor strikes along the West Coast. The largest railroads indicated they are recruiting both train and engine employees to ensure enhanced efficiency in their operations.

Figure 2.2 shows the trends in wheat and flour prices between 2015 and 2024. The average wheat price over the period was $5.83/bu with a standard deviation of $1.73 and minimum and maximum prices of $3.38/bu and 10.90/bu. Flour price per pound averaged $0.49 with a standard deviation of $0.05/pound and a minimum of $0. 36 and $0.57 over the period. The correlation coefficient between wheat price and flour price was 0.24 but not statistically significant. This would seem to support the industry view that flour price is driven by customer needs and specifications while wheat price is driven by supply and demand.

Figure 2.2: Monthly Wheat and Flour Prices in the U.S. (2015-2024)



Source: FRED Federal Reserve of St. Louis Economic Research Department.

The macro environment affects how flour mills operate but the biggest factor in influencing flour mill operations is customers. What do customers want? How much do they want? Where do they want what they want? The answers to these questions influence the strategic decisions that flour millers make and how they structure their procurement and capital investments. The rest of the research moves from macro analysis to micro, firm-level decision making about satisfying specific customer needs.

2.2 Wheat Moisture, Ash and Protein

Wheat Moisture, Ash and Protein (MAP) are the standard specifications that customers require on their Certificates of analysis (COAs). As a result, flour millers adhere to the MAP as a measure of overall quality. COAs contain testing information, such as MAP and rheological analysis such as Absorption, Stability, and Peak, and Arrival and Departure times on a doughlab curve. These analyses are done on a batch basis to provide customers with information they can use in their bakeries or pizzerias to adjust in their own production decisions, e.g., increasing or decreasing water and mixing time. Certain analyses in recent years have been further optimized by utilizing Near Infrared Reflectance (NIR) to speed up the sampling process and deliver results that are accurate enough to effectively approximate MAP values.

Let us now explore the components of the MAP in some detail because MAP is such a critical quality and operational “tool” in the dough products industry. Customers of flour mills depend on it to make several quality decisions that affect their own competitiveness.

2.2.1 Moisture

Wheat moisture is quantified by grinding a small amount of wheat and either separating the bran and germ and testing white flour or by testing the whole grain. The moisture content is then determined by heating the flour or ground wheat sample at a low temperature (130°F) in an air oven and comparing the weight of the sample before and after heating. The weight loss is then recorded as the moisture content as a percentage compared to the original sample weight (Shelton, p. 11).

2.2.2 Overnight Wheat Ash

Wheat ash is quantified by grinding a small amount of wheat and placing it into an ash cup. The sample is then heated to a high temperature (585°C) in an ash oven until the product is stable which is usually at least overnight. The residue is cooled to ambient temperature and then is weighed. Ash content is by definition the remaining residue and is recorded as a percentage of the starting weight in the ash cup (Shelton, p. 13).

2.2.3 Wheat Protein

Wheat protein is quantified using Combustion Nitrogen Analysis (CNA), which is often used to develop calibrations for other protein methods, such as Near Infrared Transmittance (NIRT) or Near Infrared Reflectance (NIRR) (Wheat Marketing Center, Inc. 2004). The process involves grinding a minute amount of wheat and putting it into a protein analyzer combustion chamber where it is heated to a high temperature of about 952°C. Nitrogen gas is produced during this process and the amount of gas is measured with a formula applied to measure the protein content in the sample (Shelton 2004, 15-16). Conversely, protein may be measured using the Kjeldahl method. The principal difference between the two methods is that it latter burn the sample at a much lower temperature, about 410°C, and measures organic nitrogen and ammonia content. These values are generally accepted and interpreted by bakers as factors that influence accurate methods to approximate rheological values such as water absorption, peak development, and stability. (Shelton, p.15).

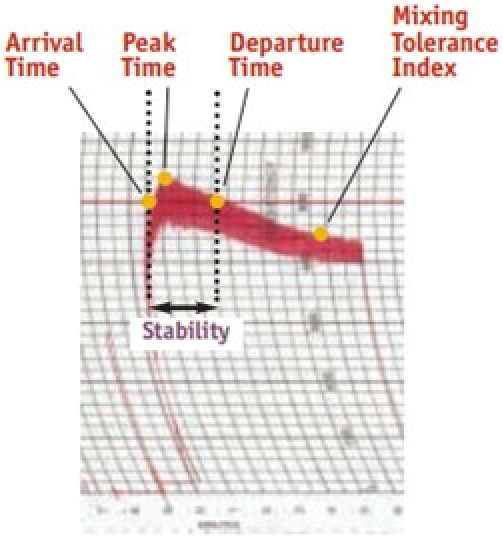
2.3 Rheological Measures

There are many rheological measures including but not limited to Absorption, Peak Time, Arrival Time, Departure Time, Stability, Mixing Tolerance Index (MTI), Falling Number Value and Modified Amylograph Value that measure flour performance. For the purpose of this study the focus will be on Absorption, Peak Time, Stability, MTI and Modified Amylograph. In addition, there will be a specific focus on Absorption and Stability in the optimization as that is what the end customer is most concerned with in their product application. Rheological results are achieved through a Perten Doughlab which is a newer machine that effectively and more precisely measures dough tolerance similar to the original Farinograph analysis (Steffe 1996, p.1-4).

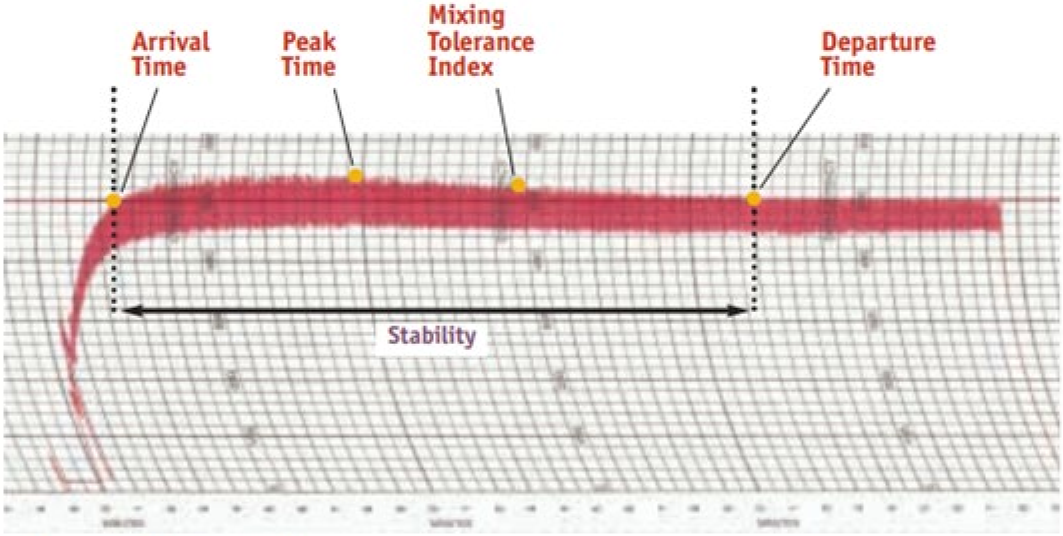
2.3.1 What is Rheology

Rheology is defined as the study of the flow of materials, or more precisely, the mode of response by materials to specific deformation strains or stresses (Steeples, 2010 p. 3). In the baking industry, the understanding and reliance by bakers on the results of these stresses on flour have turned baking into a precise science. Large bakeries depend on rheological data to ensure the ability to produce large amounts of baked goods with extreme repeatability and final product quality. The common methodology in the flour milling industry used to test rheology can be considered the rotational type and are mainly mixers or pipe viscometers. In most modern flour milling operations, the Doughlab or Farinograph is the measurement tool of choice to measure torque and various factors that affect overall extensibility and water retention (Steffe, 1996 p. 2-4). There are dozens of rheological characteristics that can be analyzed, and some are aforementioned; for this research the focus will be placed specifically on absorption and stability with this being the most critical aspect for the customer flour profile that is being studied.

Figure 2.3 Differences between Weak & Strong Gluten Flour



Weak Gluten Flour



Strong Gluten Flour

2.3.2 Absorption

Absorption is defined as the amount of water required to center curve over the 500 Brabender Unit line. This is the water retention percentage by weight that is needed to be added to the flour for optimal processing, holding all other factors such as mix time and equal. (Shelton , p.31).

2.3.3 Peak Time

Peak Time is defined as the dough development time, or the optimal mixing time from when water hits the dough until the dough reaches maximum consistency. Under standard conditions this will give you the amount of time in minutes that it takes for the dough to become consistently stable (Shelton, p.31).

2.3.4 Arrival Time

Arrival Time is defined as the time it takes, in minutes, for the top of the Doughlab Curve to touch the 500 Brabender Unit line. This is an indicator of flour hydration, or in other words, how fast the flour takes in the water before it cannot take on any more water without further breakdown of the gluten structure (Shelton, p.31).

2.3.5 Departure Time

Departure Time is defined as the time from when the top of the leaves the 500 Brabender Unit line. This is an indicator of when the dough is starting to breakdown, and it can be interpreted as relative consistency of the dough. The departure time is expressed in minutes and is a static value (Shelton, p.31).

2.3.6 Stability

Stability is defined simply as the difference in the time between the arrival and the departure time. This indicates how stable/strong the dough is as it maintains its maximum consistency throughout that time. This depends on where the peak time of the Doughlab curve is located. This heavily decides where the arrival time will be and thus where the departure time will land (Shelton, p.31).

2.3.7 Mixing Tolerance Index (MTI)

The Mixing Tolerance Index or MTI is the difference in the Brabender Unit value at the top of the curve specified at the Peak Time and the Brabender Unit value five minutes after the peak. This is an indicator of the degree of softening during the mixing of the dough (Shelton, p.31). This expected softening value can be very different for the varying classes of wheat due to the different baked goods that are made and how they are processed.

2.3.8 Load To Load Variability (LTLV)

Another important facet of this study that truly ensures customer satisfaction is the aspect of Load-to-Load Variability. Even though this isn't a rheological characteristic, it is a measure to minimize drastic changes in rheological results, most importantly absorption and rheology. This is defined by the organization as minimizing the difference from one load to another and theoretically this makes the adjustments a customer might need to make when making a batch of product minute and negligible. For the purposes of this research, the absorption and stability will be maintained within a specific range from the last result as a limit of optimization to ensure the project does not lose sight of optimal customer satisfaction when minimizing cost and maximizing efficiency.

2.4 Optimization in Flour Milling

In a previous optimization study on wheat blending and additionally additive mixing done by Philippe Steffan, it was proven that by attempting to use linear programing as well as integer linear programming ended up being the same with the LP model providing cheaper alternatives without changing the results of the optimization (Steffan 2012, p. 62-63). The LP approach will be used in this following research for simplicities sake as well as practicality. Another contributing research project with a great influence on this study was done by Nikolas Haas, and even though his optimization model was based solely on different wheat varieties based on protein contents, his goal was to make the best blends based on wheat inventory as well as Solvent Retention Capacity which will not be discussed in this thesis (Haas, 2011, p.13-15). This optimization assumed a constant wheat price for simplicity, but this thesis will look to expand and dive deeper by including costs of different wheat types as well as historical data from BSMC records to approximate a linear cost model for wheats of differing protein levels.

2.4.1 Wheat Blending in Flour Milling

The main purpose of this thesis is to address how to solve the age-old milling problem by blending of wheat given a set of known parameters to provide a consistent end product for the customer, this is usually limited to MAP but rheological characteristics will be added as the average baker has become adept at the science behind baking. The main problem that arises is the allocation of resources by an organization in a way that maximizes profits by minimizing costs while maintaining quality (Unger 1957 p.1). In Unger's (1957 p. 3-4) study of the usefulness of Linear programming in flour milling applications, he mentions that the application of optimization is distinctly important at the blending stage due to its simplicity and relatively minimal variables included at that stage. Attempting to perform similar optimization, for example in the procurement or growing process would invite a myriad of uncontrollable variables that would make linear programming more cumbersome.

2.4.2 Optimization Techniques

In looking through past history of techniques used in flour milling, it is apparent that due to the nature of different components being added at varying amounts, linear programming is the preferred methodology across the industry to optimize the blending of wheat to attain desired results. Wheat blending is a centuries old practice that has allowed millers to cut costs by adding lower quality wheat to manage costs while maintaining overall flour quality. This has resulted in dollars saved and a minimal impact to quality for organizations that have excelled in this practice of simple mathematical computations to optimize wheat mixes (Haas 2011, p. 9-10). There are other individuals such as Dr. Huseyin Avunduk, an associate professor of data analytics who posits in his article, *Linear progamming model for optimum mixing the flour from sieve passages in flour mill industry,* that most flour milling companies select different what and flour mixes simply to meet specifications based on past experiences of mostly singular individuals. The individuals typically work in a vacuum with no optimization of cost and furthermore, no feedback process between the planning and marketing/sales department (Avunduk 2017, p. 362). This research endeavors to make that association in a simplistic application that can be useful to BSMC mill managers and decision makers.

CHAPTER III: DATA AND METHODS

In this chapter, we describe the methods used to answer the research questions and achieve the research objectives. We also describe the data used for the analyses. The chapter is divided into two principal sections. The first section describes the methods employed for the analyses. The second section presents an overview of the data used.

3.1 Methods

It is theorized that the optimal cost of any flour is dependent on the prices of the different wheat types that are comingled to produce the right combination of moisture, ash, and protein to yield the desirable rheological performance. Based on this theory, then, the realized cost of wheat, C_w, used in manufacturing any flour, given the rheological specifications, may be specified as follows:

$$C_w = p_1W_1 + p_2W_2 + p_3W_3 + \ldots \tag{1}$$

where p_i is the price/bushel of each of the wheat types in the flour that enables the achievement of the desired rheological characteristics. Each wheat type has specific MAP characteristic defining its rheology, α_i such that:

$$\alpha_i = f(M, A, P) \tag{2}$$

However, the different types of wheat are priced differently. Therefore, while the unconstrained flour meeting the needs of a particular customer's rheological specifications may be feasible with a particular combination of wheat types, the price may be beyond what the customer is willing to pay for the product or the price they are willing to pay that would provide an acceptable margin for the flour miller. With the economics of milling reduced solely to wheat price, for simplicity, the miller's objective function for each kth

customer is to minimize the cost, C_k, of the combination of the different types of wheat needed to produce the flour that meets the customer's rheological specifications. That is:

$$\begin{aligned} &\min C_k = \sum_{i=1}^{N} p_i W_i \\ &s.t. \\ &\sum_{i=1}^{N} W_i = 1 \\ &\sum_{i=1}^{N} \phi_i M_i \le M_k \\ &\sum_{i=1}^{N} \theta_i A_i \ge A_k \\ &\sum_{i=1}^{N} \pi_i P_i \ge P_k \\ &W_i \ge 0 \end{aligned} \tag{3}$$

The price per bushel for each type of wheat, W_i, is defined as p_i and the proportion of moisture, ash, and protein in each type of wheat is defined as $\phi, \theta,$ and π. The desired levels of moisture, ash, and protein for each kth customer is defined as $M_k, A_k,$ and P_k. These define the optimization constraints for the cost minimization problem. The solution is also constrained for all the proportions of moisture, ash, and protein to be non-negative. The Microsoft Excel optimization macro (Solver) is used for determining the least cost combination of the different types of wheat to produce the flour with the desired rheological characteristics for each customer, *k*.

The problem of interest in this research focused on five different customers, i.e., k = 5. The company has five different types of wheat, which have been labelled as HRW 1, HRS 1, HRS 2, HRS3, HRS 4. HRW and HRS stand for Hard Red Winter and Hard Red Spring. The average prices and characteristics for each of these wheat types are estimated from the procurement profile of the miller and are presented in Table 3.1.

Table 3.1: Base Characteristics and Prices of Types of Wheat Available to Flour Miller

Wheat Type	Protein	Stability	Absorption	Usage % Max	Average 2023 Price
HRW 1	13.2+	15.5	59.5%	20%	$9.77
HRS 1	< 13.5	15.5	61.0%	40%	$10.12
HRS 2	13.6 - 14.4	14.4	62.5%	100%	$10.41
HRS 3	14.5-15.0	14	64.0%	80%	$10.77
HRS 4	15.0+	14	66.0%	40%	$11.29

The specifications for each of the customers are presented in Table 3.2. Customer 1 differs from Customer 2 in terms of protein, absorption, and stability; about 8.1% and nearly 5.9%, and 6.7% for stability. The differences between Customer 3 and Customer 2 were 6.5% for protein, 8.5% for absorption, and -6.7% for stability. This would immediately reveal that these three customers are targeting the production of different products or focusing on different end markets.

Table 3.2: Rheological Specifications by Sample Customer

Customer	Protein	Absorption	Stability
Customer 1	13.40%	62.5%	16
Customer 2	12.40%	59.0%	15
Customer 3	13.20%	64.0%	14
Customer 4	14.00%	63.5%	16
Customer 5	13.60%	63.0%	14

3.4 Expectations

Because protein tends to be more expensive and pulls up the price of wheat, it is expected that the flour for Customer 4 will be the most expensive among the five types of flour since the protein content in the specification is the highest. In the same vein, the cost of producing Customer 2's flour is expected to be the least expensive. The purpose of the optimization exercise is to determine the proportions of the different types of wheat available that go into producing each of these flours.

CHAPTER IV: RESULTS

The results from the Solver Macro in Microsoft Excel are presented in this chapter for each of the five customers' specified product characteristics. The chapter is organized by customers and the composition of their flour from the different wheat. We also show the rheological composition of the flour for each customer.

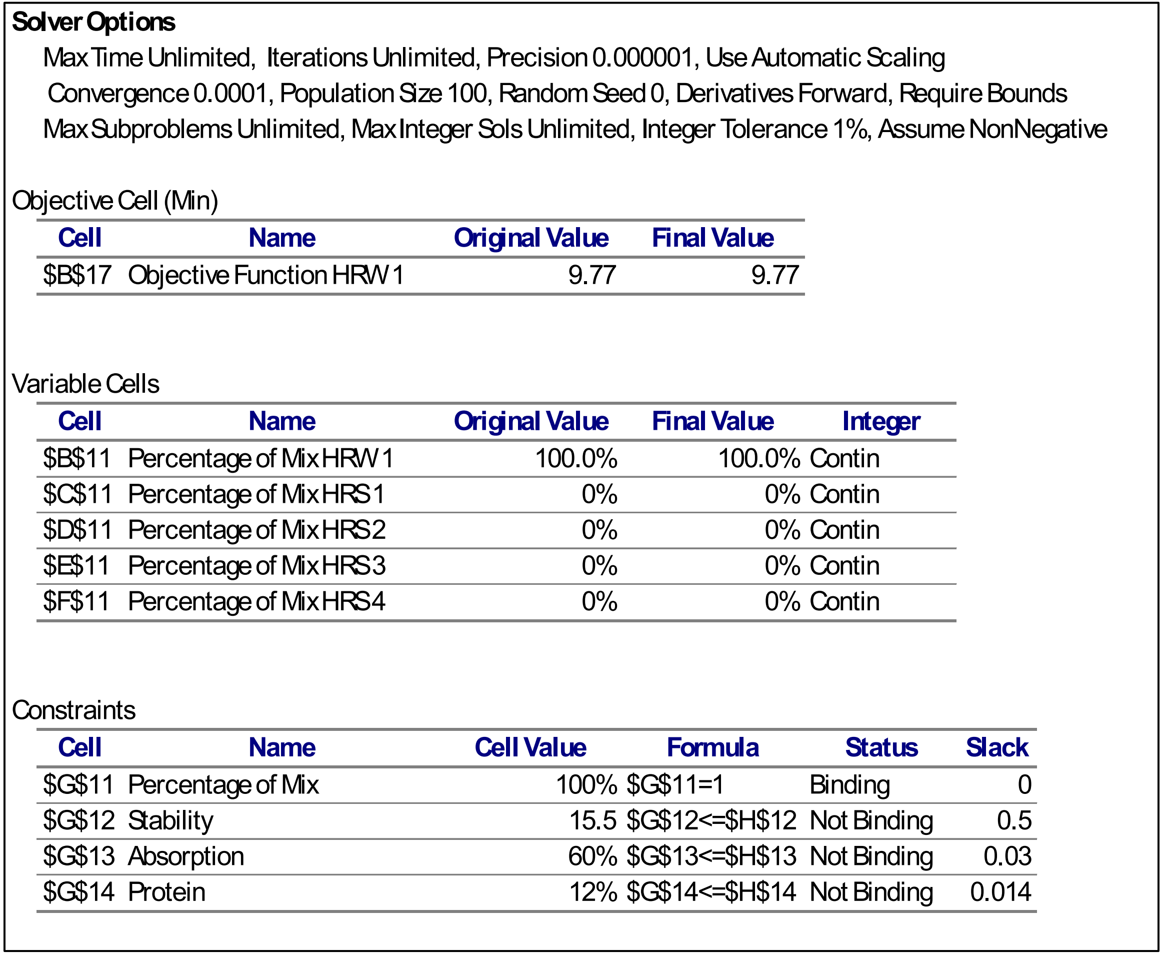
4.1 Results

The results of the Solver analysis show the differences in the different optimized wheat mixes for the different customers that were identified and analyzed during this project. This subsection is organized according to the customers optimal mix cost value, lowest to highest.

4.1.1 Customer 2

The least cost mix for Customer 2 uses 100% of the HRW 1 class wheat. Stability was at 15.5, absorption at 59.5% and protein percentage at 12%. This optimization yielded a minimum cost value of $9.77 per bushel. The solution, internally known as "Basco", is currently milled at a quantity of 102,574 bushels weekly which equates to a cost of $1,002,147 to produce on a weekly basis. The analysis summary is shown below in Figure 4.1.

Figure 4.1: Optimal Solution for Customer 2



Solver Options

Max Time Unlimited, Iterations Unlimited, Precision 0.000001, Use Automatic Scaling
Convergence 0.0001, Population Size 100, Random Seed 0, Derivatives Forward, Require Bounds
Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Assume NonNegative

Objective Cell (Min)

Cell	Name	Original Value	Final Value
$B$17	Objective Function HRW 1	9.77	9.77

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$11	Percentage of Mix HRW 1	100.0%	100.0%	Contin
$C$11	Percentage of Mix HRS 1	0%	0%	Contin
$D$11	Percentage of Mix HRS 2	0%	0%	Contin
$E$11	Percentage of Mix HRS 3	0%	0%	Contin
$F$11	Percentage of Mix HRS 4	0%	0%	Contin

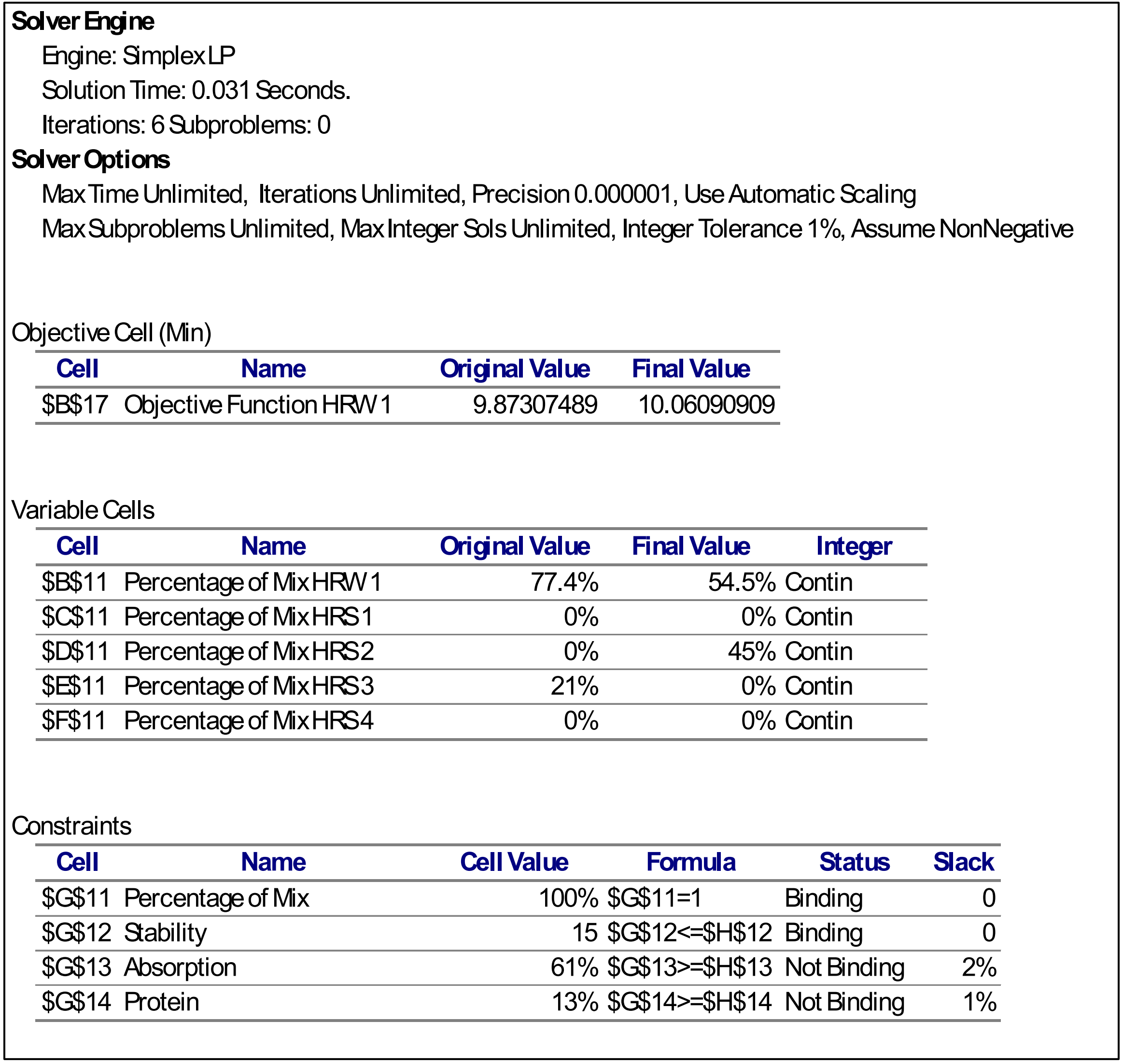
Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$G$11	Percentage of Mix	100%	$G$11=1	Binding	0
$G$12	Stability	15.5	$G$12<=$H$12	Not Binding	0.5
$G$13	Absorption	60%	$G$13<=$H$13	Not Binding	0.03
$G$14	Protein	12%	$G$14<=$H$14	Not Binding	0.014

4.1.2 Customer 1 - I56 Stallion

The second most optimal price mix was for the I56 blend for Customer 1 as it was able to use 54.5% of the HRW 1 class of wheat and 45.5% of the HRS 2 class of wheat. This blend had a stability value of 15, absorption value of 60.86% and a protein percentage of 12.95%. This optimization yielded a minimum cost of $10.06 price per bushel. I56 which is internally known as “Stallion” is currently milled at a quantity of 9,746 bushels weekly, which equates to $98,045 to produce on a weekly basis. The analysis summary is shown below in Figure 4.2.

Figure 4.2: Optimal Solution for Customer 1



Solver Engine

Engine: Simplex LP
Solution Time: 0.031 Seconds.
Iterations: 6 Subproblems: 0

Solver Options

Max Time Unlimited, Iterations Unlimited, Precision 0.000001, Use Automatic Scaling
Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Assume NonNegative

Objective Cell (Min)

Cell	Name	Original Value	Final Value
$B$17	Objective Function HRW 1	9.87307489	10.06090909

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$11	Percentage of Mix HRW 1	77.4%	54.5%	Contin
$C$11	Percentage of Mix HRS 1	0%	0%	Contin
$D$11	Percentage of Mix HRS 2	0%	45%	Contin
$E$11	Percentage of Mix HRS 3	21%	0%	Contin
$F$11	Percentage of Mix HRS 4	0%	0%	Contin

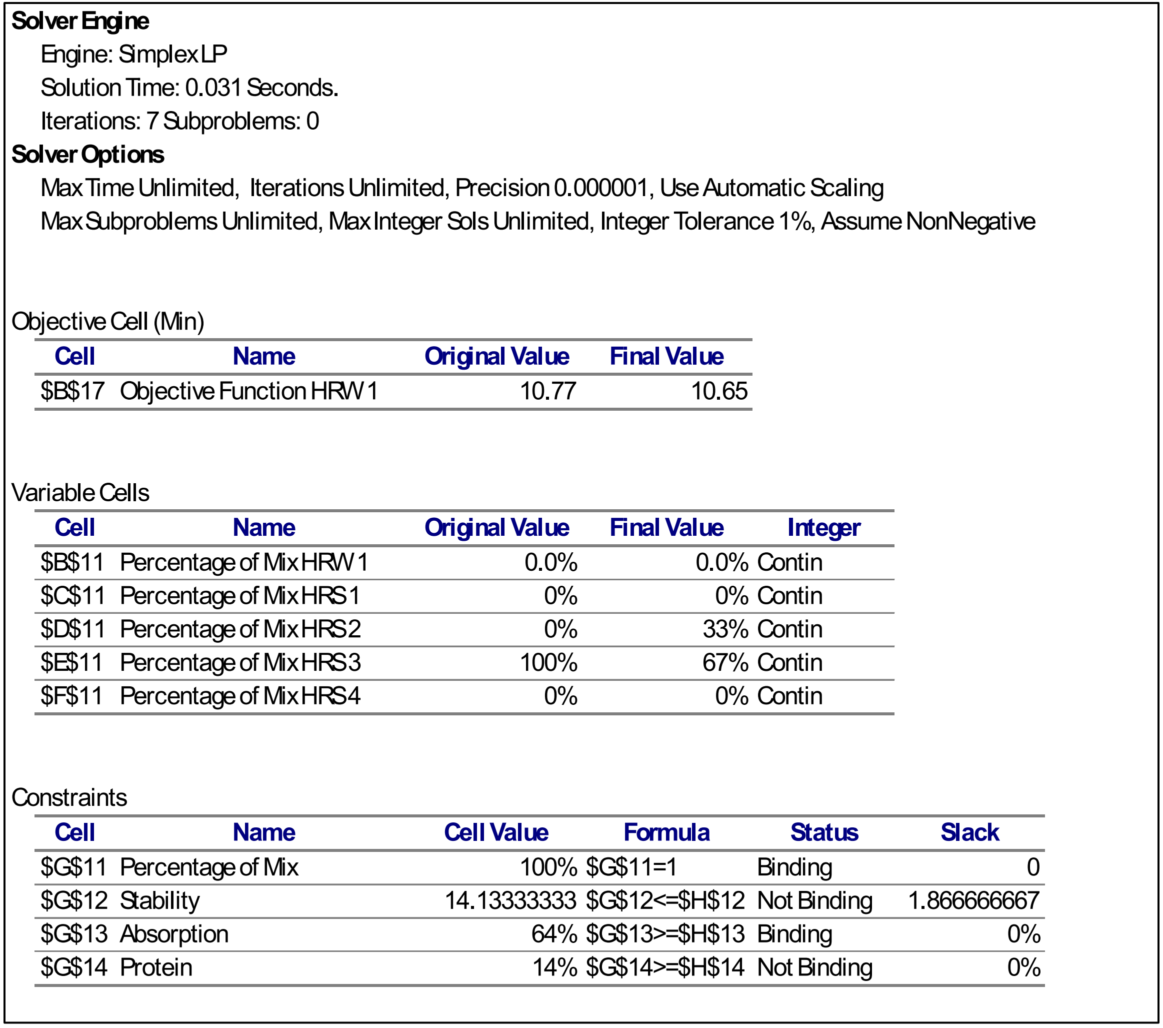
Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$G$11	Percentage of Mix	100%	$G$11=1	Binding	0
$G$12	Stability	15	$G$12<=$H$12	Binding	0
$G$13	Absorption	61%	$G$13>=$H$13	Not Binding	2%
$G$14	Protein	13%	$G$14>=$H$14	Not Binding	1%

4.1.3 Customer 4 J55 - Bouncer

The next most optimal price mix was for the I52 blend for Customer 4 as it utilized 67% of HRS 3 class wheat to meet the high rheology spec and lowered stability specification required and 33% of the HRS 2 class wheat. This blend had a stability value of 14.13, absorption value of 63.5%, and a protein value of 14.37%. This optimization yielded a minimal cost of $10.65 per bushel. J55 is milled at a quantity of 29,542 bushels weekly, which equates to $314,622 to produce on a weekly basis. This is interesting and counterintuitive due to the overall higher protein requirement of the higher protein wheat blend that requires a higher protein value but does not have such a stringent requirement on the reduced stability which is contradictory to the higher protein wheat requirement in HRS 3 class wheat, and this optimization allows for blending of the lower cost HRS 2 class wheat per the optimal mix. The analysis summary is shown below in Figure 4.3.

Figure 4.3: Optimal Solution for Customer 4



Solver Engine
Engine: Simplex LP
Solution Time: 0.031 Seconds.
Iterations: 7 Subproblems: 0
Solver Options
Max Time Unlimited, Iterations Unlimited, Precision 0.000001, Use Automatic Scaling
Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Assume NonNegative

Objective Cell (Min)

Cell	Name	Original Value	Final Value
$B$17	Objective Function HRW 1	10.77	10.65

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$11	Percentage of Mix HRW 1	0.0%	0.0%	Contin
$C$11	Percentage of Mix HRS 1	0%	0%	Contin
$D$11	Percentage of Mix HRS 2	0%	33%	Contin
$E$11	Percentage of Mix HRS 3	100%	67%	Contin
$F$11	Percentage of Mix HRS 4	0%	0%	Contin

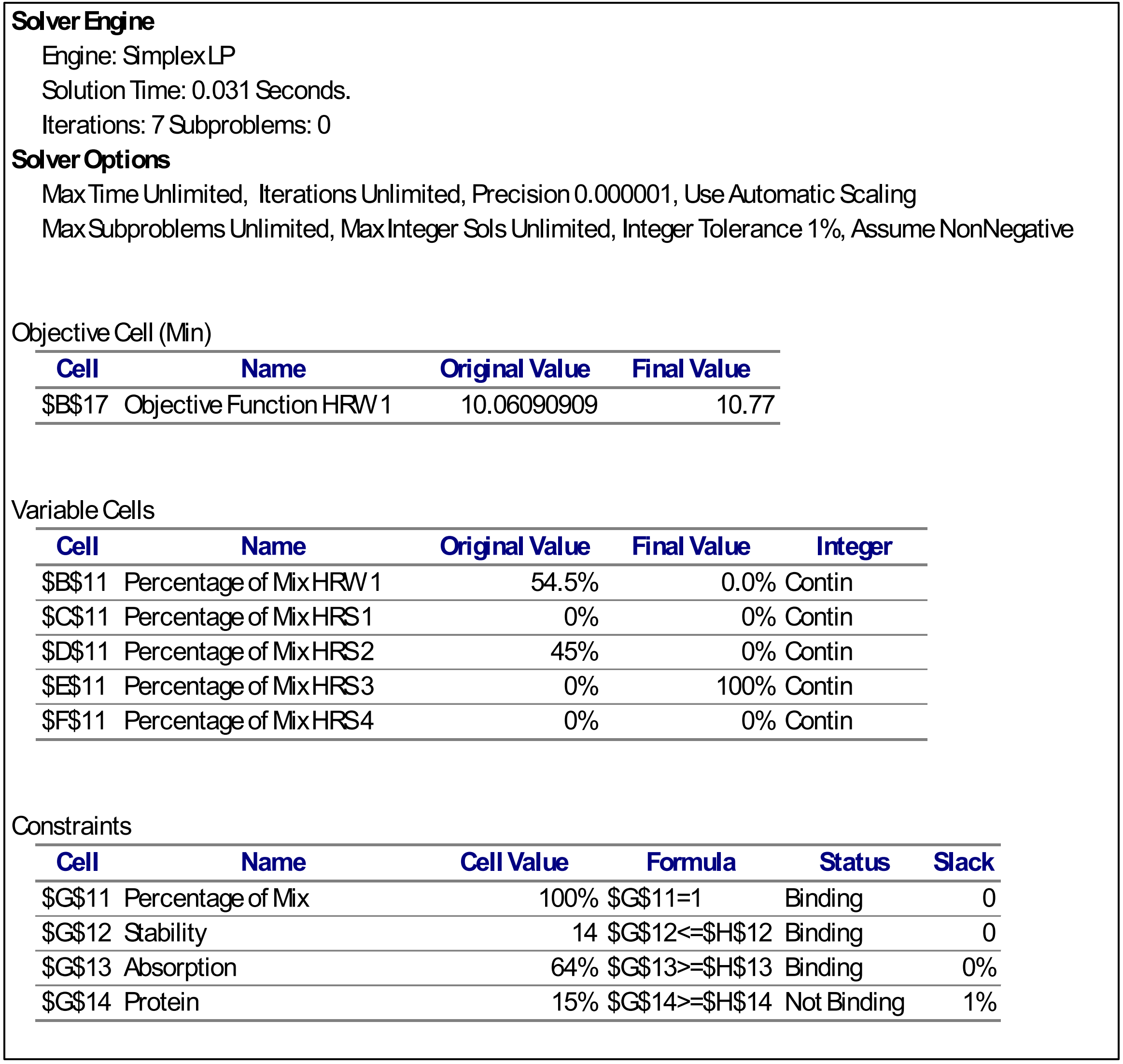
Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$G$11	Percentage of Mix	100%	$G$11=1	Binding	0
$G$12	Stability	14.13333333	$G$12<=$H$12	Not Binding	1.866666667
$G$13	Absorption	64%	$G$13>=$H$13	Binding	0%
$G$14	Protein	14%	$G$14>=$H$14	Not Binding	0%

4.1.4 Customer 3 I52 - LCE

The next most optimal price mix was for the I52 blend for Customer 3 as it utilized 100% of HRS 3 wheat blend to meet the high rheology spec and higher stability specification required. This blend had a stability value of 14, Absorption value of 64%, and a protein value of 14.5%. This optimization yielded a minimal cost of $10.77 per bushel. I52 is milled at a quantity of 26,982 bushels weekly, which equates to $290,596 to produce on a weekly basis. The analysis summary is shown below in Figure 4.4.

Figure 4.4: Optimal Solution for Customer 3



Solver Engine

Engine: Simplex LP
Solution Time: 0.031 Seconds.
Iterations: 7 Subproblems: 0

Solver Options

Max Time Unlimited, Iterations Unlimited, Precision 0.000001, Use Automatic Scaling
Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Assume NonNegative

Objective Cell (Min)

Cell	Name	Original Value	Final Value
$B$17	Objective Function HRW 1	10.06090909	10.77

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$11	Percentage of Mix HRW 1	54.5%	0.0%	Contin
$C$11	Percentage of Mix HRS 1	0%	0%	Contin
$D$11	Percentage of Mix HRS 2	45%	0%	Contin
$E$11	Percentage of Mix HRS 3	0%	100%	Contin
$F$11	Percentage of Mix HRS 4	0%	0%	Contin

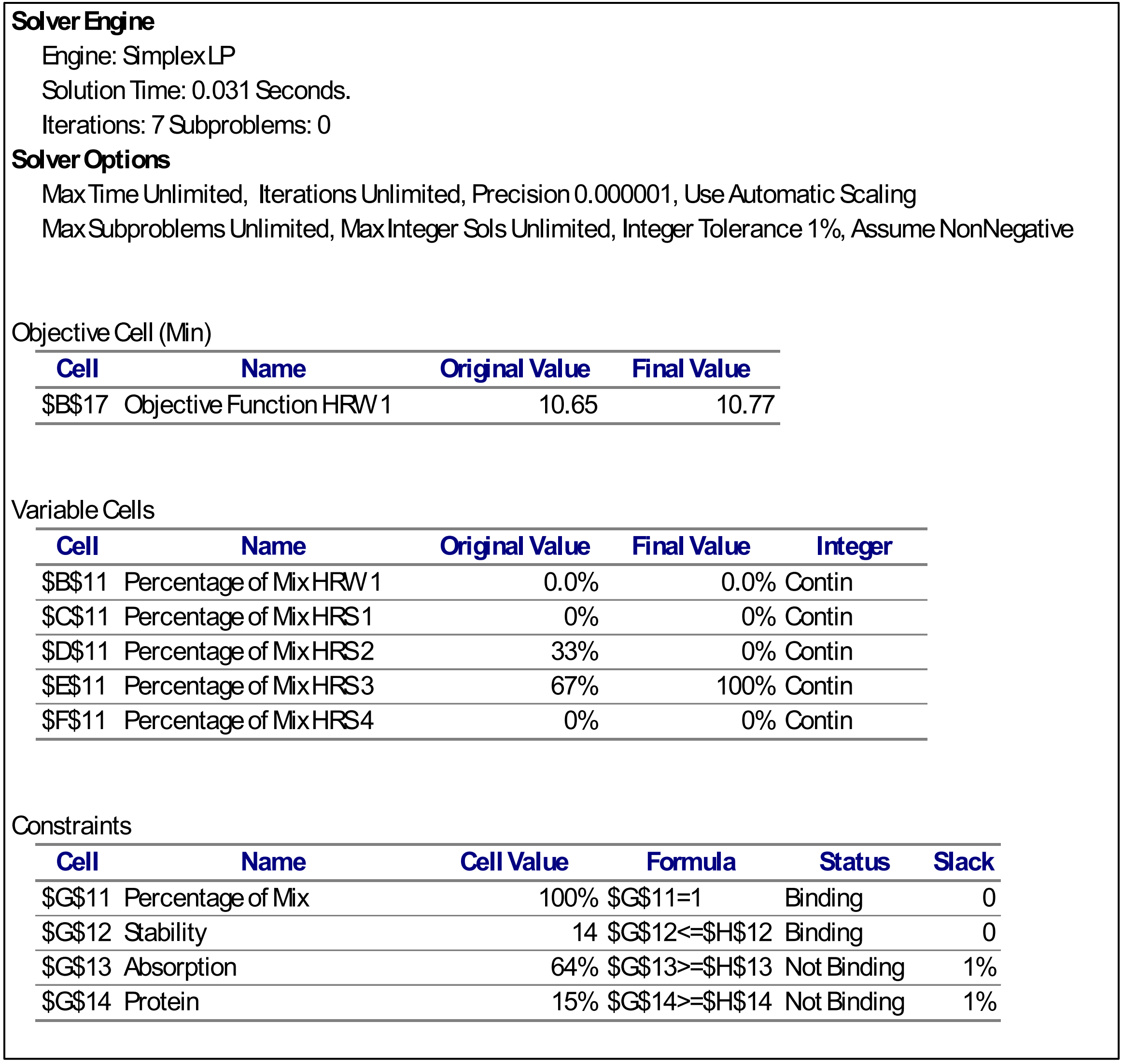
Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$G$11	Percentage of Mix	100%	$G$11=1	Binding	0
$G$12	Stability	14	$G$12<=$H$12	Binding	0
$G$13	Absorption	64%	$G$13>=$H$13	Binding	0%
$G$14	Protein	15%	$G$14>=$H$14	Not Binding	1%

4.1.4 Customer 5 I71 - Boxer

The least optimal price mix is for the I71 blend for Customer 5 as it also utilized 100% of the HRS 3 class wheat to meet the high rheology spec as well as the higher ash requirements that the higher protein wheat generally provides whilst minimizing the sacrifice in overall milling yield. This blend yielded a stability of 15, absorption of 64% and a protein percentage of 14.5%. This optimization yielded a minimal cost of $10.77 per bushel. I71 is milled at a quantity of 7,108 bushels weekly, which equates to $76,553 to produce on a weekly basis.

Figure 4.5: Optimal Solution for Customer 5



Solver Engine

Engine: Simplex LP
Solution Time: 0.031 Seconds.
Iterations: 7 Subproblems: 0

Solver Options

Max Time Unlimited, Iterations Unlimited, Precision 0.000001, Use Automatic Scaling
Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Assume NonNegative

Objective Cell (Min)

Cell	Name	Original Value	Final Value
$B$17	Objective Function HRW 1	10.65	10.77

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$11	Percentage of Mix HRW 1	0.0%	0.0%	Contin
$C$11	Percentage of Mix HRS 1	0%	0%	Contin
$D$11	Percentage of Mix HRS 2	33%	0%	Contin
$E$11	Percentage of Mix HRS 3	67%	100%	Contin
$F$11	Percentage of Mix HRS 4	0%	0%	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$G$11	Percentage of Mix	100%	$G$11=1	Binding	0
$G$12	Stability	14	$G$12<=$H$12	Binding	0
$G$13	Absorption	64%	$G$13>=$H$13	Not Binding	1%
$G$14	Protein	15%	$G$14>=$H$14	Not Binding	1%

For each of the foregoing customers, the optimal cost wheat mix to meet their rheological specifications are summarized in Table 4.1. The table shows that the optimal mix for Customer 1 is 100% HRS 1 while Customer 2's optimal mix encompassed HRW 1 and HRS 2 in 55:45 mix ratio. Customer 3 had four types of wheat in its mix while Customers 4 and 5 had three types of wheat in their mixes. The least cost mix was the one for Customer 2 at $10.06/bu while the most expensive mix was for Customer 5 at $10.54/bu. Note that the volume of flour ordered would have significant implications for the overall net revenue emanating from the different orders. The results show that HRS 4 is not employed in any of the optimal mixes and makes sense for the company to not store it in its inventory if its customer set is limited to this group of five customers.

Table 4.1: Summary Results of Optimal Mix and Cost by Customer

Customers	**Shares of Different Types of Wheat**					**Optimal Price ($/bu)**
	HRW 1	**HRS 1**	**HRS 2**	**HRS 3**	**HRS 4**	
Customer 1	0%	**100%**	0%	0%	0%	10.07
Customer 2	**55**%	0%	**45%**	0%	0%	10.06
Customer 3	**8%**	**70%**	**12%**	**10%**	0%	10.19
Customer 4	0%	**20%**	**30%**	**50%**	0%	10.53
Customer 5	0%	**18%**	**30%**	**52%**	0%	10.54

CHAPTER IV: CONCLUSIONS AND FUTURE RESEARCH

The objective of this thesis was to define and describe five different flour customer profiles and identify the most cost-effective blends in the making of these profiles to provide a template that can be used to provide added value both to prospective customers and the organization. Identifying the value provided for these final flour blends and their true cost to the organization will lay the framework for further cost-benefit analysis in accepting new customers and properly pricing wheat blends not only on the cost to produce, but additional on the cost to procure the varieties of wheat that the blends require at the optimal mix values to produce a quality that customers accept. This goal has been achieved with a general trend that was to be expected regarding the most cost effective and the least cost-effective flour blends. For this study, five flour blends were identified, analyzed, and can now be used to direct customers as well as BSMC senior management in a way to provide the most cost-effective product that meets prospective customers rheological expectations.

The most cost-effective blend was attributed to the Customer 2 blend, and it also coincidentally is the most prevalent wheat mix produced at the facility; this aligns with the overall expectation prior to the experiment. This is a positive mix from the perspective of the millers as there are minimal issues when this blend is produced, and high yields are typically documented by the millers. The second most cost-effective wheat blend was attributed to the Customer 1 blend with the negative aspect being the relatively low amount of overall production on a weekly basis that would not support a large amount of investment in the mix unless there was a substantial increase in price paid by the customer. The organization would be better served utilizing the wheat to produce more of the

Customer 2 profile product. The next most cost-effective blend was the customer 4 profile which was unexpected due to its high protein and general acceptance in the organization as the most expensive wheat mix. There is constant product made over the protein target but there is a large room for error on the rheological side that is not commonly addressed and is clear within the results of this optimization exercise. The volume and importance of that customer profile dictates its necessity within the organizational framework, and it commands the highest price paid by customers due to the inherently higher protein specification and difficulty to maintain. The last two products were the Customer 3 and Customer 4 profile blends that came in both at the same price point per bushel with the differentiating factor being the customer it is produced for. Customer 3 is a definitive product that is made for one of the biggest customers for the operation and this necessitates its continued production. On the other hand, Customer 5 is a specialty product that is made for one or two customers and commands the least amount of yield while utilizing relatively expensive wheat for production. This product would be at risk of not being produced and would free up Elevator space to hold more wheat to produce product that is more desired and fits better within other more established customer profiles. The last blend for customer profile 5 is the least produced product with a similar specification and could easily be removed and save the organization a higher cost of production without the benefits of volume or pricing to offset complexity on the mill.

Takeaways from the study point to the elimination of the use of HRW 4 class wheat as it does align with usage in any of the five customer profiles and is more costly than any other wheat blend. Further research into the reasons for its production would be needed to conclude its viability as a continued product for the organization. Other wheat varieties are utilized and appear from the results of this study to provide adequate value to provide quality to the end user and allow for requisite blending required at the mill for day-to-day operations.

The price of the individual wheat mixes are documented and can be used further to make different blends to further provide value to the company if that option is feasible regarding flour blending capabilities at the plant level. The ability of BSMC to push customers towards certain flour blends due to the ability to make those blends with the most cost-effective wheat mix would truly be a foundational shift from an industry perspective. Currently, customers ask for product and the corresponding flour mills scramble to make that flour even at a higher cost than first thought due to the lack of feedback from the mill back to the sales and marketing teams. The true cost of these sort of inefficient sales are not necessarily quantifiable with the information in the current study, but with further research could be assessed and eventually mitigated or eliminated entirely. If the mill was able to deliver this information in a data driven fashion back to the sales team, the potential to head off problematic or highly cost ineffective flour blends could prove to be a large and profitable feedback.

4.1 Future Research

Future research can be done to further optimize this data to build a more complex solver that can consider the wheat on hand to optimize the wheat mix. The current solver is limited by a generic method due to the constraints in the excel Macro that drive the solver to use the minimal amount given if possible. Acquiring more in-depth software to address this issue could be a large financial gain to the company if wheat mix can be truly optimized based on those parameters. Additionally, the consumer would eventually see a financial gain as there are ranges of acceptable rheological factors that a customer would accept but currently is unable to recoup. Today, a customer can receive a flour blend that is at the low end of the specification and pay the same price. On the contrary the company can send a customer product at the high end of the specification and essentially lose value in that transaction.

Given the available information, a customer would appreciate paying a lower price for product that still meets their demands while understanding that the mill is also able to pass on those savings due to the ability to control costs and minimize “excess” value loss. Lastly, the consumer would also receive a more consistent product due to the attention to the detail in producing the most cost-effective mix that meets customer demand rather than producing these blends in a vacuum while just trying to hit a wide range rather than a specific one. The addition of volume to the conversation as well as the ability to go back to a prospective customer with data driven decisions would aid in the organization’s ability to properly price products that are not within the framework provided. Drafting a more complex analysis of historical data as well as overarching objectives of the organization would dictate the use of this thesis to make informed decisions about which customer profiles should be produced in the future as well as the pricing that could be attached to those customer profiles.

There might be an opportunity to segment the overall customers by their needs so that the company can focus on identifying where the majority of its gross profit is coming from. This will allow the company to focus attention on meeting the rheological expectations of the customers who are willing to pay more even as it provides generic flour to the majority of customers who are not willing to pay for the rheological characteristics they are demanding. This further research will help the company streamline its operations, probably reduce its inventory of raw material (wheat) and improve overall profitability.

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