SUPPLY CHAIN MANAGEMENT: ASSESSING COSTS AND LINKAGES IN THE WHEAT VALUE CHAIN

by

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Disclaimer

ABSTRACT

In response to current market pressures, firms are forming strategies under various industry initiatives to gain competitive advantage. Whether these initiatives entail better service, lower costs, or both, they share a common essence: integrating the supply chain. The objective of this project was to contrast firm-level strategic decision criteria with integrated supply chain decision criteria for three activities in the wheat supply chain. The model developed provides a mechanism to better understand information requirements necessary for firms to evaluate supply chain integration strategies. Consistent with the strategy literature, these strategies have, heretofore, primarily been analyzed qualitatively.

Differences in wheat quality preferences among individual firms comprising the wheat supply chain were found. With the exception of protein, these are all but lost in the complexity of the competitive structures facing each individual firm. Therefore, benefits of supply chain coordination exist, but are either not compelling or tangible. Methods to quantify these benefits and how they are distributed among firms in the supply chain, however, have not been adequately addressed. By quantifying benefits and how they are distributed among a supply chain, firms can better negotiate vertical coordination strategies, ultimately improving their competitive position.

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CHAPTER I: INTRODUCTION

In response to current market pressures, suppliers, manufacturers, distributors, and retailers are all scrambling under the guise of various industry initiatives to gain competitive advantage. Whether these initiatives take the form of better service, lower prices, or some combination of both, they all share a common essence: integrating the supply chain.

These market pressures and structural changes are taking place in many food-based industries in the United States. The industries that comprise the wheat supply chain, which reaches from farmers to end-consumers, have not been immune to these changes. For example, an industry initiative termed efficient consumer response (ECR) is revolutionalizing the way groceries are distributed to consumers. The goal is to reduce the number of days in inventory between the manufacturer and the retailer from 104 to 61, a reduction of over 40 percent, and to reduce system costs by 10.8 percent (Walsh, 1995).

A pervasive theme among food-based industries has been consolidation, resulting in fewer and larger firms, larger plants, and increased concentration (Wilson, 1995). In addition to these across-industry trends, firms compete within unique industries with unique competitive forces. However, changes in one of these industries often impact the network of buyers and suppliers for firms in that industry, ultimately affecting an entire supply chain.[1] Implications of these trends on the entire supply chain are seldom analyzed. Instead, analyses usually focus narrowly on the impact to the specific industry or particular firm in question.

Several industry analyses identify and assess changes in competitive structure without addressing the entire wheat supply chain. Examples of these include a transportation analysis, an ingredient quality analysis, and a competitive analysis.

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[1] A supply chain is the network that products move through as firms process and convert raw materials into finished products and deliver them to the end-consumer (Stenger, 1994).

Babcock, Cramer, and Nelson (1985) used a transportation analysis to examine the locational attraction of flour mills between points of wheat production (origin) and those of flour consumption (destination). With their linear programming model, they analyzed flour milling location based on relative transportation costs for wheat and flour. The current industry situation confirms the model's results that flour mills are shifting their location forward. This trend has implications for elevators, bakers, and others with an interest in the wheat supply chain. For example, wheat shipments become larger and cover longer distances impacting elevator sourcing and the quality variance within and between shipments. Additionally, relationships between flour mills and bakeries might be impacted by the flour mill's increased customer specificity.

Various wheat quality attributes impact the efficiency and costs of flour milling (Liu et al., 1992). Using an economic-engineering approach, Liu et al. (1992) simulated the milling efficiency and production cost of 99 individual wheat transactions with various known wheat quality attributes. Although their work identifies links, or relationships, between flour milling and wheat suppliers, they only assessed the implications of this relationship on flour millers and ignored the implications for others in the wheat supply chain.

The dynamic evolution of the wheat flour milling industry was analyzed by Wilson (1995). According to Wilson (1995), there are two particularly important observations regarding the U.S. flour milling industry. First, even though the industry is consolidating into fewer firms and plants, both firm and plant capacity have increased. Second, flour milling firms are increasingly multiplant firms with interests in other grain businesses (e.g., Cargill, Archer Daniels Midland, and ConAgra) as opposed to being vertically integrated food processors (e.g., Pillsbury, Nabisco, General Mills, and International Multifoods). Wilson's (1995) other observations concern Canadian and Mexican flour mills. These firms are increasingly able to use procurement as a strategy due to changes in agricultural policies. Additionally, there are differences in the direction of vertical integration between U.S. firms (traditionally largely integrated backward into milling) and Canadian or Mexican firms (traditionally integrated forward into flour milling). The degree of and incentives for vertical integration in a supply chain are important concerns for all players in the supply chain.

Firms throughout the wheat supply chain are formulating competitive strategies in response to industry changes such as those previously presented. In the elevator industry, firms are shifting to multiple railcar shipments and emphasizing volume and throughput. Flour mills are shifting to forward locations, plant and firm size are increasing, and wheat is being procured in large multiple-railcar lots from multiple geographic locations, instead of from local wheat producers. Wholesale pan bread bakeries are under growing competitive pressure from in-store bakeries and other baked goods products which consumers easily substitute for bread. This has caused bakers to become more technology-driven, where conformance to specifications is the definition of quality as opposed to simply “more” of an attribute traditionally considered as representing quality. This has changed procurement strategies for wholesale pan bread firms and, correspondingly, affected flour milling firms.

Competitive strategy formulation, both for firms throughout the wheat supply chain and others, has always been an important managerial concern. However, it was not until the late 1970s that the strategic planning process received formal recognition within firms and in the literature.[2] Increased formal attention by business and non-profits has enhanced the state of the art of strategy evaluation.

Porter (1985) first suggested that strategic options should be assessed with respect to the firm’s value chain or supply chain. Based on this work, Shank and Govindarajan (1993) presented

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[2]The development of strategic management can be traced to Chandler (1962), Andrews (1971), Henderson (1979), and Porter (1980, 1985). The first issue of *Journal of Business Strategy* was published in 1980.

the theory of Strategic Cost Management (SCM) which expands Porter's work to include an assessment of cost drivers and competitive advantages to evaluate strategy choices.[3] Although there is general agreement with the ideas and concepts suggested by Porter (1980, 1985) and enhanced by Shank and Govindarajan (1993), the literature indicates they are not in widespread use by practitioners. This begs the question whether analytical tools are available or if the tools are unattractive for widespread use.

Research Problem and Justification

Numerous changes are taking place simultaneously throughout the wheat supply chain. However, many of these changes are analyzed and treated as if they are occurring independently or at one isolated point in the supply chain. Even if these changes are occurring independently, they often have ramifications throughout the supply chain. Ignoring supply chain ramifications distorts alternative strategic choices available to managers throughout the wheat supply chain. Additionally, strategic opportunities may be missed.

Historically, strategic decision analysis focused on the effects on individual firms. Decisions were based solely on firm optimization criteria, such as return on investment and net present value. Increasingly, firms are recognizing that their internal strategic choices affect their suppliers and customers. However, traditional firm profit-maximizing criteria (e.g., return on investment and net present value) often reject new and emerging technologies (Shank and Govindarajan, 1993). They also may reject alternative strategies that do not involve new technology such as new procurement strategies by Mexican and Canadian flour millers. The problem is that these strategies often are necessary for the firm and the firm's suppliers and customers to remain competitive in the future, especially in global markets. However, returns from

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[3]Costs are caused by many factors that are interrelated in complex ways — these factors are referred to as cost drivers (Shank and Govindarajan, 1993).

these investments do not necessarily flow back to the entity responsible for them. Another criticism is that these frameworks place a great deal of emphasis on short-term financial results and little emphasis on difficult-to-quantify issues such as quality enhancement or manufacturing flexibility (Shank and Govindarajan, 1993).

Strategy formulation is important to firms for several reasons. Like individuals, firms seek to perpetuate their existence. To accomplish this, they seek to create or sustain competitive advantages over their competitors. This is accomplished through their strategic choices, which may be made either explicitly or implicitly. As competition intensifies, the importance of explicitly choosing the best strategy increases. Inherent in the strategic choices of firms are relations with buyers, suppliers, and the entire supply chain.

Objective

The objective of the research reported in this thesis was to contrast firm-level strategic decision criteria for each firm within the wheat supply chain with integrated supply chain decision criteria. To accomplish this objective, the specific sub-objectives of this study were as follows:

1. Gather information about the wheat supply chain, especially regarding the linkages between activities.
2. Determine the relationship among wheat quality attributes and the economic efficiency of each activity (i.e., economic and technical performance).
3. Using the information gathered, compare the results of a single supply chain decision criteria and individual firm decision criteria for each activity in the supply chain.

4. Specifically consider the impacts of changes in wheat gluten prices and flour mill location on the various participants in the wheat supply chain as well as the impact on the supply chain as a whole.

This study provides a mechanism for developing a better understanding of the information requirements necessary for firms to evaluate supply chain management strategies. These information requirements form the basis for negotiation among firms participating, or for determining under what conditions participation would be appropriate, in the supply chain management strategy. This information also would be important for evaluating vertical integration strategies which may range from open market transactions to internalization by another player in the supply chain.

Research Method

Several methods were used to develop a better understanding of the information requirements for a supply chain management strategy. These methods included a literature review, development of a spreadsheet model, and a sensitivity analysis of model results for selected strategy scenarios.

The supply chain management literature has evolved from several subject areas. The purpose of the literature review was to provide an overview of the strategy and logistics literatures as they relate to supply chain management theories. In addition, insight into firm decision-making was gained by a review of industrial organization literature. These literatures, as well as those specifically related to various industries in the wheat supply chain, were integrated into this thesis in the context of the wheat supply chain.

Based on the literature review, a spreadsheet model was developed to reflect procurement, operation, and logistics costs and relationships in the wheat supply chain. The wheat supply chain modeled included three activities: elevation, milling, and baking.

The data used in the wheat value chain model were obtained from secondary sources. The primary sources and types of data used included bakery budgets and financial and operating characteristics for each of the activities in the wheat supply chain gleaned from the Census of Manufactures prepared by the U.S. Department of Commerce; budgets for elevators and flour mills developed by Bangsund, Sell, and Leistritz (1994); and inventory, cycle-time, and financial ratios for food-based firms including flour mills and bakeries taken from Starbird and Agrawal (1994). As such, the results were industry averages for plant capacities, throughput, and other operational characteristics. In addition, the assumed value chain reflected a specific set of players, in this case an elevator, a flour miller, and a wholesale pan white bread baker. Within this set of firms, plant capacities were fixed. Thus, the effects of economies of scale were not considered. Other data were derived from industry publications and contacts. While the hope is that the data reflect reality, their accuracy are not known. The model's intent was to illustrate the construction of an analytical tool that allows practitioners to better evaluate supply chain management concepts.

Fundamental to the analysis were wheat quality data. These data were taken from the 1994 report of an annual series on wheat quality prepared by North Dakota State University's Department of Cereal Science (Moore et al., 1994). Two sets of data were used. First, general attributes of wheat were used in the elevation, milling, and bakery activities. This data set included 437 observations, of which 333 observations were considered to be of milling quality (classified as either U.S. Number 1 or 2). The second data set contained flour, dough, and baking properties. These data were generated from the same observations reported in the first data set. However, to determine the attributes reported in the second data set, the first data set was consolidated by crop reporting district. As such, there were 22 observations in the second data set. This second data set was used to develop relationships among wheat quality attributes and milling and baking performance measures.

Given a base case scenario, the model provides many opportunities to measure the sensitivity of the results to various changes. Model results are presented for both the total supply chain as well as individual activities, including elevation, wheat transportation, milling, flour transportation, and baking.

Thesis Organization

The remainder of this thesis is divided into five parts. Theory is examined in Chapter II. The wheat supply chain is discussed in Chapter III. In Chapter IV, the spreadsheet model used to evaluate supply chain strategy alternatives is developed. Model results are presented in Chapter V. Finally, Chapter VI presents a summary and conclusions.

CHAPTER II: LITERATURE REVIEW

The literatures on industrial organization, strategy, supply chain management, and Strategic Cost Management (SCM) were reviewed. First, the theory of the firm as presented in the industrial organization literature was reviewed. Particular attention was given to the economic issue of firm objectives. Additionally, the issue of a firm's vertical size, the boundaries between a firm and its customers and suppliers, was addressed. Following this, the strategy literature was reviewed. This literature builds upon the economics of industrial organization while incorporating ideas from business management fields such as marketing, finance, and organizational behavior. The supply chain management literature was then reviewed. Supply chain management is a combination of strategy and logistic concepts. Finally, a review of Strategic Cost Management (SCM) was undertaken. The SCM work is an evolution of the managerial accounting and finance literature to incorporate strategic ideas, and it mirrors the ideas of supply chain management.

Industrial Organization

The traditional paradigm for firm behavior is profit maximization or, stated differently, firm optimization (Tirole, 1993). Failure to follow this objective, according to Tirole (1993), results in firm losses as increased costs are unable to be transmitted to customers. Sustained losses either will lead to a devaluation of the firm and the threat of elimination through acquisition, or elimination of the firm through bankruptcy (Tirole, 1993). A theoretical objective function for a profit maximizing firm can be depicted as

$$Max\ \pi = P(Q) \cdot Q - C(Q) \quad , \qquad \text{(B.1)}$$

where π = profit, P = price which is a function of quantity, Q = quantity, and C = cost which is a function of quantity.

The paradigm of firm optimization as the root for decision-making prevails throughout the managerial accounting and microeconomic literature. Practitioners, building upon managerial accounting principals, generally apply optimization criteria within the context of a business enterprise or organization, the "legal" definition of a firm. This facilitates debate on whether enterprises maximize profit or some other objective function. However, it appears the difference is in how one should define the firm for purposes of profit maximization.

According to Tirole (1993), there are three basic views of the firm: technological, contractual, and incomplete-contracting views. The technological view states that a firm is a collection of activities that exploit economies of size or of scope at a given point in time (Tirole, 1993). The contractual view of the firm is based on a longer-run arrangement of activities or units incorporating the hazards which result from longer-run exchange such as the possibility for "hold-up" and "opportunism" (Tirole, 1993). The third view, incomplete-contracting, emphasizes that firms and contracts are simply different modes for governing activities or units (Tirole, 1993). The nature of a firm is the authority and ability to resolve problems between activities arising from unforseen contingencies when a contract was made (Tirole, 1993). According to Tirole (1993), this last view comes closest to the legal definition of a firm as opposed to the first two which have little to do with legal definitions and a great deal to do with traditional economic theory.

For practitioners, firm profit-maximizing criteria are clouded by this confusion over the definition of a firm. Separate legal entities often are presumed to be separate firms even when they coordinate themselves and function as a single firm. Similarly, large multi-divisional firms often are legally a single entity, but actually function as separate firms in their operation and management. This raises issues for the managerial accounting field where practical analytical tools for achieving profit-maximizing behavior are developed.

Strategy

There is a rich, interdisciplinary literature devoted to managerial decision making. The literature builds upon industrial organization theories as well as marketing, finance, and accounting literatures. As such, there are considerable synergies and commonalities among the fields. The industrial organization literature captures the theory of the firm while the strategy literature develops techniques for managers to survive through conformance to economic theory.

The profit that economists seek to maximize is a function of firm costs and revenues. However, to maximize this profit equation, the decision maker must first know the firm's cost and revenue functions. Over 30 years ago, the principles of managerial accounting emerged as the standard for decision-making (Shank and Govindarajan, 1993). According to Shank and Govindarajan (1993), managerial accounting replaced cost accounting and introduced the concept of "relevancy" for decision making. A cost is relevant for decision-making when it is avoidable. Avoidable costs are those that can be entirely or partially eliminated as a result of selecting one alternative over another (Garrison and Noreen, 1994). However, managerial accounting data still are focused on the actions of the manager and do not provide sufficient insight so that firm profits can be maximized. Furthermore, the theoretical underpinning of managerial accounting is that cost is a function, primarily, of output volume (Shank and Govindarajan, 1993).

The notion of firm strategy surfaced about 20 years ago as a factor to consider when evaluating decisions (Shank and Govindarajan, 1993). Strategy became the fundamental ingredient for evaluating firm decisions as a result of Porter's (1980) work. Elevating the importance of strategy, Porter (1980) argued that non-quantifiable strategic concerns often are more important than quantifiable costs and benefits derived from cost analysis or managerial accounting data. Porter successfully rooted strategic analysis into firm decision-making.

The value-chain concept and its strategic role also were introduced by Porter (1985). A value-chain represents the collection of activities that firms perform in different functional areas (Figure 2.1). Porter (1985) also argued that one firm's value-chain is linked with value-chains for its buyers and suppliers. This established the notion that a firm, legally defined, does not operate as an isolated entity. To be successful, a firm's strategy must consider buyer and supplier relationships. Furthermore, competitive strategy, whether deliberately chosen or not, should enhance the entire supply chain to achieve a sustainable competitive advantage. In other words, the firm's economic concerns extend beyond their own legal and managerial boundaries.

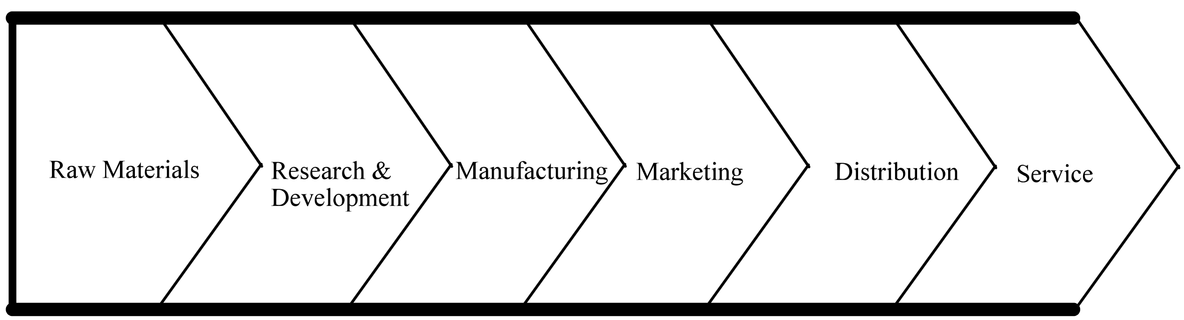

Figure 2.1. Chain of value activities within a firm.

Adapted from Michael Porter, *Competitive Advantage: Creating and Sustaining Superior Performance*, New York: The Free Press, 1985, p 37.

The literature has expanded on Porter's ideas of the value-chain. Oster (1994) includes the industrial organization field's notion of vertical linkages. According to Oster (1994), firms have incentives to develop vertical linkages which, in effect, extend the firm's managerial boundaries. These incentives include taxes and regulatory issues, transaction-cost savings opportunities, and improved access to information. From a strategic perspective, information access and transaction costs are the relevant issues. A successful vertical linkage does not require or imply ownership. It does, however, require profit maximizing behavior across the relationship. In other words, the vertical relationship must be managed as if it were a single firm regardless of the equity stakes.

Supply Chain Management

The supply chain management literature defines a supply chain as a set of facilities, technologies, suppliers, customers, products, and methods of distribution (Arntzen et al., 1995). This definition is similar to that of the value-chain presented by Shank and Govindarajan (1993). However, the basis of supply chain management is logistics as opposed to accounting or strategy. Logistics has been defined as

> the process of planning, implementing, and controlling the efficient, cost-effective flow and storage of raw materials, in-process inventory, finished goods, and related information from point-of-origin to point-of-consumption for the purpose of conforming to customer requirements. (Lambert and Stock, 1993)

Logistics is the mechanism allowing a supply chain of multiple entities, whether divisions within the firm or entirely separate legal entities, to be managed as a single, profit maximizing firm.

Although the strategic concept of a value-chain and the logistics concept of supply chain management appear to be very similar, there are notable differences. Logistics is the efficient coordination of material and information flows between customers and suppliers in a supply or value-chain. Strategy exploits and configures relationships among players in the value or supply chain to achieve sustainable competitive advantage. Engaging in a logistics strategy of supply chain management is an overt strategic choice by a firm to change its value-chain.

A fundamental barrier to the application of supply chain management, as well as other new managerial techniques, is the traditional organization of most firms (Sloan, 1989). Firms and supply chains are made up of separate production, distribution, and sales organizations often with conflicting objectives. To alleviate these conflicts, firms and managers must view their activities as a continuous flow of both products and information with the focus being to accelerate them

(Sloan, 1989). This focus on product and information flows is often depicted through the concept of a pipeline (Figure 2.2).

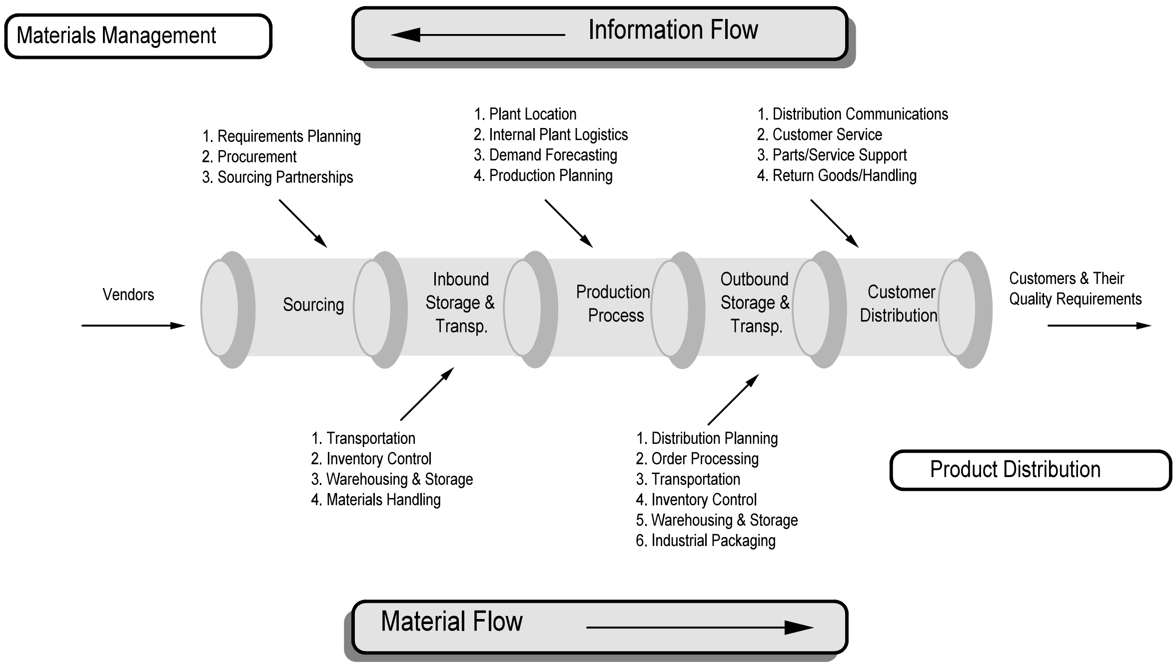

Figure 2.2. The logistics pipeline.

Adapted from John J. Coyle, Edward J. Bardi, and C. John Langley, Jr., *The Management of Business Logistics*, 5th ed., St. Paul, MN: West Publishing Company, 1992, p 71.

The logistics concept is not a recent phenomenon in the literature. In the 1960s, a strong focus on physical distribution resulted in the proliferation of warehouses, expanded inventories, and enhanced customer service (Sloan, 1989). Through the 1970s, the focus shifted toward manufacturing and production scheduling which helped to reduce inventories (Sloan, 1989). Refinements continued through the 1980s with an emphasis on new manufacturing techniques and supplier programs. These, however, were not all-encompassing solutions (Sloan, 1989). Three recent developments have renewed an emphasis on integrated logistics (Turner, 1993). These include an increased importance of logistics and customer service in the marketing mix, logistics becoming an increasingly important cost component of the firm, and the evolution of information technology which is making true integration possible.

A recurrent theme within the literature is that supply chain management is necessary to reduce costs. However, little work actually analyzed the extent of these cost reductions. Furthermore, little work was found in the literature that provided a framework for practitioners to evaluate the impact of supply chain management strategies on the various members of the supply chain.

Of the supply chain optimization models found in the literature, the most inclusive was a mixed integer programming model that optimized multiple products, facilities, production stages, technologies, time periods, and transportation modes for Digital Equipment Corporation's global operation (Arntzen et al., 1995). The model minimizes total cost and activity days subject to service (inventory), local content requirements, and other constraints. However, this model is limited to the internal logistics of Digital Equipment Corporation and is computationally intense.

Another method proposed by Cavinato (1991) identified six interfirm total cost factors in supply chain relationships that need to be addressed: labor rate, productivity, capital availability, capital cost, tax rate, and depreciation or other tax elements. Cavinato (1991) suggested firms have different cost structures, factor inputs, management skills, and buying powers that provide opportunities to evaluate jointly which firm should perform each task. His theory is that firms within a supply chain should determine where each activity should take place in the value-chain based on the lowest total cost across themselves compared against another set of competing firms.

Strategic Cost Management

Shank and Govindarajan (1993) proposed an alternative approach for evaluating strategy. Their approach recognizes the weaknesses of current managerial accounting principles. However, it also recognizes that decisions should not be made solely on the basis of strategic implications without considering cost. Their approach, termed Strategic Cost Management (SCM), includes analyses of the value chain, cost drivers, and competitive advantages. The important contribution of Shank and Govindarajan (1993) is the integration and combination of supply or value-chain ideas with strategy concepts, such as Porter's competitive advantage, and cost concepts from the managerial accounting literature. This integration builds upon ideas from the industrial organization literature.[4]

The value-chain is defined as the linked set of activities required to transform raw materials to products for end-users (Shank and Govindarajan, 1993). This analysis considers a strategy's impacts on the firm as well as on suppliers and customers throughout the value-chain. Considering the importance of linkages among members of a value-chain makes this method superior to traditional value-added approaches.

Cost driver analysis explains variations in costs at each value activity. In managerial accounting, costs are seen only as a function of output volume (Shank and Govindarajan, 1993). In Garrison and Noreen (1994), a graduate-level managerial accounting text, cost discussions are dominated by fixed versus variable cost, average versus marginal cost, cost-volume-profit analysis, break-even analysis, flexible budgets, and contribution margin, all based on output volume.

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[4]For an example of a Strategic Cost Management analysis, see "Cost Analysis Considerations and Managerial Applications of Value Chains: An Extended Field Study" as presented in John K. Shank and Vijay Govindarajan, *Strategic Cost Management: The New Tool for Competitive Advantage*, New York: The Free Press, pp. 73-92.

Although these concepts are based upon simple microeconomic models, Shank and Govindarajan (1993) indicated that output volume explains little of the cost behavior in a value chain.

To get away from output volume, Shank and Govindarajan (1993) built upon models from the economics of industrial organization literature, primarily Scherer's (1980) work. Shank and Govindarajan (1993) indicated it is more useful to explain cost position in terms of structural choices and executional skills that determine a firm's competitive position. Structural choices include plant and operational scale, degree of vertical integration or scope, experience, process technologies employed, and product line complexity. Executional skills are determined by work force involvement, total quality management, capacity utilization, plant layout efficiency, product configuration, and exploiting supplier or customer linkages. According to Shank and Govindarajan (1993), increasing a structural driver is not always better for the firm's cost position; however, increasing an executional driver always is.

The competitive advantage portion of Shank and Govindarajan's (1993) model is taken directly from the strategy literature, primarily from Porter (1980, 1985). There are three generic strategies for sustainable competitive advantage: cost leadership, differentiation, and focus (Porter, 1980). A cost leadership strategy achieves lower costs relative to competitors. It can be attained through economies of scale of production, learning curve effects, cost control capabilities, and cost minimization in research and development, service, or marketing (Porter, 1980). Differentiation is a strategy to create something customers perceive as unique (Porter, 1980). Brand loyalty, customer service, distribution networks, product design and features, and product technology can be used to achieve differentiation (Porter, 1980). The focus strategy achieves its objectives by serving a particular group of buyers better than a firm that competes more broadly in the industry (Porter, 1980). The difference between a focus strategy and the other two is the emphasis on a particular group or niche of buyers as opposed to the entire industry.

The goal of SCM is supply chain optimization. The motivation for supply chain optimization is sustainable competitive advantage for all players in the value-chain gained through lower costs and/or greater differentiation. Upstream links are largely dependent for their survival on the competitive position of firms or links satisfying the ultimate end-user. Similarly, the competitive position of downstream firms is largely dependent upon their supplier's costs and actions. Implications of SCM and supply chain management include modifying the individual business entity's objective function to be compatible with a single profit maximizing objective for the entire supply chain. Identification of performance measures between activities is required to manage the supply chain.

In summary, the economic definition of a firm has little to do with the "legal" definition of a firm. This creates challenges for profit seeking managers. As a result, the strategy literature has developed the notion of the value-chain, integrating industrial organization theory with firm specific actions. Additionally, recent work in supply chain management or supply chain optimization in the logistics literature has evolved parallel to the value-chain concept. The literature of both areas attempts to provide decision-makers with justification and methods for employing the strategies. However, little evidence of quantitative methods for analyzing the value or supply chain were discovered in either of the literatures. Strategic Cost Management (SCM) is a recent literature devoted to developing quantitative tools for evaluating alternative strategies on a value chain. However, even this literature has not evolved to where the tools and methods are easily deployed in a practical setting. Furthermore, the SCM is an accounting approach and does not consider the parallel evolution of supply chain management in the logistics literature. Therefore, it is desirable to integrate the advancements in value-chain evaluation and analysis from the SCM literature with the logistics literature.

CHAPTER III: WHEAT SUPPLY CHAIN

This chapter provides background information on the wheat supply chain. Although the objective of this thesis as well as the concepts developed are not industry specific, the theoretical underpinnings are best communicated and appreciated through a specific application. This chapter was included solely as a reference for the reader. The intention was simply to provide background information on the specific application. As such, the contents of this chapter are not essential to attaining the objectives of this thesis.[5]

The chapter is organized around three stages or links in the wheat value chain: elevators, flour millers, and bakers. Each of these links represents an important economic activity within the supply chain. Although heavily intertwined, each link competes in a unique economic environment. The discussion for each link focuses on industry structure and competitiveness.

Elevators

The first link in the supply chain, elevators, serves two primary purposes. First, it provides a mechanism for accumulating and combining the production of several individual wheat producers (farmers). Second, this link provides storage because wheat is a seasonal commodity. In essence, the elevation activity is solely a logistical function. As a result, this activity is particularly impacted by transportation. Elevators also provide numerous additional services including cleaning (removing non-wheat matter), inspection (identifying and measuring various quality attributes), and blending (combining portions of wheat with differing quality attributes to attain a certain specification in that attribute).

Dramatic changes in infrastructure have impacted the grain handling and transportation system in the United States. Most of this change has occurred since 1980. Important factors

[5]This chapter was largely adapted from Barber and Titus (1995).

impacting this change include the widespread adoption of multiple railcar grain rates, rail line abandonment, energy considerations, and technological advances (Ming and Wilson, 1983). As a result of these forces, considerable economic pressure is exerted on the elevator industry to attain efficiencies in both transportation and handling. An economic incentive exists for the development of large elevators, commonly referred to as subterminals, capable of loading and transporting grain in multiple railcar shipments or what the industry refers to as "unit trains" (Ming and Wilson, 1983).

Industry Structure

The production of grain and the development of country elevators were directly influenced by the development of the railroad network.[6] In turn, the success of country elevators expanded the development of the railroad network, particularly branchlines. Country elevators often were located within a few miles of each other along the rail line as producers could not transport large quantities of grain large distances in the "horse-and-wagon" era (Ming and Wilson, 1983).

The original structure of the industry was determined largely by constraints on the inbound movement of grain. As these constraints were lifted over time, size economies exerted more influence on the structure of the industry. The replacement of the "horse-and-wagon" era with the development and subsequent improvement of motor vehicles and road networks began an unending trend that has had substantial implications for the elevator industry, including fewer and larger elevators (Ming and Wilson, 1983). In 1923, North Dakota had 1,832 country elevators, by 1965 there were 789, and in 1981 there were 592 (Ming and Wilson, 1983). Although the number of elevators declined to 425 in 1994, the rate of decline appears to have slowed (Andreson, Young, and Vachal, 1994). Over this same time span, the average elevator's trade area increased

[6]Country elevators are the initial receiving point for grain produced by local farmers and are located within the production area (Bangsund, Sell, and Leistritz, 1994).

substantially as did average storage capacity (Ming and Wilson, 1983). These trends are not unique to country elevators in North Dakota but have occurred throughout wheat producing areas of the United States.

Although the number of elevator firms has diminished dramatically, the industry can still be described as extremely competitive. Elevator ownership is a mixture of privately held and farmer-owned cooperative firms. Farmer-owned cooperatives exceed the number of elevators privately held by a sizeable margin. Profit maximization is often not a sole objective of these cooperative firms. This behavior preserves excess capacity and fosters low profitability. Additionally, a farmer's switching cost among elevators is limited to the difference in transportation costs between competing elevators.[7] Similarly, grain buyers can purchase grain from a large number of homogenous elevator suppliers, with the only switching cost again being transportation. Finally, no single firm or small group of firms appear to dominate the elevator industry. In the 1993 to 1994 marketing year, North Dakota's largest 10 elevator firms controlled less than 20 percent of the total grain handled (Andreson, Young, and Vachal, 1994).

Milling

The second link in the wheat supply chain is milling. Milling is a process of grinding and sifting wheat into flour and millfeeds (Harwood, Leath, and Heid, 1989). Flour is an ingredient in baked-goods destined for human consumption while millfeeds are sold as animal feed.

The U.S. milling industry has experienced many changes since the mid-1970s. A major change occurring is a trend toward larger firms and increased concentration (Wilson, 1995). A result of this is fewer, high capacity firms exploiting economies of scale making it difficult for small mills to compete. In addition, large mills are increasing the level of automation and

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[7]Switching costs are one-time costs incurred by either buyers or suppliers resulting from either party switching to an alternative, or competitor, to the original buyer or supplier (Porter, 1980).

incorporating new technologies to improve plant efficiency (Harwood, Leath, and Heid, 1989). In addition to economies of scale, these large milling firms are increasing capacity utilization. Furthermore, they are marketing specialized products for particular market niches with an objective to differentiate products and increase profits (Harwood, Leath, and Heid, 1989).

A positive trend for the industry has been increased consumer demand for flour products. In 1987, per capita consumption in the United States was 128 pounds, up dramatically from the 1960s and 1970s (Harwood, Leath, and Heid, 1989). This trend has continued into the 1990s and can be attributed to increased health concerns, the introduction of more flour-based products, and higher consumption of fast foods containing wheat flour. Although flour exports have historically been a relatively small percentage of demand, they do provide an important source of revenue for some millers. From 1980 through 1987, exports averaged about 8 percent of total flour demand or disappearance (Harwood, Leath, and Heid, 1989).

Industry Structure

As previously mentioned, the structure of the wheat flour milling industry has greatly changed in the last few decades. This industry segment is typical of the structural dynamics confronting other segments of the agricultural processing industry (Wilson, 1995). Flour milling accounts for over 90 percent of domestic wheat processing use (Harwood, Leath, and Heid, 1989). The primary product is wheat flour for baking, while by-products are used for such things as livestock feed, pet food, and industrial applications.

The number of wheat flour mills in the U.S. was 204 in 1990, down from 280 in 1974 (Table 3.1). However, industry capacity rose 22 percent over approximately the same period. In addition, the number of mills operated by each firm increased from 1.7 to 2.2, with average firm capacity more than doubling (Wilson, 1995).

Table 3.1. Flour milling industry statistics

Characteristics	Year 1974	1980	1990
Mills:			
Number	280	255	204
Average Capacity (cwt/day)	3,541	4,212	5,937
Firms:			
Number	161	140	95
Average Capacity (cwt)	6,158	7,672	12,534
Average Number of Mills	1.7	1.8	2.2
Percent with Multiple Mills	37%	42%	58%

Adapted from Sosland Companies Inc., *Milling Directory & Buyer's Guide*, Merriam, KS: Sosland Publishing Company, 1974, 1980, and 1990.

Due to changing rail transportation rates, new mills usually have been built near population centers. In contrast, many of the older mills were located near wheat growing areas. As a result, the number of mills in Southern and Midwestern states fell during the 1980s while it increased or remained constant in large population areas throughout the country.

Two technological changes were responsible for this change in transportation cost. The first was the introduction of multiple car or unit train technology. This provided a transportation cost incentive for shipping larger quantities at one time. However, since individual bakers do not require large quantities of flour or desire to hold large quantities of flour inventory, shipments of flour generally do not take advantage of these rail pricing mechanisms. As a result, it is feasible for large quantities of wheat to be shipped to a mill located near flour demand even though the milling process is a weight losing activity. A second innovation was enhanced hopper car technology that reduced costs of bulk wheat shipments. In addition to these technological changes, a pricing mechansim known as "transit" was gradually eliminated. Transit allowed a shipment of wheat to stop en route and be milled into flour.

As the number of mills in the United States has fallen, the industry also has become more concentrated. The top four firms in the industry controlled 70 percent of capacity in 1992, up from 34 percent in 1974 (Wilson, 1995). In addition, ownership of milling companies has changed drastically from the early 1970s. Traditionally, single-plant firms dominated the industry. Furthermore, these firms were typically small family owned and managed operations, but have since given way to an industry increasingly dominated by large multi-plant corporations. For example, ConAgra, the largest flour miller in the United States, expanded its capacity from 88,300 cwt. in 1973 to 270,000 cwt. by 1988 (Harwood, Leath, and Heid, 1989). Much of this capacity was gained through acquisition of existing structures as opposed to new construction. These large multi-plant firms often have agribusiness interests other than milling, including prepared foods, restaurant holdings, grain merchandising, feed manufacturing, and others.

The acquisition of flour mills often allows these firms to become more vertically integrated. Interestingly, the reasons for this are not clear. While some firms may be able to reduce costs through improved communication and scheduling, this has not always been the case. The milling operations of several agribusiness firms have been sold because of high risk and low profits (Harwood, Leath, and Heid, 1989).

Baking

The final stage in the wheat supply chain is the baking activity. Flour is a principal ingredient in the manufacturing and production of bakery goods.

The domestic wholesale baking industry uses 70 percent of the flour produced by domestic flour mills (Harwood, Leath, and Heid, 1989). Other major uses of flour include the production of macaroni and spaghetti (9 percent), and blended and prepared flour packages (6 percent) (Harwood, Leath, and Heid, 1989). The wholesale baking industry is comprised of two groups: bread, cake, and related products; and cookie and cracker manufacturers. The bread, cake, and related products segment consumes three times the flour consumed by the cookie and cracker segment (Harwood, Leath, and Heid, 1989). Wheat flour represented 26 percent of the value of all ingredients purchased by bread and cake wholesale bakeries in 1992 (U.S. Department of Commerce, 1995).

In 1992, there were approximately 3,150 wholesale bakery plants in the United States (U.S. Department of Commerce, 1995). The majority (2,539) were classified as bread and cake bakeries while cookie and cracker (441) and frozen non-bread bakery products (172) completed the industry (U.S. Department of Commerce, 1995). The differences in plant numbers between segments can best be explained by the perishability of each segment's products. Since bread and cake products are more perishable than either cookie and cracker products or frozen products, bread and cake plants are more locally oriented (Harwood, Leath, and Heid, 1989).

Although per-capita consumption of flour has been increasing, this trend has not carried into wholesale bakery products (Harwood, Leath, and Heid, 1989). With the exception of variety breads and bagels, consumption of bakery products has remained flat throughout the 1980s (Figures 3.1 and 3.2). In general, the consumption of higher value products, including certain cookies, select crackers, and variety breads, has increased while consumption of lower value products, including white bread, decreased through the 1980s (Harwood, Leath, and Heid, 1989). What was lost during the 1980s in white bread consumption appears to have been regained during the 1990s. Harwood, Leath, and Heid (1989) attribute these trends to the increasing popularity of in-store bakeries which offer the consumer convenience, service, and variety. To compete with in-store bakeries, wholesale bakers are increasing their efficiency and exploiting economies of scale.

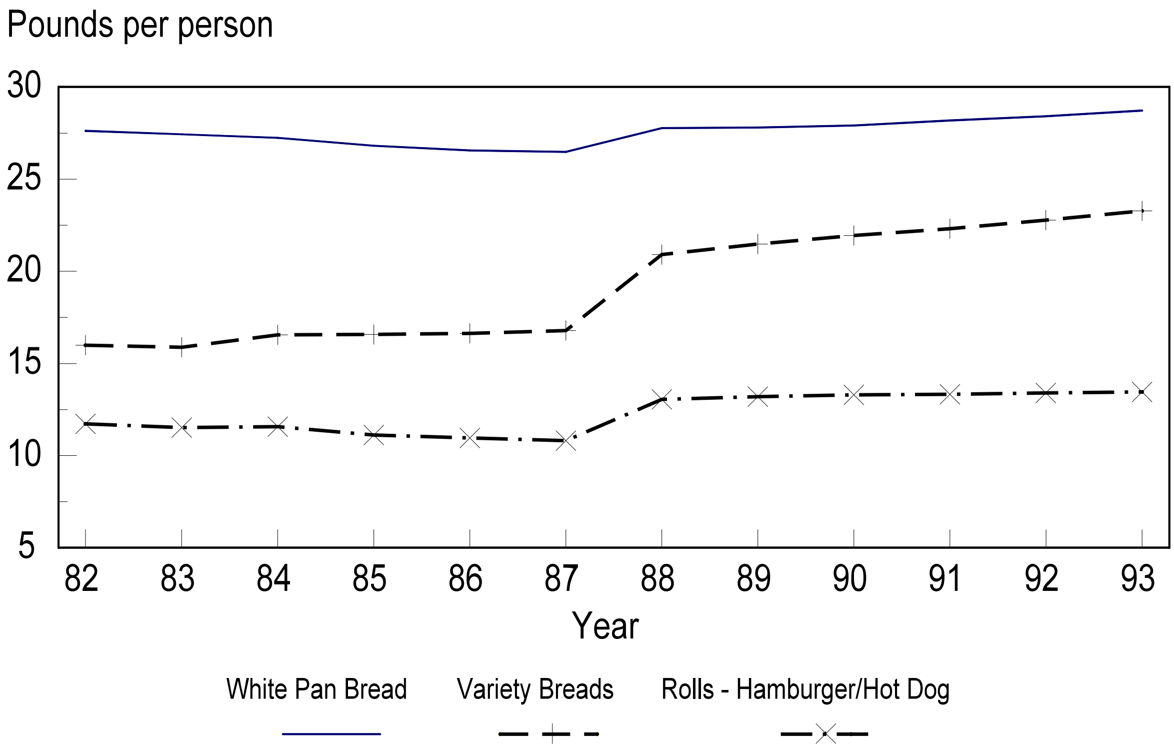

Figure 3.1. Per capita consumption of white pan bread, variety bread, and hamburger and hot dog rolls from 1982 to 1993.

Adapted from U.S. Department of Commerce, International Trade Administration, *1988 U.S. Industrial Outlook* and *1992 U.S. Industrial Outlook*, Washington, DC: U.S. Government Printing Office, 1988 and 1992, respectively.

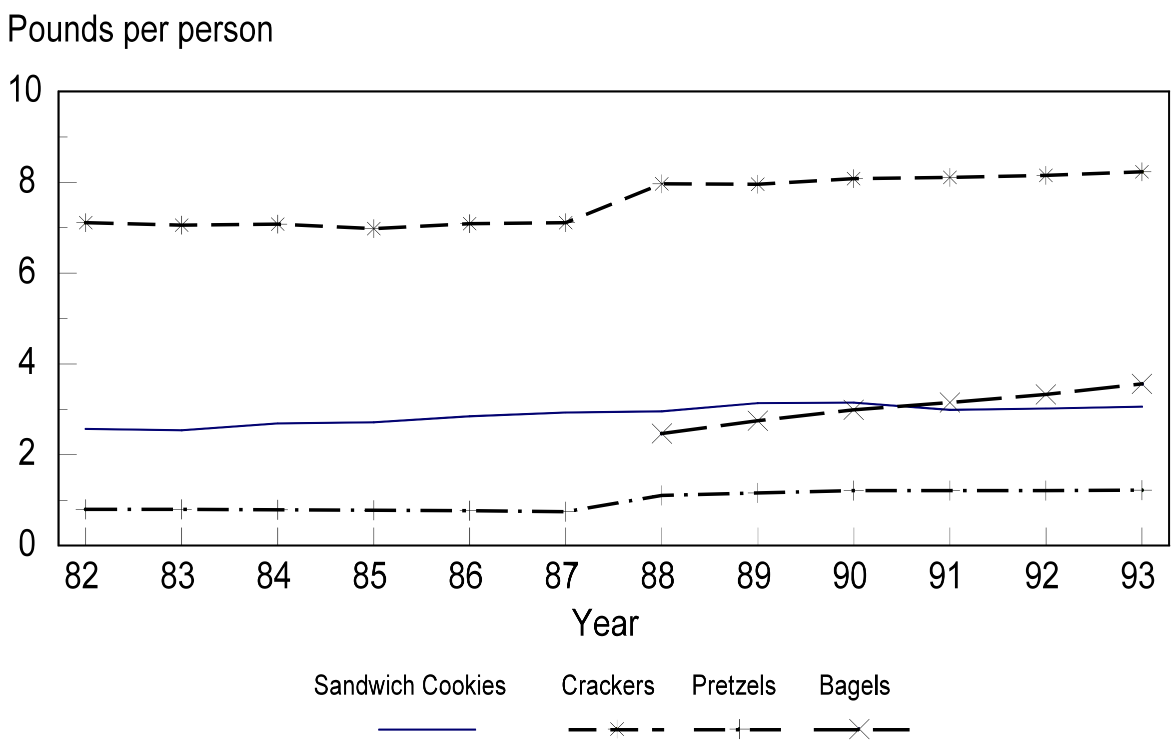

Figure 3.2. Per capita consumption of sandwich cookies, crackers (excluding pretzels), pretzels, and bagels for 1982 through 1993.

Adapted from U.S. Department of Commerce, International Trade Administration, *1988 U.S. Industrial Outlook* and *1992 U.S. Industrial Outlook*, Washington, DC: U.S. Government Printing Office, 1988 and 1992, respectively.

Industry Structure

The wholesale bakery industry is undergoing rapid changes. A consolidation of large bakeries with diversified agricultural firms has linked bakeries more closely to other food processing activities, increasing marketing strengths and capital available to the bakery industry (Harwood, Leath, and Heid, 1989).

Additionally, the number of plants producing bread and cake products is changing. From 1972 to 1982, the number of plants decreased as larger firms took advantage of size economies and smaller firms exited the industry (Harwood, Leath, and Heid, 1989). However, as Figure 3.3 shows, in both the 1987 and 1992 Census of Manufactures, the number of plants increased (U.S. Department of Commerce, 1995). This increase has primarily occurred in plants with fewer than 20 employees (U.S. Department of Commerce, 1995). The implications of this increase are not clear. An increase associated with the growth of in-store bakeries may imply grocery stores are further eroding the wholesale "bread" market with niche products perceived by consumers to be superior. Alternatively, this growth may be the result of facilities exchanging capital for labor. Therefore, number of employees may be less important as an indicator of output or size. Smaller bakeries, in terms of employment, may be able to compete more effectively with larger wholesale bakeries by exploiting recent technological advancements. For example, a newly constructed bakery in Mexico produces 14,600 pounds of white pan bread per hour per line with only eight employees per line ("Producing 14,600 lbs. of Bread an Hour," 1994)

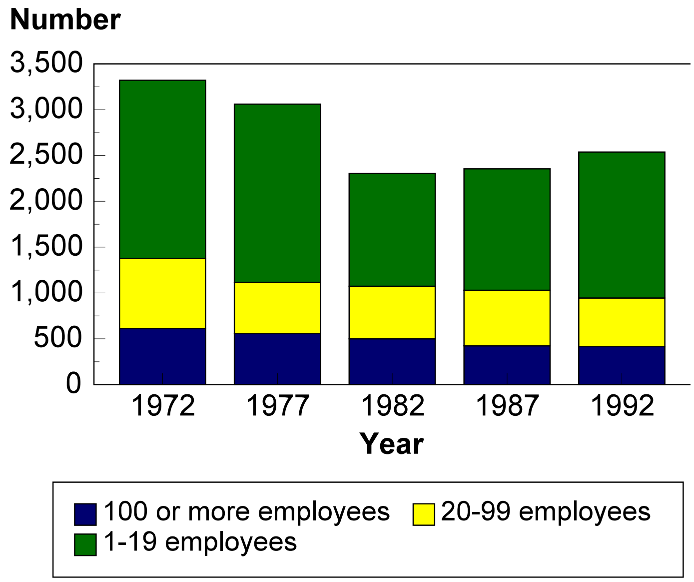

Figure 3.2. The number of bread and cake plants by number of employees.

Adapted from "Baking Census Report." *Milling and Baking News*, 16 May 1995: 28-30.

Although large plants (those employing more than 100 persons) have declined in number, their share of the total market remains stable. In the 1992 Census of Manufactures, firms with more than 100 employees were responsible for approximately 87 percent of the total bread and cake market compared to 81 percent in 1977, 86 percent in 1982, and 86 percent in 1987 (U.S. Department of Commerce, 1995; Harwood, Leath, and Heid, 1989; U.S. Department of Commerce, 1993).

The ownership of every major wholesale bakery, whether in the bread and cake segment or the cookie and cracker segment, has changed (Harwood, Leath, and Heid, 1989). Furthermore, Harwood, Leath, and Heid (1989) indicated that many of these changes occurred since 1982 and involved large, diverse food-oriented firms. These large firms have introduced financial, managerial, and marketing resources previously not available to the bakery industry (Harwood, Leath, and Heid, 1989). This has worked to increase operational efficiencies, new product development, and deployment of new technologies.

Like the evolution in the elevator industry, advances in transportation and logistics have had a profound impact on the bread and cake segment. The development and continued improvement of the highway network and motor vehicles, combined with technologies that have diminished product perishability, have extended the geographic scope of firms in the bread and cake segment (Harwood, Leath, and Heid, 1989). Since there is a tradeoff between product distribution and plant size, relative decreases in product distribution costs would allow firms to increase their plant size and market area to exploit additional economies of scale.

Summary

Competitive forces are changing the structure of industries that encompass the wheat supply chain. Elevators are increasing throughput (facility utilization) with larger shipments taking advantage of multiple-railcar technologies. Flour mills are shifting locations, increasing plant size, investing in technology, and developing strategic alliances with customers. Mergers among Class I railroad carriers, price incentives reflecting rail cost advantages for multiple-railcar movements over long distances, and evolution in innovations in forward-pricing mechanisms continue to affect the structure of the transportation sector. Consolidation and acquisition of the largest bakeries, changing procurement practices, increasing deployment of new technologies, increasing plant size, increased research and product development efforts, and improving efficiency of distribution practices all are forces taking shape in the bakery industry.

CHAPTER IV: MODEL DEVELOPMENT

A goal of this thesis was to develop a spreadsheet model of the wheat supply chain. The spreadsheet model developed requires coefficient estimates to determine ingredient, operating, inventory, and logistics costs for the elevation, milling, and baking activities in the supply chain. Within each of these cost categories, the specific model coefficient values are developed in Appendix A.

Cost Categories

The discussion on costs has been organized around four principle categories: ingredient, operating, inventory, and logistics. Within each category, issues associated with the elevation, milling, and baking activities are presented.

Ingredient Costs

Acquisition costs at the elevation activity are a function of the firm's margin, the firm's location relative to competitors, wheat quality, quality of wheat in the firm's inventory, established grain exchange prices, and localized demand for elevated wheat. In addition, an elevator's transportation characteristics (e.g., truck only, single railcar, or unit train) relative to competitors influence the firm's acquisition cost.

At the milling activity, acquisition costs are basically a function of established grain exchange prices adjusted for quality requirements and transportation. Alternatively, the mill's acquisition cost could be viewed as the sum of the elevator's costs, elevator margin, and transit. Some of these quality requirements are characteristics of the wheat while others, such as grain cleaning or conditioning, may require services to be performed by the elevator. The primary controllable determinant of mill ingredient cost is quality specifications, which are partially derived from flour customer requirements.

Bakery ingredient costs are a function of established grain exchange prices for wheat and flour quality purchased. Flour quality specifications are determined by production requirements and substitution relationships with other ingredients. For example, bakeries can blend vital wheat gluten into their wheat flour to increase protein content and enhance other flour attributes.[8]

Operating Costs

The operating cost at the elevation stage is primarily a function of asset utilization and scale. Elevator utilization is measured by comparing an elevator's total shipments for one year to its one-time physical storage capacity. Operating costs include labor, utilities, maintenance and repair, sampling or inspection, depreciation, interest, and administrative and miscellaneous expenses (Bangsund, Sell, and Leistritz, 1994). An additional operating cost is cleaning. Cleaning costs are a function of beginning dockage levels, ending dockage levels, capacity per time period, and cost per time period (Johnson, Scherping, and Wilson, 1992).

Utilization and scale are important operating cost determinants in flour milling. Flour mill utilization is measured by comparing the product of a mill's daily capacity and the number of milling days in a time period (usually a six-day work week) to the actual flour production in that same time period. Operating costs for flour milling include labor, utilities, maintenance and repair, sampling or inspection, depreciation, interest, and administration and miscellaneous (Bangsund, Sell, and Leistritz, 1994).

Bakery operating costs, with reference to flour, are primarily a function of the flour characteristics. Flour characteristics impact the technical production process or bakery output as

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[8]Vital wheat gluten is obtained by "washing" a dough of wheat flour and water (Harwood, Leath, and Heid, 1989). Wheat flours can be fortified with vital wheat gluten to produce a desired protein level as well as to increase water absorption, improve dough handling and mixing characteristics, and increase the volume of bread loaves (Harwood, Leath, and Heid, 1989).

well as the requirements for alternative ingredients. Overall bakery operating costs in the white bread segment appear also to be heavily influenced by scale economies. A new Grupo Industrial Bimbo bakery in Mexico, for example, produces 14,600 pounds of white bread per hour with eight employees ("Producing 14,600 lbs. of Bread an Hour," 1994).

Economies of scale appear to be important in all activities of the wheat supply chain. However, in a specific value-chain analysis, the importance of these economies are diminished because plant scale, for all links in the supply chain, are fixed. In contrast, the importance of utilization is enhanced for the same reason.

Inventory Costs

Inventory costs for the elevation, milling, and baking activities are a function of utilization, value-added, and carrying cost:

$$Inv = f\,(U,\ V,\ CC) \quad , \tag{4.1}$$

where *Inv* is inventory cost, *U* is utilization, *V* is value-added, and *CC* is carrying cost. Utilization is determined by comparing the firm's total shipments to its capacity. Value-added is simply the accumulation of procurement and operating costs for each link in the supply chain. Finally, carrying cost represents those costs that vary with the level of inventory. Carrying cost includes the cost of capital; inventory servicing costs, such as insurance and taxes on inventory; storage space costs; and inventory risk, including damage and pilferage (Lambert and Stock, 1993).

Logistics Costs

Logistics costs were defined in this model as the transportation and in-transit inventory linkages between members of the supply chain. A set of logistics costs exists between the elevator and the flour mill and between the flour mill and the bakery. These two sets of costs were attributed to the inbound or recipient member of the supply chain. The following shipment characteristics were incorporated into the model: transportation cost, shipment volume, transit time, and in-transit carrying cost. An in-transit carrying cost is similar to the carrying cost described in the previous section on inventory. Although in-transit inventory generally does not incur space costs or have as great a risk of obsolescence or deterioration, it does tie up capital and incurs insurance costs (Coyle, Bardi, and Langley, 1992). Therefore, in-transit inventory requires a carrying cost, albeit less than that for warehoused inventory.

CHAPTER V: MODEL RESULTS

In this chapter, empirical results for the wheat supply chain model are presented. First, results of the base case analysis are presented. Potential uses of the model are discussed in the second section, including alternative scenarios that could be analyzed with the model. Finally, scenarios analyzed by the model are presented, then discussed and compared with the base case results.

Base Case

Assumptions for the base case scenario were discussed in detail in the preceding chapter. However, the major assumptions for the base case were as follows:

1. Elevation takes place at the origin of wheat production;
2. Milling takes place at an origin location with inbound shipments of wheat received in 26 railcar lots from 146 miles away; and
3. Baking takes place at a point of flour consumption, 757 miles from the flour mill, where flour is received in single railcar lots.

Procurement, operating, cleaning, and inventory results from the elevator module of the model are presented. In the model, it was assumed that the elevator stored wheat on the basis of protein. Therefore, within a given protein category, all other quality attributes are blended (averaged).

Procurement reflects the elevator's cost of purchasing wheat. The price of wheat at an elevator is driven by major commodity markets, competition from other elevators, current inventory situation, and available transportation capacity. In the model, wheat was purchased at a discount to the Minneapolis cash price for wheat. This discount was the same for all protein levels of wheat. In addition, protein premiums and discounts were computed based on Minneapolis prices.

Operating costs include the cost of labor, utilities, maintenance and repair, sampling, depreciation, interest, and administration and miscellaneous expenses. A relationship between these costs and wheat quality attributes was not identified. However, plant utilization did affect these costs in the model.

Cleaning cost reflects the cost of removing dockage from wheat. In the model, the elevator was assumed to pass 80 percent of this cost back to suppliers (farmers) in the form of a lower purchase price. The remaining 20 percent was passed forward to the customer (flour mill) in the form of a higher sales price. Since dockage varies independently from wheat protein, cleaning costs varied across protein categories.

Inventory reflects the opportunity cost of owning and storing wheat at the elevator. On average, there is a certain quantity of wheat in an elevator. Larger average inventory quantities require greater capital investments and have a greater risk of loss. Also, greater unit values in inventory require greater capital investment. With a premium for higher protein wheats, there is a greater cost associated with holding that inventory relative to lower protein wheats. In this model, inventory cost accounts for most of the variation in elevator costs across protein levels.

Model results for the elevator activity are presented in Table 5.1. The total cost incurred by the elevator, excluding purchase of wheat, varies from $0.133 to $0.143 per bushel. Subtracting total cost, including wheat purchases, from sales revenue results in an elevator margin that varies from $0.013 per bushel for the highest protein wheats to $0.024 per bushel for the lowest protein wheats. Again, most of the variation can be explained by greater inventory carrying costs for higher protein wheats. Low margins and little control over wheat quality greatly increase the importance of volume and utilization for elevators.

Table 5.1. Base case empirical results for the elevator activity in the wheat supply chain model

Wheat Protein (%)	Wheat Grade	Operating Cost ($/bushel)	Inventory Cost ($/bushel)	Procurement Cost ($/bushel)	Sales Revenue ($/bushel)	Elevator Margin ($/bushel)
< 11.5	US 1	$0.1075	$0.0256	$3.2006	$3.3581	$0.0240
	US 2	$0.1075	$0.0256	$3.2006	$3.3581	$0.0240
< 12.5	US 1	$0.1066	$0.0272	$3.3815	$3.5383	$0.0230
	US 2	$0.1066	$0.0272	$3.3815	$3.5383	$0.0230
< 13.0	US 1	$0.1074	$0.0280	$3.4707	$3.6281	$0.0220
	US 2	$0.1074	$0.0280	$3.4707	$3.6281	$0.0220
< 13.5	US 1	$0.1064	$0.0287	$3.5618	$3.7184	$0.0220
	US 2	$0.1064	$0.0287	$3.5618	$3.7184	$0.0220
< 14.0	US 1	$0.1066	$0.0297	$3.6515	$3.8083	$0.0210
	US 2	$0.1066	$0.0297	$3.6515	$3.8083	$0.0210
< 14.5	US 1	$0.1067	$0.0305	$3.7414	$3.8983	$0.0200
	US 2	$0.1067	$0.0305	$3.7414	$3.8983	$0.0200
< 15.0	US 1	$0.1075	$0.0315	$3.8606	$4.0181	$0.0190
	US 2	$0.1075	$0.0315	$3.8606	$4.0181	$0.0186
< 15.5	US 1	$0.1061	$0.0331	$4.0420	$4.1984	$0.0172
	US 2	$0.1061	$0.0331	$4.0420	$4.1984	$0.0172
< 16.5	US 1	$0.1070	$0.0341	$4.2211	$4.3782	$0.0160
	US 2	—	—	—	—	$0.0000
16.5 <	US 1	$0.1056	$0.0374	$4.5225	$4.6785	$0.0129
	US 2	$0.1056	$0.0374	$4.5225	$4.6785	$0.0129

— No observations were recorded in this category.

Wheat is often transported between the elevator and flour mill by either rail or truck. In this model, wheat was assumed to move by rail. The rail carrier's costs and revenues are constant regarding wheat quality. However, when calculated on a per unit basis, these costs and revenues exhibit some variation across wheat qualities (Table 5.2). This is primarily caused by variations in wheat test weight which appears to be inversely related to protein levels in the wheat data set used in the model. Additional variation was caused by the conversion to a common unit of measure, 1,000 pounds of white pan bread. This variation results from differing quantities of wheat required to manufacture the bakery unit. The margin for wheat transportation varied from $3.59 for lower protein wheats to $3.97 for higher protein wheats on a per 1,000 pounds of bread basis.

There was considerable variation in flour mill results across wheat protein levels. This variation comes from the impact of wheat attributes on the technical milling process as well as wheat and flour pricing practices. The principle ingredient in flour is milled wheat. However, mills also may use wheat gluten as an ingredient. Wheat gluten typically increases flour protein, improves water absorption, and enhances other dough handling and mixing characteristics (Harwood, Leath, and Heid, 1989). The conversion of wheat into flour varied from 2.26 to 2.62 bushels of wheat to produce one hundred pounds of flour. Better efficiencies were achieved with lower protein wheats. All flours were manufactured to comply with or exceed the bakery's protein specification. Therefore, some required a mixture of milled wheat and wheat gluten while others simply contained milled wheat.

Table 5.2. Base case empirical results for the wheat transportation activity in the wheat supply chain model

Wheat Protein (%)	Wheat Grade	URCS Rail Cost ($/unit†)	Rail Tariff Revenue ($/unit†)	Rail Margin ($/unit†)
< 11.5	US 1	$1.4144	$5.0087	$3.5944
	US 2	$1.4246	$5.0449	$3.6203
< 12.5	US 1	$1.4382	$5.0931	$3.6549
	US 2	$1.4852	$5.2597	$3.7745
< 13.0	US 1	$1.4667	$5.1939	$3.7272
	US 2	$1.4985	$5.3065	$3.8080
< 13.5	US 1	$1.4797	$5.2401	$3.7604
	US 2	$1.5441	$5.4683	$3.9242
< 14.0	US 1	$1.4855	$5.2606	$3.7751
	US 2	$1.5367	$5.4419	$3.9052
< 14.5	US 1	$1.4994	$5.3099	$3.8105
	US 2	$1.5326	$5.4274	$3.8948
< 15.0	US 1	$1.5070	$5.3367	$3.8297
	US 2	$1.5364	$5.4408	$3.9044
< 15.5	US 1	$1.5026	$5.3211	$3.8185
	US 2	$1.5611	$5.5282	$3.9671
< 16.5	US 1	$1.5262	$5.4049	$3.8787
	US 2	—	—	$0.0000
16.5 <	US 1	$1.5340	$5.4323	$3.8983
	US 2	$1.5617	$5.5304	$3.9687

†A unit is based on the requirements to manufacture 1,000 pounds of white bread.
—No observations were recorded in this category.

The maximum requirement for wheat gluten required was approximately 3 percent of total flour composition. In 8 of 20 categories modeled, wheat gluten was required. Flour mill model results are presented in Table 5.3. Margins for the flour mill ranged from $1.68 to a loss of $1.03 per hundredweight of flour. Those containing a mixture of lower protein wheats and wheat gluten resulted in larger margins.

Table 5.3. Base case empirical results for the flour mill activity in the wheat supply chain model

Wheat Protein (%)	Wheat Grade	Operating Cost ($/cwt)	Inventory Cost ($/cwt)	Purchase Cost ($/cwt)	Inbound Cost ($/cwt)	Sales Revenue ($/cwt)	Mill Margin ($/cwt)
< 11.5	US 1	$2.6778	$0.0802	$8.5191	$0.8280	$13.6541	$1.5489
	US 2	$2.6780	$0.0794	$8.3807	$0.8362	$13.6541	$1.6798
< 12.5	US 1	$2.6785	$0.0821	$8.6576	$0.8482	$13.6541	$1.3877
	US 2	$2.6791	$0.0839	$8.8747	$0.8745	$13.6541	$1.1419
< 13.0	US 1	$2.6790	$0.0831	$8.7370	$0.8672	$13.6541	$1.2877
	US 2	$2.6794	$0.0850	$8.9748	$0.8863	$13.6541	$1.0285
< 13.5	US 1	$2.6792	$0.0841	$8.8099	$0.8790	$13.6541	$1.2019
	US 2	$2.6801	$0.0873	$9.2310	$0.9151	$13.6541	$0.7406
< 14.0	US 1	$2.6795	$0.0862	$9.0830	$0.8843	$13.7233	$0.9902
	US 2	$2.6802	$0.0886	$9.3839	$0.9136	$13.7233	$0.6569
< 14.5	US 1	$2.6799	$0.0890	$9.4590	$0.8957	$13.8616	$0.7380
	US 2	$2.6804	$0.0906	$9.6574	$0.9145	$13.8616	$0.5188
< 15.0	US 1	$2.6800	$0.0916	$9.8174	$0.9035	$14.0000	$0.5075
	US 2	$2.6805	$0.0931	$10.0009	$0.9204	$14.0000	$0.3052
< 15.5	US 1	$2.6802	$0.0955	$10.3409	$0.9048	$14.2767	$0.2553
	US 2	$2.6810	$0.0987	$10.7288	$0.9387	$14.2767	($0.1705)
< 16.5	US 1	$2.6804	$0.0994	$10.8581	$0.9237	$14.5535	($0.0081)
	US 2	—	—	—	—	—	$0.0000
16.5 <	US 1	$2.6812	$0.1082	$12.0474	$0.9359	$15.1069	($0.6658)
	US 2	$2.6816	$0.1101	$12.2573	$0.9522	$14.9686	($1.0326)

—No observations were recorded in this category.

Flour transportation costs and revenues to the transportation service provider are constant with regard to wheat quality. However, when calculated on a per unit basis, these costs and revenues exhibit some variation across wheat qualities (Table 5.4). This is caused by variations in the quantity of flour required in a bakery unit, 1,000 pounds of white pan bread. Variations in flour requirements are determined by flour attributes. Converted to a common unit of measure from the bakery activity, 1,000 pounds of white pan bread, the margin for flour transportation varied from $3.60 to $3.73 per bakery unit. Larger costs, revenues, and margins occur on flour from lower protein wheats when the bakery has greater flour requirements.

Table 5.4. Base case empirical results for the flour transportation activity in the wheat supply chain model

Wheat Protein (%)	Wheat Grade	URCS Rail Cost ($/unit†)	Rail Tariff Revenue ($/unit†)	Rail Margin ($/unit†)
< 11.5	US 1	$3.0112	$6.7417	$3.7305
	US 2	$3.0031	$6.7236	$3.7205
< 12.5	US 1	$2.9918	$6.6983	$3.7065
	US 2	$2.9969	$6.7097	$3.7128
< 13.0	US 1	$2.9855	$6.6841	$3.6986
	US 2	$2.9846	$6.6821	$3.6975
< 13.5	US 1	$2.9727	$6.6555	$3.6828
	US 2	$2.9798	$6.6713	$3.6915
< 14.0	US 1	$2.9682	$6.6455	$3.6773
	US 2	$2.9721	$6.6541	$3.6820
< 14.5	US 1	$2.9595	$6.6259	$3.6664
	US 2	$2.9629	$6.6335	$3.6706
< 15.0	US 1	$2.9503	$6.6053	$3.6550
	US 2	$2.9526	$6.6105	$3.6579
< 15.5	US 1	$2.9402	$6.5827	$3.6425
	US 2	$2.9441	$6.5916	$3.6474
< 16.5	US 1	$2.9270	$6.5532	$3.6262
	US 2	—	—	$0.0000
16.5 <	US 1	$2.9090	$6.5129	$3.6039
	US 2	$2.9109	$6.5170	$3.6062

†A unit is based on the requirements to manufacture 1,000 pounds of white bread.
—No observations were recorded in this category.

There was limited variation in bakery results across the wheat protein categories. This is primarily because flour is a small portion of the bakery's total cost. However, the quantity of flour required to manufacture bread does vary with flour attributes. In Table 5.5, model results indicate a variation in the cost of flour from $83.84 to $88.84 for a unit of bread (1,000 pounds of bread). The bakery margin ranged from $79.85 to $85.84 per bread unit. Smaller margins occurred at the highest and lowest wheat protein categories, while greater margins were experienced in the middle wheat protein categories.

In summary, costs vary in the operations of all the selected supply chain players. Furthermore, the variations are not consistent among these players. Higher protein wheats result in higher inventory costs for elevators. As a result, elevators have little incentive to store higher protein wheats when they provide a lower return than lower protein wheats. Furthermore, the elevator margin is small, providing incentive for large volume shipments. Enhancing the elevator's incentive toward large shipments are railroads, the principle transporter of wheat, who gain operating efficiencies from these movement types. Flour mills enjoy the largest margins when they include wheat gluten in their flour products. This indicates that the tradeoff between wheat gluten and higher protein wheats appears to favor wheat gluten. In another observation regarding the flour mill activity, US Number 1 wheats provide consistently greater margins than US Number 2 wheats with the exception of the lowest protein wheat category ($\leq$ 11.5 percent protein). Flour is transported by both rail and truck. In the base case scenario, flour is transported by single railcar. The railroad's margins for the flour and wheat shipments are similar, although the rates and costs differ substantively for these shipments.

Table 5.5. Base case empirical results for the bakery activity in the wheat supply chain model

Wheat Protein (%)	Wheat Grade	Operating Cost ($/unit[†])	Inventory Cost ($/unit[†])	Purchase Cost ($/unit[†])	Inbound Cost ($/unit[†])	Sales Revenue ($/unit[†])	Bakery Margin ($/unit[†])
< 11.5	US 1	$423.1100	$1.4966	$83.8360	$6.8814	$600.00	$84.6756
	US 2	$423.1100	$1.4960	$83.6106	$6.8629	$600.00	$84.9200
< 12.5	US 1	$423.1100	$1.4952	$83.2956	$6.8371	$600.00	$85.2615
	US 2	$423.1100	$1.4956	$83.4381	$6.8488	$600.00	$85.1070
< 13.0	US 1	$423.1100	$1.4948	$83.1192	$6.8226	$600.00	$85.4529
	US 2	$423.1100	$1.4947	$83.0941	$6.8205	$600.00	$85.4801
< 13.5	US 1	$423.1100	$1.4939	$82.7636	$6.7934	$600.00	$85.8386
	US 2	$423.1100	$1.4944	$82.9605	$6.8096	$600.00	$85.6250
< 14.0	US 1	$423.1100	$1.4959	$83.0583	$6.7839	$600.00	$85.5514
	US 2	$423.1100	$1.4962	$83.1660	$6.7927	$600.00	$85.4346
< 14.5	US 1	$423.1100	$1.4999	$83.6485	$6.7653	$600.00	$84.9758
	US 2	$423.1100	$1.5002	$83.7436	$6.7730	$600.00	$84.8727
< 15.0	US 1	$423.1100	$1.5039	$84.2206	$6.7457	$600.00	$84.4193
	US 2	$423.1100	$1.5041	$84.2870	$6.7510	$600.00	$84.3474
< 15.5	US 1	$423.1100	$1.5124	$85.5916	$6.7254	$600.00	$83.0602
	US 2	$423.1100	$1.5126	$85.7068	$6.7344	$600.00	$82.9356
< 16.5	US 1	$423.1100	$1.5206	$86.8599	$6.6980	$600.00	$81.8110
	US 2	—	—	—	—	—	$0.0000
16.5 <	US 1	$423.1100	$1.5375	$89.6089	$6.6623	$600.00	$79.0808
	US 2	$423.1100	$1.5331	$88.8441	$6.6651	$600.00	$79.8472

[†]A unit is based on the requirements to manufacture 1,000 pounds of white bread.
—No observations were recorded in this category.

Bakery margins are greatest at mid-protein wheats. This indicates that a tradeoff in technical efficiency, flour requirements, and ingredient cost exists. As flour protein increases initially, technical efficiency increases. However, at some point, the cost of higher protein flours exhausts these efficiency gains. Additional information is necessary on the attributes of flour containing both milled wheat and wheat gluten to derive any specific conclusions on the impact of flours containing lower protein milled wheat and wheat gluten.

Base case results for each of the activities are shown in Figure 5.1. For comparison purposes, all information is reported using a common unit, 1,000 pounds of white pan bread. The elevator and the two transportation activities, wheat and flour, have relatively stable results across all wheat categories. The flour mill activity exhibits the greatest variation. This in turn causes the majority of variation in the total supply chain results. The bakery activity also exhibits some variation, albeit much less than the flour mill. As wheat protein increases, bakery performance initially improves and then falls off.

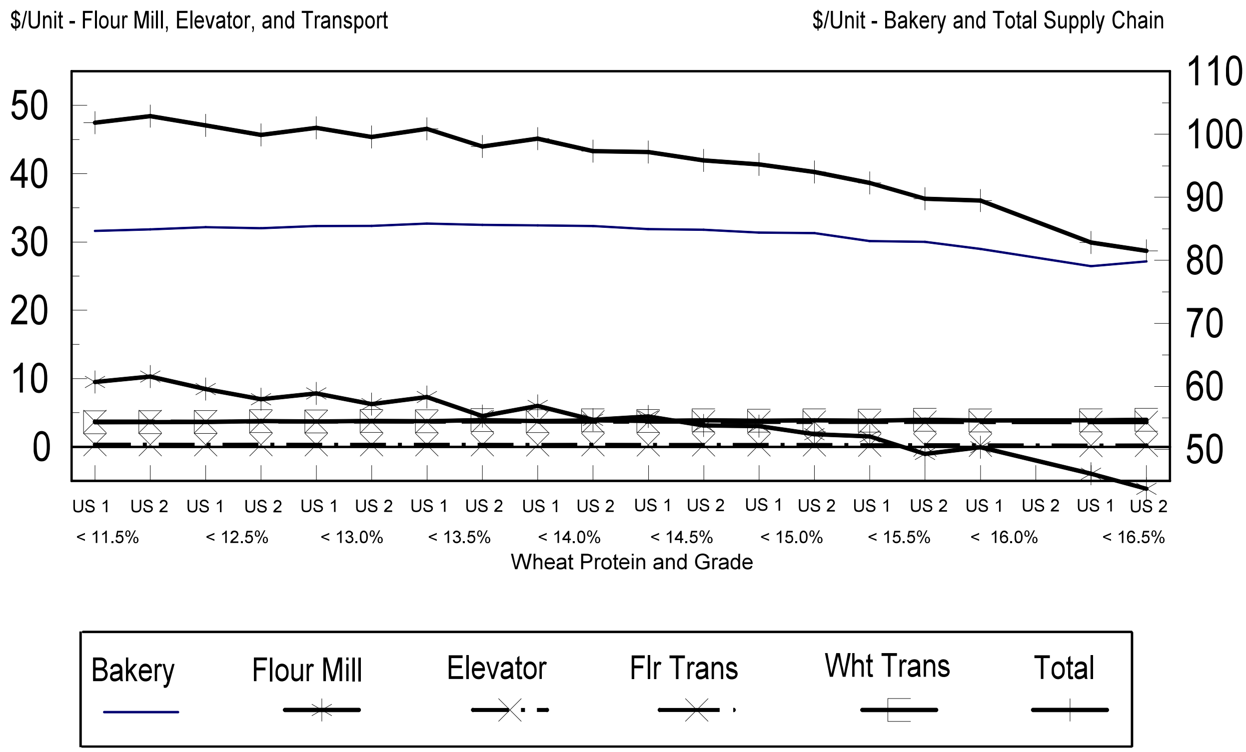

Figure 5.1. Summary of base case margins for each activity and for the entire wheat supply chain.

Note: A unit is based on the requirements to manufacture 1,000 pounds of white pan bread and Flr Trans pertains to the flour transportation activity and Wht Trans pertains to the wheat transportation activity.

Scenarios Evaluated

In addition to the base case, three scenarios were analyzed with the model. The first and second scenarios evaluated the implications of specific changes in the price of wheat gluten. In the third scenario, the location of the flour mill was changed from an origin to a destination mill.

In the first wheat gluten pricing scenario, the price of wheat gluten was assumed to increase 50 percent. In the second, the price of wheat gluten was assumed to increase 100 percent. Currently, many experts in the industry consider the U. S. wheat gluten market a “dump” market for Canadian, Australian, and European wheat gluten. If this is the case, one would expect the price of wheat gluten to increase over time.

At a 50 percent increase in the price of wheat gluten, model results differ substantially from the base case. The difference is entirely realized by changes in the flour mill activity. The profitability of making flour out of lower protein wheats and wheat gluten declines relative to those flours made without wheat gluten. Although the flour mill achieves its largest margin at the same wheat protein level as in the base case, the supply chain optimum shifts from lower-protein toward middle-protein wheats (Table 5.6). This shows the diminished substitutability of wheat gluten for milled wheat flour as the price of wheat gluten increases.

A 100 percent increase in the price of wheat gluten further decreases the total supply chain margin, particularly the flour margin. However, the flour mill’s optimal wheat protein shifts toward middle-protein wheats when gluten prices are increased 100 percent (Table 5.7). Optimum wheat proteins remain the same for the entire supply chain and all of the other activities in both the 50 percent and 100 percent scenarios. By increasing gluten prices from 50 to 100 percent, the flour mill’s optimum result shifts to a common optimum wheat protein category shared by the supply chain, bakery, and flour mill.

Table 5.6. Scenario 1 activity margins for the elevator, flour mill, bakery, wheat transportation, and flour transportation components of the wheat supply chain on a 1,000 lbs. of bread basis†

Wheat Protein (%)	Wheat Grade	Elevator Margin	Flour Mill Margin	Bakery Margin	Wheat Transport Margin	Flour Transport Margin	Supply Chain Margin	Base Case Supply Chain Margin
< 11.5	US 1	$0.3289	$5.9158	$84.6756	$3.5944	$3.7305	$98.2452	$101.8398
	US 2	$0.3313	$7.3519	$84.9200	$3.6203	$3.7205	$99.9440	$102.8780
< 12.5	US 1	$0.3174	$6.4795	$85.2615	$3.6549	$3.7065	$99.4197	$101.4061
	US 2	$0.3277	$5.0828	$85.1070	$3.7745	$3.7128	$98.0048	$99.9001
< 13.0	US 1	$0.3111	$6.8617	$85.4529	$3.7272	$3.6986	$100.0516	$101.0291
	US 2	$0.3179	$5.1206	$85.4801	$3.8080	$3.6975	$98.4241	$99.5626
< 13.5	US 1	$0.3071	$7.0377	$85.8386	$3.7604	$3.6828	$100.6266	$100.8739
	US 2	$0.3205	$4.0605	$85.6250	$3.9242	$3.6915	$97.6217	$98.0609
< 14.0	US 1	$0.2961	$5.9931	$85.5514	$3.7751	$3.6773	$99.2929	$99.2929
	US 2	$0.3063	$3.9809	$85.4346	$3.9052	$3.6820	$97.3091	$97.3091
< 14.5	US 1	$0.2876	$4.4537	$84.9758	$3.8105	$3.6664	$97.1940	$97.1940
	US 2	$0.2940	$3.1345	$84.8727	$3.8948	$3.6706	$95.8666	$95.8666
< 15.0	US 1	$0.2728	$3.0528	$84.4193	$3.8297	$3.6550	$95.2297	$95.2297
	US 2	$0.2782	$1.8372	$84.3474	$3.9044	$3.6579	$94.0251	$94.0251
< 15.5	US 1	$0.2535	$1.5306	$83.0602	$3.8185	$3.6425	$92.3054	$92.3054
	US 2	$0.2633	($1.0238)	$82.9356	$3.9671	$3.6474	$89.7897	$89.7897
< 16.5	US 1	$0.2370	($0.0483)	$81.8110	$3.8787	$3.6262	$89.50	$89.5045
	US 2	—	—	—	—	—	$0.0000	$0.0000
16.5 <	US 1	$0.1977	($3.9493)	$79.0808	$3.8983	$3.6039	$82.8316	$82.8316
	US 2	$0.2013	($6.1289)	$79.8472	$3.9687	$3.6062	$81.4945	$81.4945

†Scenario 1 reflects a 50 percent increase in the vital wheat gluten price for the flour mill.
—No observations were recorded in this category.

Table 5.7. Scenario 2 activity margins for the elevator, flour mill, bakery, wheat transportation, and flour transportation components of the wheat supply chain on a 1,000 lbs. of bread basis†

Wheat Protein (%)	Wheat Grade	Elevator Margin	Flour Mill Margin	Bakery Margin	Wheat Transport Margin	Flour Transport Margin	Supply Chain Margin	Base Case Supply Chain Margin
< 11.5	US 1	$0.3289	$2.3211	$84.676	$3.5944	$3.7305	$94.6505	$101.8398
	US 2	$0.3313	$4.4178	$84.920	$3.6203	$3.7205	$97.0099	$102.8780
< 12.5	US 1	$0.3174	$4.4931	$85.262	$3.6549	$3.7065	$97.4334	$101.4061
	US 2	$0.3277	$3.1875	$85.107	$3.7745	$3.7128	$96.1096	$99.9001
< 13.0	US 1	$0.3111	$5.8842	$85.453	$3.7272	$3.6986	$99.0741	$101.0291
	US 2	$0.3179	$3.9821	$85.480	$3.8080	$3.6975	$97.2856	$99.5626
< 13.5	US 1	$0.3071	$6.7904	$85.839	$3.7604	$3.6828	$100.3793	$100.8739
	US 2	$0.3205	$3.6213	$85.625	$3.9242	$3.6915	$97.1825	$98.0609
< 14.0	US 1	$0.2961	$5.9931	$85.551	$3.7751	$3.6773	$99.2929	$99.2929
	US 2	$0.3063	$3.9809	$85.435	$3.9052	$3.6820	$97.3091	$97.3091
< 14.5	US 1	$0.2876	$4.4537	$84.976	$3.8105	$3.6664	$97.1940	$97.1940
	US 2	$0.2940	$3.1345	$84.873	$3.8948	$3.6706	$95.8666	$95.8666
< 15.0	US 1	$0.2728	$3.0528	$84.419	$3.8297	$3.6550	$95.2297	$95.2297
	US 2	$0.2782	$1.8372	$84.347	$3.9044	$3.6579	$94.0251	$94.0251
< 15.5	US 1	$0.2535	$1.5306	$83.060	$3.8185	$3.6425	$92.3054	$92.3054
	US 2	$0.2633	($1.0238)	$82.936	$3.9671	$3.6474	$89.7897	$89.7897
< 16.5	US 1	$0.2370	($0.0483)	$81.811	$3.8787	$3.6262	$89.5045	$89.5045
	US 2	—	—	—	—	—	$0.0000	$0.0000
16.5 <	US 1	$0.1977	($3.9493)	$79.081	$3.8983	$3.6039	$82.8316	$82.8316
	US 2	$0.2013	($6.1289)	$79.847	$3.9687	$3.6062	$81.4945	$81.4945

†Scenario 2 reflects a 100 percent increase in the vital wheat gluten price for the flour mill.
—No observations were recorded in this category.

As was discussed earlier, changes are taking place in the location of the flour milling industry. Most of this change has occurred through the expansion of flour milling activity in destination markets. The final scenario analyzed was the implications of flour mill location on the supply chain and its players. In the model, all prices are free-on-board (FOB) origin. This means the purchaser pays the freight. As a result, the flour mill pays for the transportation of wheat from the elevator to its location and the bakery pays for the transportation of flour from the mill to its location. The flour mill's inbound transportation costs will increase as the flour mill's location shifts further away from the source of wheat. Similarly, the bakery's inbound transportation costs would be expected to decline as the flour mill becomes closer to the bakery.

Given the assignment of transportation costs in the model, FOB origin, it would appear the flour mill would be worse off and the bakery would be better off from a destination flour mill because actual flour price was unchanged. However, one also would expect the price of flour to change. The bakery's total expenditure on flour, including transportation, would be expected to be similar under both scenarios. This would compensate the flour mill for its additional wheat transportation costs. However, exactly how the net change in transportation costs would be split between the flour mill and the bakery would be a point of negotiation between them. Therefore, the model did not specifically consider a change in the price of flour. As a result, model results make the flour mill appear to be much worse off and the bakery much better off from a change in location than what would be expected to occur.

The results for the supply chain, on the other hand, are more instructive as to the implications of a change in location. The profit maximizing supply chain for the destination flour mill occurs at the same level of wheat protein as in the base case. However, total supply chain margin fell $2.74 per 1,000 pounds of bread. Increased inbound wheat transportation costs decreased the flour mill's margin by $5.99 per 1,000 pounds of bread (since flour price was held constant). Similarly, decreased inbound flour transportation costs should result in an increased bakery margin. Interestingly, the bakery's margin only increased $5.35 per 1,000 pounds of bread. Out of the $2.74 per 1,000 pounds of bread that the supply chain lost, the flour mill and the bakery contributed a net loss of $0.64 per 1,000 pounds of bread from this change in flour mill location.

The remainder of the difference in supply chain margins between origin and destination flour mill location must be accounted for by the remaining activities in the model. Since the elevator's margin was unchanged, the only remaining activity was transportation. The relative profitability of wheat transportation increased $1.62 per 1,000 pounds of bread as the rail carrier provides service over a longer distance (between Rugby and Chicago). The margin for flour transportation decreased to zero as the mode changes from rail to short-distance truck. This created an interesting observation as it appears that the rail carrier has exchanged a total transportation margin of $7.34 per 1,000 pounds of bread for transporting both wheat ($3.62) and flour ($3.72) for a $5.24 per 1,000 pounds of bread margin on just wheat transportation.

Summarizing this scenario, the positive benefits to the wheat transport carrier (from a change in wheat shipments) and to the bakery (from decreased inbound flour transportation costs) are less than the negative impacts on the flour mill (from higher inbound wheat transportation costs) and the flour transport carrier (forgone margins from flour shipments). Additionally, the implications are dependent upon the transportation cost calculations. In the model, rail costs for both flour and wheat shipments were estimated using URCS. It is possible that URCS under- or over estimates the cost of shipping flour from Grand Forks to Chicago or wheat from Rugby to Grand Forks or Chicago. Model results from the third scenario are presented in Table 5.8.

Table 5.8. Scenario 3 margins for the elevator, flour mill, bakery, wheat transportation, and flour transportation components of the wheat supply chain on a 1,000 lbs. of bread basis†

Wheat Protein (%)	Wheat Grade	Elevator Margin	Flour Mill Margin	Bakery Margin	Wheat Transport Margin	Flour Transport Margin	Supply Chain Margin	Base Case Supply Chain Margin
< 11.5	US 1	$0.3289	$3.5668	$90.035	$5.2046	$0.00	$99.1350	$101.8398
	US 2	$0.3313	$4.2994	$90.265	$5.2422	$0.00	$100.1381	$102.8780
< 12.5	US 1	$0.3174	$2.4171	$90.587	$5.2923	$0.00	$98.6141	$101.4061
	US 2	$0.3277	$0.7315	$90.442	$5.4654	$0.00	$96.9663	$99.9001
< 13.0	US 1	$0.3111	$1.6684	$90.768	$5.3970	$0.00	$98.1444	$101.0291
	US 2	$0.3179	($0.0455)	$90.794	$5.5140	$0.00	$96.5799	$99.5626
< 13.5	US 1	$0.3071	$1.0573	$91.132	$5.4451	$0.00	$97.9411	$100.8739
	US 2	$0.3205	($1.9991)	$90.930	$5.6822	$0.00	$94.9336	$98.0609
< 14.0	US 1	$0.2961	($0.2620)	$90.838	$5.4663	$0.00	$96.3387	$99.2929
	US 2	$0.3063	($2.4898)	$90.728	$5.6548	$0.00	$94.1994	$97.3091
< 14.5	US 1	$0.2876	($1.8627)	$90.251	$5.5176	$0.00	$94.1933	$97.1940
	US 2	$0.2940	($3.3217)	$90.154	$5.6397	$0.00	$92.7655	$95.8666
< 15.0	US 1	$0.2728	($3.2984)	$89.682	$5.5454	$0.00	$92.2016	$95.2297
	US 2	$0.2782	($4.6378)	$89.614	$5.6536	$0.00	$90.9077	$94.0251
< 15.5	US 1	$0.2535	($4.8071)	$88.312	$5.5292	$0.00	$89.2871	$92.3054
	US 2	$0.2633	($7.6082)	$88.194	$5.7444	$0.00	$86.5933	$89.7897
< 16.5	US 1	$0.2370	($6.4890)	$87.046	$5.6163	$0.00	$86.4103	$89.5045
	US 2	—	—	—	—	—	$0.0000	$0.0000
16.5 <	US 1	$0.1977	($10.4331)	$84.297	$5.6448	$0.00	$79.7068	$82.8316
	US 2	$0.2013	($12.7298)	$85.064	$5.7467	$0.00	$78.2820	$81.4945

†Scenario 3 reflects a destination flour mill (the base case reflected an origin location).
—No observations were recorded in this category.

Summary

With respect to wheat protein, results from the scenarios and base case are compared and contrasted in Figure 5.2. The optimum wheat quality for each activity and the supply chain are presented. Again, the model considered a base case, 50 percent increase in gluten price, 100 percent increase in gluten price, and destination location flour mill situations. In all scenarios, the elevator prefers lower quality wheats. This is because lower protein wheats require smaller capital investments in inventory. The flour mill activity presents the greatest variation in wheat quality preferences. In the base case, lower protein wheats are desired. As the price of gluten is increased in the first and second scenarios, the preference shifts toward middle protein wheats. In the third scenario, the flour mill's wheat quality preference shifts back to lower wheat protein levels. The bakery exhibits no variation in preferences for wheat quality under any scenario. The supply chain preference for wheat quality mirrors the flour mill's. In the base case, lower protein wheats are prefered from a supply chain perspective. In the first and second scenarios, supply chain preference shifts toward middle protein wheats. In the final scenario, the wheat quality preference from the supply chain's perspective returns to lower protein wheats.

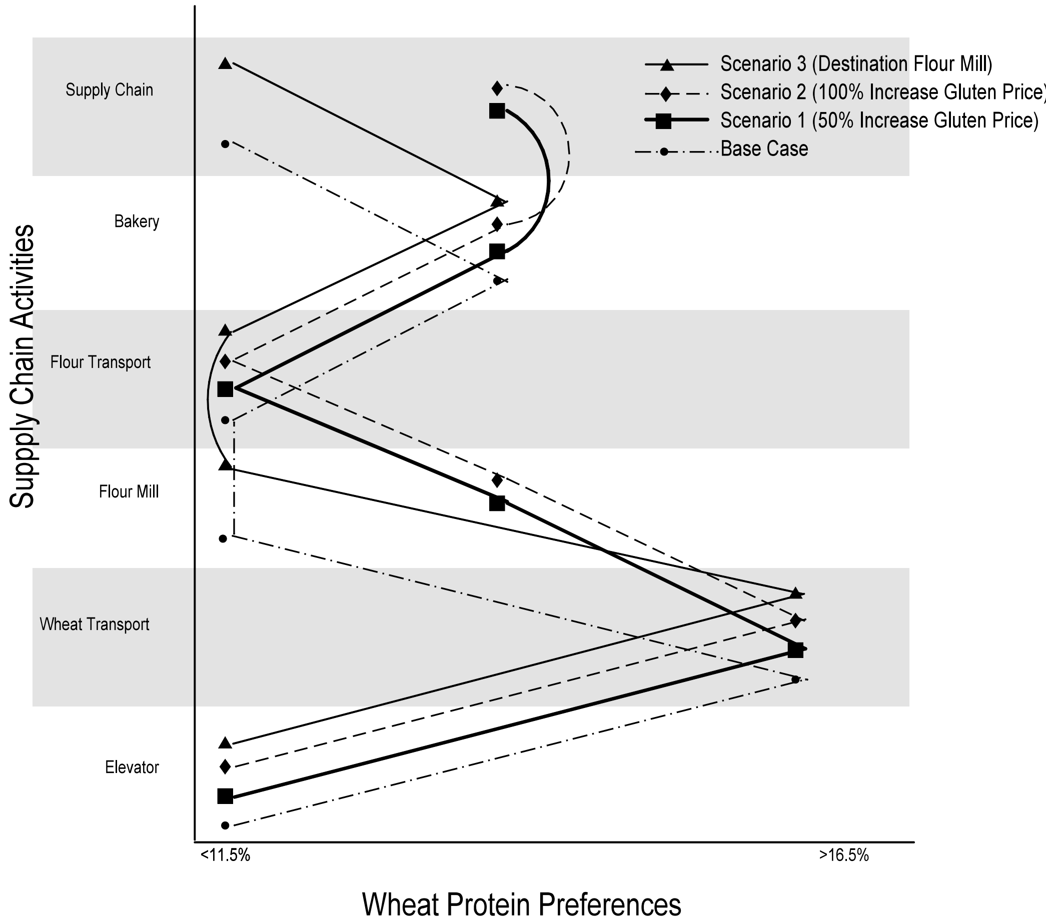

Figure 5.2. Summary of wheat quality preferences for each activity in the wheat supply chain for each of the scenarios modeled.

CHAPTER VI: CONCLUSIONS

In this chapter, a summary of the study is presented. In addition, conclusions drawn from the study are presented. Finally, study limitations and the need for further study are addressed.

Summary

The base case models the relationships among three players in the wheat supply chain. Cost and technical relationships were taken from secondary sources and do not necessarily reflect the actual cost and technical relationships within and between any particular set of firms. The discussion is organized around wheat attributes; an elevator, a flour mill, and a bakery firm; and the transportation linkages between these three firms.

The wheat attributes available to a particular elevator are limited to the quality attributes of the local wheat production. Competition among elevators effectively limits the sourcing area for any particular elevator. This means a particular elevator has only a small influence over the quality of wheat that it can purchase. In the model, wheat quality data were summarized for the entire Hard Red Spring wheat growing region (encompassing eastern Montana, North Dakota, South Dakota, and western Minnesota). Therefore, the wheat quality data used in the model reflect regional averages as opposed to the localized conditions of a particular elevator.

In the model, the location of the elevator activity was specified as Rugby, in north central North Dakota. There is only one elevator in Rugby, and it has the ability to load unit trains in excess of 49 railcars (*North Dakota Railroad Map*, 1994). Furthermore, unit train shipments have occurred between Rugby and the location of the flour mill (Grand Forks, North Dakota) (Upper Great Plains Transportation Institute, 1995). Wheat prices in Rugby were assumed to be driven by the cash price in Minneapolis. Other elevator data, including the cost and technical relationships, were taken from previous analyses of the elevator industry (Bangsund, Sell, and Leistritz, 1994 and

Johnson, Scherping, and Wilson, 1992). Freight terms of wheat sales from the elevator were assumed to be free-on-board (FOB) origin, meaning the buyer takes possession upon shipment and is responsible for paying freight charges.

Rugby is served by a single rail carrier, Burlington Northern (BN). Although substantive changes in rail pricing have been introduced by BN (i.e., the Certificate of Transportation program), published rate tariffs remain the source of secondary data on rail prices. The actual costs incurred by BN for moving a particular shipment or for a particular origin-destination pair are not available. However, the Interstate Commerce Commission developed, using an extensive database of confidential rail cost information, the Uniform Rail Costing System (URCS). With information on the rail carrier, shipment distance, railcar type and ownership, and shipment payload per car and number of cars, URCS can compute the single shipment cost. In the model, URCS was used to estimate BN's cost of moving 26 railcars, each with 100 tons of wheat, in railroad-owned, covered hopper cars from Rugby to Grand Forks.

This analysis was not conducted at the request of or with the support of any particular flour mill. However, its initial focus was Grand Forks, the location of the North Dakota Mill. Furthermore, cost and technical data for the model were not obtained, either in confidence or publicly, for this particular mill. The only data obtained that potentially reflect the North Dakota Mill's operations were that (1) 26 railcar shipments have occurred between Rugby and Grand Forks, (2) a rail tariff for this type of wheat shipment exists, and (3) a rail tariff for flour between Grand Forks, North Dakota, and Chicago, Illinois, the location of the bakery in the model, exists. In the model, flour was priced FOB origin. Additionally, flour with higher protein contents were priced at a premium to the base price.

Burlington Northern also is the sole rail service provider for Grand Forks, North Dakota. Rail tariffs for flour between Grand Forks and Chicago were used in the model. The rail carrier's cost of providing this service also was estimated using URCS. In the model, URCS was used to estimate BN's cost of moving 100 tons of flour in a single privately owned general service hopper car from Grand Forks to Chicago.

The bakery analysis did not reflect the operations or strategies of any particular bakery. Chicago was selected for analysis because there are currently two flour mills in operation, one recently constructed. Additionally, Chicago represents a flour market that may be served by a mill in Grand Forks. In the model, flour quality requirements were specified by the bakery. Although specifications were taken from an actual bakery not located in the Chicago area, a white pan bread bakery in Chicago likely would have similar flour product specifications.

Conclusions

Several conclusions can be drawn from this study. First, there are natural pressures for individual participants to pursue different policies and strategies to maximize profit. Second, coordination among the elevation, milling, and baking activities could provide benefits to the supply chain. Third, improving supply chain coordination among the wheat value chain would be difficult due to the distribution of power and benefits among players.

The result of each firm following an uncoordinated strategy is a supply chain with lower total margin. All firms could be better off through cooperation. However, from an individual firm's perspective, one has to assess what it will take to move to the supply chain profit maximizing strategy. The key is determining how information should flow through the supply chain to avoid strategies that lead to a lower total margin. When assessing information flows, buyer-supplier relationships become more important as does the relative balance of power among individual firms.

Coordination among the elevation, milling, and baking activities could provide benefits to the supply chain. The pressures to achieve sustainable competitive advantage exist in both the milling and baking activities. By linking with the elevation stage, all firms could gain added competitive advantage. Wheat of the optimum quality could be procured and stored by the elevator with the proper incentive from the mill. Additionally, the wheat would contain attributes positively impacting the extraction rate and optimizing the protein strength-quantity tradeoff for the baker.

Under current, or traditional, buyer-supplier relationships in the wheat value chain, supply chain coordination would be difficult to acheive. Flour millers appear to have the most to gain with respect to their individual financial performance through supply chain coordination. However, bakers appear to have the upper hand over flour mills in terms of power within that relationship. Similarly, individual flour mills appear to have little power over their elevator suppliers.

The remainder of this discussion focuses on how well the model works. The usefulness of the model is dependent upon the quality of data available. The model could be a valuable tool in evaluating strategy alternatives when firm specific data are available. However, less insight is provided when data are unavailable or when data need to be estimated from secondary sources. Furthermore, simply improving data used in the portion of the model dealing with a particular firm does not solve data problems in the other activities in the supply chain. Therefore, firms will need to learn more about their suppliers' and customers' operations to fully utilize this model. Depending upon the relationship between these firms, this data could be difficult to ascertain.

The model provides a good indication of the potential impacts of quality attributes on the various players in the supply chain. The linkages between players in the model are reflected through wheat quality characteristics and bakery ingredient requirements.

Although many quality attributes in agricultural crops are determined by climatic conditions, producers can influence many of these attributes directly. Perhaps the largest strategic choice confronting producers is plant variety. Varietal decisions are influenced by current pricing mechanisms, as well as expected yields.

As shipment size between elevators and flour mills increase, it is plausible that blending among wheat protein categories increases. This could potentially increase the quality variance within and between shipments. By shifting location and increasing the emphasis for volume wheat shipments from elevators, flour mills have contributed to an associated increase in quality variance and uncertainty. Alternatively, destination flour mills can effectively source wheat from multiple geographic regions, reflecting the wheat quality attributes of the region and the flour mill's quality needs.

The transformation of white pan bakeries to highly automated production facilities decreases their tolerance for attribute variance and uncertainty. Conformance to ingredient specifications become increasingly important. This conflicts with blending practices that may result in the increased variance in quality attributes. However, bakers also value the service aspects associated with their flour purchases. This includes the decreased transportation time and inventory requirements associated with closer flour mills.

The model has several strengths for use in analysis. First, it explicitly considers the implications on the supply chain. It also has the flexibility to include additional or to modify existing linkages, cost drivers, and technical relationships. Additionally, the model's ease of use is a considerable strength.

One weakness of the model is that technical relationship data are a prerequisite to analysis. Also, cost and price data are often difficult to determine even within a firm let alone for suppliers and customers. Another weakness is in evaluating firms where one's output is another's input. A firm level decision by the elevator would not consider the amount of wheat in flour or in a bakery unit. However, to evaluate the supply chain, all of the firms need to be converted to a common unit.

In summary, the model provides a mechanism to identify improvements in the relationships among members of the supply chain and to evaluate impacts of strategy choice on a particular firm and the supply chain. With good data, the model would provide valuable insight into firm level strategic planning.

Study Limitations

The purpose of the spreadsheet model is to assist firms in the wheat supply chain to evaluate strategic alternatives. In addition, the model presents a method for strategy analysis that can be replicated by firms in other supply chains. Examples of strategic choices that could be evaluated with the model include location analysis, vertical integration and relationship analysis, plant utilization implications, ingredient pricing mechanisms, input substitution analysis, and impacts to supply chain from changes in wheat or flour quality attributes. These strategy choices are primarily specific to supply chain members. However, the last strategic decision, concerning wheat and flour quality attributes, has implications for both the public sector, especially agricultural research concerning plant breeding, and the private sector, especially farmer's varietal decisions.

There are several limitations to the results of the model presented in this thesis. The major limitation is that the data used in the model are illustrative. Individual firms in the wheat supply chain would have more applicable data for their unique situations. For instance, the quality of wheat available from a given elevator would differ, the relationships between wheat and flour characteristics could be refined for a particular situation, and specific cost and revenue data could be incorporated. Additionally, many assumptions inherent with the method used for estimating rail transportation costs, URCS, limit the accuracy of the results. However, this model illustrates that relationships exist between activities that impact each other's performance. Furthermore, the model illustrates that many of these relationships are not captured in the current pricing mechanism nor are they captured through alternative methods.

Need for Additional Study

Whether a firm should participate in Supply Chain Management initiatives with its supply chain partners is unclear. There are tradeoffs within and between firms that are unclear. This thesis attempted to identify the information requirements and illustrate how a firm in the wheat supply chain could evaluate such a strategy.

Model results confirm that firm optimization and supply chain optimization are often not the same. Also, the technical and economic relationships between wheat quality and performance provide insight into future strategic directions for the supply chain players but more information is needed. For instance, more research is needed into the actual drivers of various cost components, especially operating costs, for all players in the model. More knowledge of the relationship between product attributes and technical output is required, especially for the bakery activity. Also, the impact of wheat gluten on mill and bakery performance is not well known. In summary, better data on cost behavior and implications on technical relationships for all levels are needed.

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Appendix A

Specific Model Coefficients

VARIABLE ESTIMATES

Variables were used to model the ingredient, operating, inventory, and logistics costs associated with the wheat supply chain. Following Bierman, Bonini, and Hausman (1991), variables were classified as either decision, exogenous, intermediate, or performance measures. Decision variables are controlled by the decision maker; exogenous variables are beyond the control of the decision maker; intermediate variables are necessary to relate decision variables and exogenous variables to performance measures; and performance measures are a quantitative expression of the decision maker's objectives (Bierman, Bonini, and Hausman, 1991).

The spreadsheet model developed for the wheat supply chain was comprised of five linked sheets. The first sheet contained wheat quality data used in the elevation and milling activity. The second through fourth sheets represented the activities of the sectors (elevation, milling, and baking) within the model. The final sheet, provided a summary of the activities in the wheat supply chain.

The following discussion is organized by activities in the wheat supply chain. The spreadsheet model appears in Appendix B Portions of the spreadsheet model and the data used have been reproduced and appear throughout this section to aid the discussion.

Initial Characteristics

The first set of variables in the spreadsheet model were considered decision variables. Two principle characteristics of the wheat supply chain are determined independently of any one specific supply chain's economic activities. These include physical characteristics of the wheat crop and wheat prices. This section of the model refers to the wheat data sheet which was reproduced as pages 1 and 2 in Appendix B.

To illustrate the characteristics of wheat available to a generic wheat supply chain, data were taken from the Hard Red Spring Wheat 1994 Regional Quality Report (Moore et al., 1994).

These data represent the entire 1994 wheat crop for North Dakota, South Dakota, Montana, and Minnesota. Of the 437 observations available, only those observations that were considered U.S. Number 1 or 2 were included in the analysis (n=333). Wheat of lower quality is not typically used in the flour milling or baking activities. The 333 remaining observations were first grouped into 10 protein categories to mirror current elevator binning practices. Table A1 depicts the wheat characteristics and coefficients available to the elevation activity. These variables were estimated as the mean value for each characteristic of the observations in each category, with the exception of wheat ash. Wheat ash characteristics were estimated by the regression equation (n=333):

$$\underset{Ash}{Wht} = \underset{(1.915)}{1.1288} - \underset{(-5.211)}{0.0094} \cdot \underset{Krnl}{Vit} - \underset{(-2.143)}{0.069} \cdot \underset{Krnl}{Sh/Br} + \underset{(2.171)}{0.0838} \cdot \underset{Prot}{Wht} + \underset{(1.78)}{0.0006} \cdot \underset{FN}{Wht} , \qquad R^2 = 0.82 \tag{A.1}$$

where *Wht Ash* is wheat ash content, *Vit Krnl* is vitreous kernel count, *Sh/Br Krnl* is shrunken and broken kernel count, *Wht Prot* is wheat protein content, and *Wht FN* is wheat falling number value. Among the 10 categories, approximately 23 percent of the observations were 13 percent protein or less, 29 percent were between 13 and 14 percent protein, 32 percent were between 14 and 15 percent protein, and 16 percent exceeded 15 percent protein (Table A1).

Table A.1. Wheat characteristics for 10 elevator bins

Wheat Attribute	Wheat Categories (Protein)									
	<11.5%	<12.5%	<13.0%	<13.5%	<14%	<14.5%	<15.0%	<15.5%	<16.5%	16.5%<
Protein	10.99	12.10	12.80	13.32	13.83	14.32	14.79	15.30	15.83	16.84
Falling Number	381.79	386.45	385.06	377.40	382.83	394.68	397.90	405.21	374.81	388.60
Dockage	2.11	1.52	2.08	1.35	1.56	1.59	2.13	1.16	1.80	0.72
Test Weight	61.77	61.16	60.99	61.07	60.44	60.14	60.21	59.76	60.56	58.98
Kernel Weight	32.87	32.74	33.54	32.90	33.41	33.19	33.89	31.80	32.88	31.28
Vitreous Kernel	66.29	78.24	81.00	89.93	88.16	91.17	92.21	95.51	97.13	97.80
Shrunken/ Broken	1.53	1.52	1.22	1.39	1.02	1.03	0.99	1.16	0.88	0.98
Foreign Material	0.07	0.07	0.05	0.03	0.04	0.09	0.03	0.03	0.06	0.00
Damage	0.29	0.28	0.60	0.27	0.87	0.76	0.49	0.78	0.22	0.04
Defects	1.89	1.86	1.87	1.69	1.92	1.88	1.51	1.97	1.16	1.02
Wheat Ash	1.55	1.40	1.53	1.68	1.59	1.61	1.53	1.34	1.62	1.81
Distribution	0.04	0.10	0.09	0.12	0.17	0.16	0.16	0.10	0.05	0.02

Adapted from Wheat Supply Chain Spreadsheet Model, Wheat Data Sheet (B3:V17), page 1 Appendix B.

In addition to protein considerations, millers purchase wheat on the basis of grade. Each of the 10 protein categories were divided into subgroups representing U.S. Number 1 and 2 official grades. Within each of the 10 categories, the majority of all observations were classified as U.S. Number 1. The associated mean values for wheat characteristics are presented for the 20 groups in Table A.2.

Wheat characteristics for 20 lots available to mills

Wheat Categories (Protein and Grade)

Wheat Attribute	16.5% < US 2
Falling Number	16.6
	367
Test Weight	0.1
	57.8
Kernel Weight	30.1
Vitreous Kernel	98.0
Shrunken /Broken	
Foreign Material	1.3
	0.0
	0.2
Wheat Ash	1.5
	1.7
Cumm. Dist.	0.2

Adapted from Wheat Supply Chain Spreadsheet Model, Wheat Data Sheet (B20:V36), page 1, Appendix B.

0

The price of wheat is discovered on established grain commodity exchanges (e.g., Minneapolis, Kansas City, and Chicago) and reflects what a seller would receive at these markets. However, sellers must transport their wheat to these markets. Therefore, the grain exchange price reflects a "landed" price. A local price can be established by subtracting a seller's costs associated with transporting grain to these markets from the exchange price. Elevators offer farmers a local price that reflects, among other things, the elevator's costs of transporting grain to the commodity exchange. The difference between one elevator's local price and the cash price in a major commodity market (i.e., Minneapolis) is often referred to as the cash basis.

Prices usually are based on wheat containing 13, 14, or 15 percent protein. The price for 13 and 15 percent protein wheats usually are at a discount and premium, respectively, to 14 percent protein wheat. Wheat prices and protein adjustments vary independently over time, reflecting supply and demand considerations. The basis also can vary over time. Two main causes of basis variation include transportation and competition with other elevators and/or local demand for wheat (e.g., for feed).

The wheat price, protein adjustments, and basis used in the model are depicted in Table 4.3. The following data from the week of June 12, 1995, were used in the model: Minneapolis Grain Exchange cash price of $4.67 per bushel for 14 percent protein, $0.30 per bushel premium for 15 percent protein, $0.15 per bushel discount for 13 percent protein, and a cash price from Rugby, North Dakota, of $3.84 per bushel (*Agweek*, 12 June 1995). In practice, elevators calculate adjustments for protein in increments of less than 1 percent. Adjustments in the model were made for every 0.20 percent increment in protein content and were extended to cover the entire protein range present in the wheat characteristic data set. Basis was $0.83 per bushel below the Minneapolis price and was found by subtracting the Rugby cash price from the Minneapolis market price.

Table A.3. Wheat price and protein adjustments used in model

Description	Protein Content (%)	Value ($/bu)
Minneapolis Cash Price	14.0	$4.67
Local Elevator Basis		($0.83)
Local Price		$3.84
Protein Adjustments	9.0	($0.75)
	10.0	($0.60)
	10.2	($0.57)
	10.4	($0.54)
	10.6	($0.51)
	10.8	($0.48)
	11.0	($0.45)
	11.2	($0.42)
	11.4	($0.39)
	11.6	($0.36)
	11.8	($0.33)
	12.0	($0.30)
	12.2	($0.27)
	12.4	($0.24)
	12.6	($0.21)
	12.8	($0.18)
	13.0	($0.15)
	13.2	($0.12)
	13.4	($0.09)
	13.6	($0.06)
	13.8	($0.03)
	14.0	$0.00
	14.2	$0.06
	14.4	$0.12
	14.6	$0.18
	14.8	$0.24
	15.0	$0.30
	15.2	$0.36
	15.4	$0.42
	15.6	$0.48
	15.8	$0.54
	16.0	$0.60
	16.2	$0.66
	16.4	$0.72
	16.6	$0.78
	16.8	$0.84
	17.0	$0.90

Adapted from Wheat Supply Chain Spreadsheet Model, Wheat Data Sheet (B39:E82), page 2, Appendix B.

Elevator Module

Country elevators are those that procure wheat from farmers, provide storage and other value-adding services, and blend and consolidate wheat to meet buyer quality requirements. They do not physically alter, manufacture, or process wheat into some other product. Their purpose is purely logistical and service orientated.

In the elevation module of the model, decision variables, exogenous variables, intermediate variables, and performance measures were used. This section of the model refers to the elevator sheet, which was reproduced as pages 3 through 8 in Appendix B.

Decision Variables

Decision variables represent the first section of this module. Variables were defined for elevator utilization, operating characteristics, and operating costs. A portion of the spreadsheet model where these decision variables exist was reproduced in Figure A.1.

The first decision variables concern utilization. Elevator utilization was measured on a percent of full utilization basis (Figure A.1, row 7). Because utilization impacts the elevator's per unit cost of operation, the portion of each operating cost category that varies with utilization was specified (Figure A.1, rows 8 to 15). These data were not available and were estimated to illustrate the capability of the model.

	B	C	D	E
3			< 11.5	
4	**Decision Variables:**			
5				
6	**Utilization**			
7	Current Utilization (%)	90		
8	Labor (% Variable)	60		
9	Utilities (% Variable)	75		
10	Maint. & Repair (% Variable)	25		
11	Sampling / Testing (% Variable)	10		
12	Depreciation (% Variable)	5		
13	Interest (% Variable)	10		
14	Admin / Misc. (% Variable)	20		
15	Cleaning (% Variable)	50		
16				
17	**Operating Characteristics**			
18	Turnover (volume)	2.27		
19	Capacity (bu)	600,000		
20	Operating Days	307		
21	Cleaner Capacity (bu/hr)	1,000		
22	Cleaning Cost (%, Vendor)	80		
23	Cleaning Cost (%, Customer)	20		
24	Inventory Carrying Cost (%)	25		
25	Outbound Shipment Size (100 tons)	26		
26				
27	**Operating Costs (100% Utilization)**			
28	Labor ($/bu)	$0.034		
29	Utilities ($/bu)	$0.006		
30	Maint. & Repair ($/bu)	$0.003		
31	Sampling / Testing ($/bu)	$0.001		
32	Depreciation ($/bu)	$0.010		
33	Interest ($/bu)	$0.008		
34	Administration / Misc. ($/bu)	$0.030		
35	Cleaner Cost ($/hour)	$5.05		
36	Difference between Buy/Sell Price ($/bu)		($0.15)	($0.15)

Figure A.1. Portion of the model reflecting elevator decision variables.

Adapted from Wheat Supply Chain Spreadsheet Model, Elevator Sheet (B2:W36), page 3, Appendix B.

The second group of decision variables relates to operating characteristics. First, the firm's capacity turnover ratio was specified (Figure A.1, row 18). The average turnover ratio for elevators in North Dakota, 2.27, was used (Andreson, Young, and Vachal, 1994). Second, elevator storage capacity was determined (Figure A.1, row 19). A capacity of 600,000 bushels was used in the model; mean capacity from the 1993-94 Annual North Dakota Elevator Marketing Report was 589,412 bushels (Andreson, Young, and Vachal, 1994). Third, 307 days was used as the value for annual operating days, based on a six-day work week (Figure A.1, row 20). Fourth, cleaner capacity was specified (Figure A.1, row 21). A value of 1,000 bushels per hour was used (Johnson, Scherping, and Wilson, 1992). The sixth and seventh variables specified were percent of cleaner cost passed on to the vendor (farmer) and the customer, respectively (Figure A.1, rows 22 and 23). Data were unavailable for this variable, and a rough estimate of 80 percent to the vendor and 20 percent to the customer was included to reflect the model's capability. Next, an estimate for inventory carrying cost was made (Figure A.1, row 24). It was specified as 25 percent of the firm's investment in inventory. Finally, the elevator's outbound shipment size was specified (Figure A.1, 25). In the elevator industry, transportation issues prevail over other concerns in determining lot size. When lot size is known, average inventory can be found by dividing *Q*, lot size, by 2 (Bierman, Bonini, and Hausman, 1991). In this model, a lot size of 85,000 bushels, approximate volume of a 26 railcar unit train, was used, yielding an average inventory of 42,500 bushels.

The third group of decision variables represents operating costs for the elevator. Within the context of this model, the modeler controls and determines the values for these variables. Data for the labor, utilities, maintenance and repair, sampling or testing, depreciation, interest, and administration and miscellaneous variables were obtained from elevator budgets prepared by Bangsund, Sell, and Leistritz (1994) (Figure A.1, rows 28 to 34). These data are representative of actual operating conditions that reflect unknown levels of utilization, but for the model were assumed to represent 100 percent utilization in the firm. Similarly, the hourly cleaner cost value, taken from Johnson, Scherping, and Wilson (1992), was assumed to reflect 100 percent utilization (Figure A.1, row 35). The final decision variable in this section concerns gross margin (Figure A.1, row 36). An elevator offers to buy grain from farmers at a discount to what it can ultimately sell the grain for. This discount was referred to in this model as gross margin and was assumed to be $0.15 per bushel for each of the 10 protein categories.

Exogenous Variables

Exogenous variables represent the second section of this module. Variables were defined for protein adjustments, sales price, and logistics characteristics. A portion of the spreadsheet model where these exogenous variables exist was reproduced in Figure A.2.

The protein adjustment variable reflects the protein premium or discount applicable to each of the 10 wheat categories (Figure A.2, row 41). The sales price variable reflects both the grain price and the applicable protein adjustment for each of the 10 wheat categories (Figure A.2, row 44). The elevator's logistics characteristics were represented by variables for the transportation rate per shipment (Figure A.2, row 47), the transportation provider's cost of service (Figure A.2, row 48), and transit time for the shipment (Figure A.2, row 49). The transportation rate was based on the tariff for a 26 railcar shipment of wheat from Rugby, North Dakota, to Grand Forks, North Dakota. The transportation provider's cost of service was estimated using the Uniform Rail Costing System (URCS) developed by the Interstate Commerce Commission. Transit time was estimated at three days for the shipment.

	B	C	D	E
38	**Exogenous Variables:**			
39				
40	**Protein Adjustment**			
41	Adjustment ($/bu)		($0.48)	($0.48)
42				
43	**Sales Price**			
44	Price ($/bu)		$3.36	$3.36
45				
46	**Logistics Characteristics**			
47	Rate ($/Shipment)	$31,356		
48	URCS ($/Shipment)	$8,854		
49	Transit Time (Days)	3		

Figure A.2. Portion of the model reflecting elevator exogenous variables.

Adapted from Wheat Supply Chain Spreadsheet Model, Elevator Sheet (B38:W49), page 5, Appendix B.

Intermediate Variables

Intermediate variables represent the third section of this module. Variables were defined for procurement cost, operating cost, cleaning cost, inventory cost, and total activity cost. A portion of the spreadsheet model where these intermediate variables exist was reproduced in Figure A.3.

The procurement cost variable was calculated by subtracting the gross margin decision variable from the exogenous variable for sales price (Figure A.3, row 54). This variable represents the amount the elevator pays for wheat.

	B	C	D	E
51	**Intermediate Variables:**			
52				
53	**Procurement Cost**			
54	Price ($/bu)		$3.20	$3.20
55				
56	**Operating Cost**			
57	Labor ($/bu)	1.0444	$0.035	$0.035
58	Utilities ($/bu)	1.0278	$0.006	$0.006
59	Maint. & Repair ($/bu)	1.0833	$0.003	$0.003
60	Sampling / Testing ($/bu)	1.1000	$0.001	$0.001
61	Depreciation ($/bu)	1.1056	$0.011	$0.011
62	Interest ($/bu)	1.1000	$0.009	$0.009
63	Administration / Misc. ($/bu)	1.0889	$0.033	$0.033
64	*Operating Cost ($/bu)*		$0.098	$0.098
65				
66	**Cleaning Cost**			
67	*Cleaning Cost ($/bu)*	1.0556	$0.009	$0.009
68				
69	**Inventory Cost**			
70	Per Unit Investment		$3.31	$3.31
71	Average Inventory (bu)		1,768	1,768
72	Annual Inventory Cost ($)		$1,462	$1,462
73	*Inventory Cost ($/bu)*		$0.0256	$0.0256
74				
75	**Total Activity Cost**			
76	*Cost ($/bu) excluding procurement*		$0.133	$0.133
77	*Cost ($/bu)*		$3.334	$3.334

Figure A.3. Portion of the model reflecting elevator intermediate variables.

Adapted from Wheat Supply Chain Spreadsheet Model, Elevator Sheet (B51:W77), page 5, Appendix B.

The operating cost variables were calculated in two steps. First, a utilization factor was determined (Figure A.3, column C, rows 57 through 63) as

$$UF = \frac{(1 - C\%)}{(U\%)} + C\% \quad , \tag{A.2}$$

where *UF* is utilization factor, *C%* is percent of cost variable with utilization, and *U%* is utilization as percent of full. This factor was based on the current level of utilization and the proportion of each cost item that varies with utilization, which were both specified as decision variables. Second, this factor was multiplied by the operating cost assuming 100 percent utilization (Figure A.3, columns D and E, rows 57 through 63). As a result, operating cost values reflect the specified level of utilization. Finally, a variable was defined as the sum of these operating cost values (Figure A.3, row 64).

Cleaning cost represents the third intermediate variable (Figure A.3, row 67). In addition to hourly cost and capacity, the beginning level of wheat dockage and desired ending level of dockage were required. Beginning dockage level was obtained from the wheat characteristics data. Ending dockage was specified in the flour mill portion of the model which will be discussed later. Cleaning cost was estimated with the following equation:

$$CC = \frac{Cost/Hour}{[\,(0.7449 - 0.1019 \cdot BD + 0.3882 \cdot ED) \cdot CCap/Hour\,]} \quad , \tag{A.3}$$

where *CC* is cleaning cost, *BD* is beginning dockage level of wheat, *ED* is desired ending dockage level of wheat, and *CCap/Hour* is cleaner capacity per hour (Johnson, Scherping, and Wilson, 1992).

The fourth group of intermediate variables estimated in the elevation module dealt with inventory cost. Inventory cost per bushel (Figure A.3, row 73) was found by dividing annual inventory costs by the number of bushels shipped from each wheat category and was functionally defined as

$$IC = \frac{((PC + OC + CC) \cdot (WDist \cdot AI))}{(ECap \cdot TOV \cdot WDist)} \quad , \tag{A.4}$$

where *IC* is inventory cost, *PC* is procurement cost, *OC* is operating cost, *CC* is cleaning cost, *WDist* is the distribution of wheat samples, *AI* is average elevator inventory quantity, *ECap* is elevator capacity, and *TOV* is elevator turnover. Annual inventory cost was found by multiplying per unit inventory investment (*PC* + *OC* + *CC*) (Figure A.3, row 70) by average inventory of each wheat category (*WDist* × *AI*) (Figure A.3, rows 71). The number of bushels shipped of each wheat category was found by multiplying total elevator turnover by the distribution of wheat in each category.

The final group of intermediate variables in the elevation module concerned total activity cost. The first variable was the sum of the operating, cleaning, and inventory intermediate variables (Figure A.3, row 76). This variable excludes procurement and resembles value-added by the elevation activity. The second variable encompasses all four of the intermediate cost variables: procurement, operating, cleaning, and inventory (Figure A.3, row 77).

Performance Measures

Performance measures represent the fourth section of this module. Elevator margin was used as the performance measure in the elevation module (Figure A.4, row 82). It was found by subtracting the intermediate variable for total activity cost including procurement from the sales revenue exogenous variable for each wheat category.

	B	C	D	E
79	**Performance Measures:**			
80				
81	**Margin**			
82	*Elevator Margin ($/bu)*		$0.024	$0.024

Figure A.4. Portion of the model reflecting elevator performance measures.

Adapted from Wheat Supply Chain Spreadsheet Model, Elevator Sheet (B79:W82), page 7, Appendix B.

Flour Milling Module

Milling is a process that alters wheat into two distinct products, flour and mill feeds. Although mill feeds have a value, it is substantially lower than that of flour. Therefore, mills have an incentive to maximize the extraction of flour, minimizing the production of mill feeds. In addition, since flour is usually manufactured to order, millers store wheat as opposed to flour (Harwood, Leath, and Heid, 1989). The quality characteristics of flour are a function of the milled wheat's characteristics.

This module of the spreadsheet model reflects the flour milling activity and is made up of four components: decision, exogenous, intermediate, and performance measures variables. Building upon the elevation module, each wheat category was further separated by grade, either U.S. Number 1 or 2. This was discussed in the first module of the model, wheat characteristics. This section of the model refers to the flour mill sheet that was reproduced as pages 9 through 16 in Appendix B.

Decision Variables

Decision variables represent the first section of this module. Variables were defined for mill utilization, operating characteristics, operating costs, and wheat procurement specifications. A portion of the spreadsheet model where these decision variables exist was reproduced in Figure A.5.

The first decision variables concern utilization. Mill utilization was measured on a percent of full utilization basis (Figure A.5, row 8). Because utilization impacts the flour mill's per unit cost of operation, the portion of each operating cost category that varies with utilization was specified (Figure A.5, rows 9 through 16). These data were not available and were estimated solely to illustrate the capability of the model.

The second group of decision variables relates to mill operating characteristics. Variables represent inventory turnover, annual production, operating days, inventory carrying cost, and in-transit inventory carrying cost (Figure A.5, rows 19 through 24). An inventory turnover value of 46.3 times per year was obtained from a survey of flour millers by the Institute of Agribusiness at

Santa Clara University (Starbird and Agrawal, 1994). Second, an annual production value of 1.8 million hundredweights (cwt) of flour was calculated from data on white bread-producing firms in the 1992 Census of Manufactures (U.S. Department of Commerce). A value of 307 days was used for annual operating days based on a six-day work week. Fourth, cleaner capacity was valued at 1,000 bushels per hour (Johnson, Scherping, and Wilson, 1992). The sixth variable, inventory carrying cost, was valued as 25 percent of the firm's investment in inventory. Finally, a value of 20 percent was used for the in-transit inventory carrying cost.

The third group of decision variables represents operating costs for the flour mill. Data for the labor, utilities, maintenance and repair, sampling or testing, depreciation, interest, and administration and miscellaneous variables were obtained from flour mill budgets prepared by Bangsund, Sell, and Leistritz (1994) (Figure A.5, rows 27 through 33). These data are representative of actual operating conditions reflecting unknown levels of utilization, but for the model were assumed to represent 100 percent utilization in the firm. The flour mill's hourly cleaner cost was assumed to be greater than that of the elevator and was valued at $6 per hour, reflecting 100 percent utilization (Figure A.5, row 34).

The final group of decision variables concerns wheat procurement specifications. Two variables were included: the level of dockage in wheat procured and the level of dockage in wheat prior to milling (Figure A.5, rows 37 and 38). The values used imply the elevation activity cleaned wheat from the wheat characteristic level to 0.1 percent and that the milling activity further cleaned the wheat to a level of 0.001 percent.

	B	C	D	E
3			< 11.5	
4			US 1	US 2
5	**Decision Variables:**			
6				
7	**Utilization**			
8	Current Utilization (%)	90		
9	Labor (% Variable)	25		
10	Utilities (% Variable)	75		
11	Maint. & Repair (% Variable)	25		
12	Sampling / Testing (% Variable)	10		
13	Depreciation (% Variable)	10		
14	Interest (% Variable)	10		
15	Admin / Misc. (% Variable)	10		
16	Wheat Cleaning (% Variable)	25		
17				
18	**Operating Characteristics**			
19	Finished Goods Inventory Turnover (Times/Yr)	46.30		
20	Annual Production (cwt)	1,800,000		
21	Operating Days	307		
22	Cleaner Capacity (bu/hour)	1,000		
23	Inventory Carrying Cost (%)	25		
24	Intransit Inventory Carrying Cost (%)	20		
25				
26	**Operating Costs (100% Utilization)**			
27	Labor ($/cwt)	$0.86		
28	Utilities ($/cwt)	$0.25		
29	Maintenance & Repair ($/cwt)	$0.25		
30	Sampling / Testing ($/cwt)	$0.00		
31	Depreciation ($/cwt)	$0.42		
32	Interest ($/cwt)	$0.20		
33	Administration / Misc ($/cwt)	$0.47		
34	Cleaning Cost ($/hour)	$6.00		
35				
36	**Wheat Product Specifications**			
37	Dockage Procured (%)		0.1	0.1
38	Dockage Prior to Milling (%)		0.001	0.001

Figure A.5. Portion of the model reflecting flour mill decision variables.

Adapted from Wheat Supply Chain Spreadsheet Model, Flour Mill Sheet (B3:W38), page 9, Appendix B.

Exogenous Variables

Exogenous variables represent the second section of this module. Variables were defined for the physical characteristics of milled wheat, mill efficiency, physical characteristics of flour sold, purchase cost, and sales revenue. A portion of the spreadsheet model where these exogenous variables exist was reproduced in Figure A.6.

The first group of exogenous variables concerns physical characteristics of the milled wheat. A technical relationship exists between wheat and flour characteristics. This relationship represents important linkages between members of the wheat supply chain. Linkages were estimated by regression from additional data included in the wheat quality data set previously discussed. In the data set, flour characteristics were aggregated and averaged by crop reporting districts, resulting in 22 observations. Equations 4.6 through 4.10 reflect the relationship between various wheat characteristics and the protein, falling number, amylograph peak viscosity, flour ash, and wet gluten characteristics of milled wheat (Figure A.6, rows 43 through 47).

$$\begin{array}{c} \textit{Flour} \\ \textit{Protein} \end{array} = \underset{(1.563)}{1.8019} + \underset{(9.618)}{0.7919} \cdot \begin{array}{c} \textit{Wheat} \\ \textit{Protein} \end{array} . \qquad R^2 = 0.822 \tag{A.5}$$

$$\begin{array}{c} \textit{Flour Falling} \\ \textit{Number} \end{array} = \underset{(2.619)}{93.51} + \underset{(7.927)}{0.7689} \cdot \begin{array}{c} \textit{Wheat Falling} \\ \textit{Number} \end{array} . \qquad R^2 = 0.7586 \tag{A.6}$$

$$\begin{array}{c} \textit{Amylograph} \\ \textit{Peak Viscosity} \end{array} = \underset{(-4.526)}{-3060.3167} + \underset{(7.83)}{14.3858} \cdot \begin{array}{c} \textit{Wheat} \\ \textit{Falling Number} \end{array} . \qquad R^2 = 0.754 \tag{A.7}$$

	B	C	D	E
40	**Exogenous Variables:**			
41				
42	**Milled Wheat Characteristics**			
43	Protein		10.44	10.83
44	Falling Number		386	395
45	Amylograph Peak Viscosity		2407	2579
46	Flour Ash		0.3932	0.3881
47	Wet Gluten		30.63	31.40
48				
49	**Mill Efficiency**			
50	Extraction Rate		71.68	71.21
51	Bushels Wheat = 1 cwt Flour		2.26	2.27
52				
53	**Characteristics of Flour Sold**			
54	Added Protein		2.055	1.672
55	Net Flour Protein		12.5	12.5
56				
57	Proportions:			
58	Milled Wheat		0.969	0.975
59	Wheat Gluten (65% protein)		0.031	0.025
60				
61	Falling Number		386	395
62	Amylograph Peak Viscosity		2411	2578
63	Flour Ash		0.3935	0.3885
64	Wet Gluten		30.81	31.53
65				
66	**Purchase Cost**			
67	Wheat Price ($/bu wheat)		$3.36	$3.36
68	Gluten Price ($/cwt gluten)		38	38
69	*Purchase Cost ($/cwt flour)*		$8.5191	$8.3807
70				
71	**Sales Price**			
72	Base Flour Pirce ($/cwt)	$14.00		
73	Flour Protein Adjustment ($/cwt)		-0.34592	-0.34592
74	*Price Received ($/cwt flour)*		$13.654	$13.654

Figure A.6. Portion of the model reflecting flour mill exogenous variables.

Adapted from Wheat Supply Chain Spreadsheet Model, Flour Mill Sheet (B40:W74), page 11, Appendix B.

$$\begin{array}{l} \textit{Flour Ash} = 0.1297 + 0.1704 \cdot \textit{Wheat Ash} \\ R^2 = 0.51 \quad (2.12) \quad (4.563) \end{array} \qquad (A.8)$$

$$\begin{array}{l} \textit{Wet Glutten} = 4.1963 + 2.5871 \cdot \begin{matrix}\textit{Wheat}\\ \textit{Protein}\end{matrix} - 0.01 \cdot \begin{matrix}\textit{Wheat}\\ \textit{Falling Number}\end{matrix} \\ R^2 = 0.763 \quad (0.768) \quad (7.086) \quad (-2.511) \end{array} \qquad (A.9)$$

The second group of exogenous variables reflects mill efficiency. A measure of mill efficiency is extraction rate, which represents the percent flour produced from a quantity of wheat. In addition to flour, milling wheat produces mill feeds. Certain characteristics in wheat impact a miller's extraction rate, including test weight, vitreous kernel count, and protein level (Moore, 1995). From the wheat characteristics data set, Equation A.11 was estimated and used to determine extraction rate (n=22) (Figure A.6, row 50). Extraction rate data from Moore et al. (1995) are consistently lower than industry results presented by Harwood, Leath, and Heid (1989). There are two reasons for this: the laboratory mill used is less efficient at extraction than commercial grade mills, and milling small samples results in lower extractions than when large quantities of wheat are milled. This is not a concern since the interest is in relative extraction performance among different lots of wheat. The next variable simply converts from percent of flour in wheat to the number of bushels in one hundred pounds of flour (Figure A.6, row 51).

$$\begin{array}{l} \begin{matrix}\textit{Extraction}\\ \textit{Rate}\end{matrix} = 90.6211 - 0.1173 \cdot \begin{matrix}\textit{Test}\\ \textit{Weight}\end{matrix} + 0.0132 \cdot \begin{matrix}\textit{Vitreous}\\ \textit{Kernel \%}\end{matrix} - 1.1505 \cdot \begin{matrix}\textit{Wheat}\\ \textit{Protein}\end{matrix} \\ R^2 = 0.498 \quad (8.894) \quad (-0.877) \quad (0.733) \quad (-3.806) \end{array} \qquad (A.10)$$

The third group of exogenous variables represents characteristics of the flour sold. In addition to milled wheat, other ingredients can be included to produce a flour consistent with buyer specifications. Primarily, wheat gluten which is 65 percent protein can be added to milled wheat to produce a higher protein flour. This can be done either by the baker or during the milling process. In the spreadsheet model, a desired flour protein level was specified in the bakery activity of the wheat supply chain, which will be discussed later. The difference between protein from milled wheat and the customer specification is the amount of protein needed from wheat gluten (Figure A.6, row 54). The second set of variables represents the proportion of milled wheat and wheat gluten in one hundred pounds of flour (Figure A.6, rows 58 and 59). The third set of variables recalculates the falling number, amylograph peak viscosity, flour ash, and wet gluten attributes for the flour which now contains both milled wheat and gluten (Figure A.6, rows 61 through 64). Equations 4.7 through 4.10 are used again, reflecting the proportions and attributes of milled wheat and wheat gluten.

The fourth group of exogenous variables represents purchasing costs. The mill's wheat purchase cost was estimated from the Minneapolis Grain Exchange price adjusted for protein premiums and discounts and equates to the elevator's sales revenue (Figure A.6, row 67). These values were discussed previously in both the elevation module and the initial characteristics module. In addition to wheat, mills may procure wheat gluten. The price of gluten was estimated from the U.S. Department of Commerce's (1995) 1992 Census of Manufactures at $38 per one-hundred pounds (cwt) (Figure A.6, row 68). The purchase cost variable was calculated as the sum of the milled wheat and wheat gluten components in one-hundred pounds of flour (Figure A.6, row 69).

The fifth set of exogenous variables in the milling module deals with sales price. Like wheat, flours are priced with premiums and discounts for protein. The amount of these adjustments is equivalent for wheat and flour, recognizing that approximately 0.5 percent protein is lost through milling. In other words, the protein adjustment for 12.5 percent wheat and 12 percent flour would be approximately the same. In addition, the adjustment has to be multiplied by the extraction rate to reflect the premium or discount on a hundredweight (cwt) of flour basis. An average extraction rate for all wheat categories was used because price quotes are often made prior to any milling that takes place, so exact extraction rates are unknown. In the model, sales price was simply a base flour price, taken from industry sources, adjusted to reflect protein premiums and discounts (Figure A.6, row 72 through 74).

Intermediate Variables

Intermediate variables represent the third section of this module. Variables were defined for flour mill operating cost, cleaning cost, inventory, procurement, and total activity cost. A portion of the module where these variables were calculated has been reproduced in Figure A.7.

The operating cost variables were calculated in two steps. First, a utilization factor was determined (Figure A.7, column C, rows 79 through 85):

$$UF = \frac{(1 - C\%)}{(U\%)} + C\% \quad , \tag{A.11}$$

where UF is utilization factor, $C\%$ is percent of cost variable with utilization, and $U\%$ is utilization as percent of full. This factor is based on the current level of utilization and the proportion of each cost item that varies with utilization, both of which were specified as decision variables. Second, this factor was multiplied by the operating cost assuming 100 percent utilization (Figure A.7, columns D and E, rows 79 through 85). As a result, operating cost values reflect the specified level of utilization. Finally, a variable was defined as the sum of these operating cost values (Figure A.7, row 86).

Cleaning cost represents the second intermediate variable (Figure A.7, row 89). It was calculated similarly as in the elevation module.

	B	C	D	E
76	**Intermediate Variables:**			
77				
78	**Operating Cost**			
79	Labor ($/cwt)	1.0833	$0.93	$0.93
80	Utilities ($/cwt)	1.0278	$0.26	$0.26
81	Maintenance & Repair ($/cwt)	1.0833	$0.27	$0.27
82	Sampling / Testing ($/cwt)	1.1000	$0.00	$0.00
83	Depreciation ($/cwt)	1.1000	$0.46	$0.46
84	Interest ($/cwt)	1.1000	$0.22	$0.22
85	Administration / Misc ($/cwt)	1.1000	$0.52	$0.52
86	*Operating Cost ($/cwt flour)*	1.0833	$2.66	$2.66
87				
88	**Cleaning Cost**			
89	*Wheat Cleaning Cost ($/cwt flour)*		$0.0194	$0.0196
90				
91	**Inventory**			
92	Daily Flour Production (cwt)	5,863		
93				
94	Wheat Inventory Cost:			
95	Daily Requirements (bu)		12,841	12,968
96	Required Per Time Period (bu)		385,223	389,048
97	Shipments Received Per Time Period		5	5
98	Days Between Shipments		6.6	6.5
99	Average Wheat Inventory (bu)		42,105	42,003
100	Annual Inventory Cost ($)		$35,349	$35,263
101	Wheat Inventory Cost ($/bu)		$0.0090	$0.0089
102	*Wheat Inventory Cost ($/cwt flour)*		$0.0196	$0.0196
103				
104	Flour Inventory:			
105	Days Production on Hand	6.63		
106	Average Flour Inventory (cwt flour)	38,877		
107	Per Unit Investment ($/cwt)		$11.217	$11.078
108	Annual Inventory Cost ($)		$109,016	$107,672
109	*Flour Inventory Cost ($/cwt)*		$0.061	$0.060
110				
111	*Total Inventory Cost ($/cwt)*		$0.080	$0.079
112				
113	**Procurement Costs**			
114	Inbound Material Movement Costs:			
115	Intransit Inventory Cost ($/bu wheat)		$0.0056	$0.0056
116	Inbound Transit Cost ($/bu wheat)		$0.372	$0.372
117	*Inbound Material Movement Cost ($/cwt)*		$0.8280	$0.8362
118				
119	*Total Procurement Cost ($/cwt)*		$9.3471	$9.2169
120				
121	**Total Activity Cost**			
122	*Cost ($/cwt) excluding procurement*		$2.7580	$2.7574
123	*Cost ($/cwt)*		$12.105	$11.974

Figure A.7. Portion of the model reflecting flour mill intermediate variables.

Adapted from Wheat Supply Chain Spreadsheet Model, Flour Mill Sheet (B76:W123), page 13, Appendix B.

The third group of intermediate variables was associated with inventory. The first variable defined, daily flour production, was found by dividing annual production by annual operating days (Figure A.7, row 92). Next, eight variables were defined in relation to wheat inventory. These were followed by five variables defined for flour inventory. Finally, a variable was defined that summarized the wheat and flour inventory values.

To determine wheat inventory, daily wheat requirements were first estimated from daily flour production and the extraction rates (Figure A.7, row 95), followed by a determination of wheat requirements for the time period (the time period will be discussed with the summary module) (Figure A.7, row 96). Next, the number of shipments received during the time period and the number of days between shipments were determined (Figure A.7, rows 97 and 98). Fifth, average inventory was calculated as one-half of the average shipment, taking into account the wheat's test weight (Figure A.7, row 99). The total inventory cost variable was calculated by multiplying average inventory, procurement cost, and carrying cost (Figure A.7, row 100). The per bushel wheat inventory cost variable was calculated by dividing total inventory cost by total wheat requirements, which is the product of daily wheat requirements and annual operating days (Figure A.7, row 101). The final wheat inventory intermediate variable calculated was a conversion of the wheat inventory cost from per bushel to per hundredweight of flour (Figure A.7, row 102).

The first variable for determining flour inventory, the number of days' production on hand, was determined by dividing annual operating days by the turnover of finished goods inventory, both decision variables (Figure A.7, row 105). Next, daily flour production was multiplied by the number of days on hand to determine average flour inventory (Figure A.7, row 106). The third variable, per unit investment in inventory, was the sum of procurement, operating, wheat cleaning, and wheat inventory costs on a per hundredweight of flour basis (Figure A.7, row 107). Multiplying the average inventory quantity by the per unit investment yielded total flour inventory cost (Figure A.7, row 108). The fifth and final flour inventory variable, the per hundredweight of flour inventory cost, was found by dividing total flour inventory cost by annual flour production for the mill (Figure A.7, row 109).

The final inventory variable is a summary of wheat and flour inventory costs. It was defined as the sum of the per hundredweight of flour inventory costs for wheat and flour.

The fourth group of intermediate variables in the milling module represents procurement costs. These costs were associated with the inbound movement and acquisition of wheat for the milling activity. In addition to the purchasing cost previously specified, variables for inbound in-transit inventory and transportation were defined. According to Coyle, Bardi, and Langley (1992), in-transit inventory cost is a function of the percentage of time inventory is in-transit per cycle period, the quantity in-transit, the per unit value of goods in-transit, and the carrying cost of inventory in-transit. Therefore, the cost of carrying in-transit inventory in the model was estimated as

$$Intransit\ IC = \frac{t_m}{t} \cdot Q \cdot V \cdot \left(\frac{AITCC}{360} \cdot TP \right)$$
$$where \quad t = \frac{TP \cdot Q}{R} \quad , \tag{A.12}$$

Intransit IC is in-transit inventory cost, t_m is transit time, *Q* is the order or shipment quantity, *V* is the inventory's per unit value, *AITCC* is annual in-transit inventory carrying cost, *TP* is time period in days, and *R* is requirements for time period (Coyle, Bardi, and Langley, 1992). In-transit inventory cost was divided by the requirements for the time period to determine per unit in-transit inventory cost (Figure A.7, row 115).

Although the transportation rate for wheat is constant, the volume of wheat, or bushels, in a particular shipment is influenced by the wheat's test weight. Therefore, the inbound transportation cost, on a per bushel basis (Figure A.7, row 116), was estimated as

$$Bu = RC \cdot \frac{200{,}000}{TW} \quad , \tag{A.13}$$

where *Bu* is bushels shipped, *RC* is number of 100 ton rail cars transported, and *TW* is test weight of wheat shipped.

Inbound procurement costs were summarized in two steps. First, the in-transit inventory and inbound transit costs were summed and converted to a per hundredweight of flour basis (Figure A.7, row 117). Second, the wheat purchase cost and associated inbound costs were summed to determine total procurement cost (Figure A.7, row 119).

The final group of intermediate variables in the flour milling module define total activity cost. The first variable, the sum of the operating, cleaning, and inventory intermediate variables (Figure A.7, row 122), excludes procurement and resembles value added by the milling activity. The second variable encompasses all four of the intermediate cost variables: procurement, operating, cleaning, and inventory (Figure A.7, row 123).

Performance Measures

Performance measures represent the fourth section of this module. Flour mill margin was used as the performance measure in the milling module (Figure A.8, row 128). It was found by subtracting the intermediate variable for total activity cost from the sales revenue exogenous variable for each wheat category.

	B	C	D	E
125	**Performance Measures:**			
126				
127	**Marg in**			
128	*Mill Margin ($/cwt)*		$1.549	$1.680

Figure A.8. Portion of the model reflecting flour mill performance measures.

Adapted from Wheat Supply Chain Spreadsheet Model, Flour Mill Sheet (B125:W128), page 15, Appendix B.

Bakery Module

Bakeries produce an assortment of flour-derived products that are distributed to ultimate end consumers. The bakery industry is comprised of three basic segments: bread, cake, and related products; cookies and crackers; and frozen bakery products. Considerable differences in the flour and other ingredient requirements exist among these segments. This model focused on the bread, cake, and other related products segment. Within this segment, bread products dominate in number of establishments, volume shipped, and value of product shipments (U.S. Dept. of Commerce, 1995).

Bread baking has become increasingly automated in recent years. This has diminished the ability of firms to respond to variations in the quality attributes of ingredi ents, especially flour. As a result, the importance of conformance to technical specifications for ingredients has greatly increased.

The bakery contains the same variable categories as the previous modules: decision, exogenous, intermediate, and performance measures. This section of the model refers to the bakery sheet (reproduced as pages 17 through 24 in Appendix B).

Decision Variables

Decision variables represent the first section of this module. Variables were defined for bakery utilization, operating characteristics, operating costs, and flour procurement specifications. A portion of the spreadsheet model where these decision variables exist was reproduced in Figure A.9.

The first decision variable concerns bakery units. In the model, the basis of a bakery unit is weight; and one unit was defined as 1,000 pounds of bread (Figure A.9, row 6).

The second group of decision variables concerns utilization. Bakery utilization was measured on a percent of full utilization basis (Figure A.9, row 9). Because utilization impacts the bakery's per unit cost of operation, the portion of each operating cost category that varies with utilization was specified (Figure A.9, rows 10 through 17). These data were not available and were estimated solely to illustrate the capability of the model.

The third group of decision variables relates to bakery operating characteristics. Variables representing inventory turnover, throughput time, annual production, operating days, inventory carrying cost, in-transit inventory carrying cost, and shipment size were defined (Figure A.9, rows 20 through 26). An inventory turnover value of 101.8 times per year and a throughput time of 1.9 days were obtained from a survey of firms in the food industry by the Institute of Agribusiness at Santa Clara University (Starbird and Agrawal, 1994). Third, an annual production value of 13.6 million pounds of bread was calculated from data on white bread-producing firms in the 1992 Census of Manufactures (U.S. Department of Commerce). A value of 307 days was used for annual operating days based on a six-day work week. The sixth variable, inventory carrying cost, was valued as 25 percent of the firm's investment in inventory. Next, a value of 20 percent was used for the in-transit inventory carrying cost. Finally, inbound shipment size was defined in hundredweight (cwt) units; there are approximately 2,000 cwt in a single railcar which was the value used in the model.

The fourth group of decision variables represents operating costs for the bakery (Figure A.9, rows 29 through 38). Data for the labor requirements, labor cost, utility requirements, utility cost, maintenance and repair, and packaging and other materials variables were obtained from the 1992 Census of Manufactures data (U.S. Department of Commerce, 1995). Data for the sampling or testing, depreciation, interest, and administration and miscellaneous variables were unavailable, and values were not estimated. Data used were representative of actual operating conditions, reflecting unknown levels of utilization, but, for the model, were assumed to represent 100 percent utilization in the firm.

The final group of decision variables concerns flour procurement specifications. Variables were included for flour protein, falling number, absorption, peak time, and mixing tolerance (Figure A.9, rows 41 through 45). Only the flour protein specification was linked to both the elevation and flour milling activities. Flour product requirements issued by the bakery to the flour mill were taken from industry sources (Moore, 1995). The following specifications for each product characteristic were used: protein, 12.5 percent; falling number, 260 seconds or longer; farinograph for absorption, 63 seconds; and farinograph for mixing tolerance index, 25 B.U. (Brabender unit).

	B	C	D	E
3			< 11.5	
4			**US 1**	**US 2**
5	**Decision Variables:**			
6	Unit (in lbs)	1,000		
7				
8	**Utilization**			
9	Current Utilization (%)	90		
10	Labor (% Variable)	10		
11	Electricity (% Variable)	75		
12	Maint & Repair (% Variable)	10		
13	Sampling / Testing (% Variable)	40		
14	Depreciation (% Variable)	10		
15	Interest (% Variable)	10		
16	Admin / Misc (% Variable)	10		
17	Packaging & Other materials (% Variable)	85		
18				
19	**Operating Characteristics**			
20	Inventory Turnover (Times/Yr)	101.80		
21	Throughput Time (Days)	1.90		
22	Annual Production (lbs)	13,600,000		
23	Operating Days	307		
24	Inventory Carrying Cost (%)	25		
25	Intransit Inventory Carrying Cost (%)	20		
26	Inbound Shipment Size (cwt)	2,000		
27				
28	**Operating Costs (100% Utilization)**			
29	Labor ($/hr)	$12.90		
30	Labor (hr/Unit)		7.5	7.5
31	Electricity ($/kwh)	$0.0629		
32	Electricity (kwh/Unit)		209.1	209.1
33	Maint & Repair ($/lbs)	$12.20		
34	Sampling / Testing ($/lbs)	$0.00		
35	Depreciation ($/lbs)	$19.70		
36	Interest ($/lbs)	$0.00		
37	Administration / Misc. ($/lbs)	$102.30		
38	Other Materials ($/lbs)*	$153.00		
39	*includes other ingredients such as sweetners, yeasts, and fats and oils, and packaging and other materials			
40	**Flour Product Specifications**			
41	Protein	12.50		
42	Falling Number	260		
43	Farino: Absorption	63		
44	Farino: Peak Time	7		
45	Farino: Mixing Tolerance	25		

Figure A.9. Portion of the model reflecting bakery decision variables.

Adapted from Wheat Supply Chain Spreadsheet Model, Bakery Sheet (B3:W45), page 17, Appendix B.

Exogenous Variables

Exogenous variables represent the second section of this module. Variables were defined for the dough characteristics of the procured flour, bakery efficiency, procurement cost, sales revenue, and logistics characteristics. A portion of the spreadsheet model where these exogenous variables exist was reproduced in Figure A.10.

The first group of exogenous variables was dough characteristics. These variables represent technical relationships between flour characteristics and dough used to bake bread. Baking absorption reflects the amount of water required for optimal dough mixture. It is expressed as a percent of flour weight. Mixing tolerance index is a measure of protein "strength" and indicates the length of time a dough mixture will remain stable. Baking absorption and mixing tolerance index were the two dough characteristics included in this model (Figure A.10, rows 50 and 51). They were estimated by regression equations developed from the wheat characteristic data set discussed previously (n=22):

$$\begin{array}{llllll} \mathit{Bakery\ Absorption} = & 53.1165 & - & 19.9217 \cdot \mathit{Flour\ Ash} & + & 0.4735 \cdot \mathit{Wheat\ Wet\ Glutten} \; . \\ R^2 = 0.289 & (10.374) & & (-2.224) & & (2.686) \end{array} \qquad \text{(A.14)}$$

$$\begin{array}{lllllll} MTI = & 125.2171 & - & 10.5102 \cdot FP & + & 0.2690 \cdot FFN & - \; 0.029 \cdot APV \; , \\ R^2 = 0.799 & (2.438) & & (-2.507) & & (3.799) & (-7.237) \end{array} \qquad \text{(A.15)}$$

where *MTI* is mixing tolerance index, *FP* is flour protein, *FFN* is flour falling number, and *APV* is amylogram peak viscosity.

	B	C	D	E
47	**Exogenous Variables:**			
48				
49	**Dough Characteristics**			
50	Baking Absorption		59.87	60.31
51	Mixing Tolerance Index		28	25
52				
53	**Bakery Efficiency**			
54	Lbs Flour Required / Bread Unit		613.9991	612.3485
55				
56	**Purchase Cost**			
57	Flour Price ($/cwt)		13.65408	13.65408
58	*Purchase Cost ($/Unit)*		$83.8360	$83.6106
59				
60	**Sales Price**			
61	White Bread Price ($/lb)	$0.6000		
62				
63	**Logistics Characteristics**			
64	Rate ($/Shipment)	$2,196.00		
65	URCS ($/Shipment)	$980.85		
66	Transit Time (Days)	3		

Figure A.10. Portion of the model reflecting bakery exogenous variables.

Adapted from Wheat Supply Chain Spreadsheet Model, Bakery Sheet (B47:W66), page 19, Appendix B.

The second exogenous variable was bakery efficiency. Bakery efficiency was measured through flour utilization (Figure A.10, row 54). The composition of bread was found to be a function of flour content:

$$\begin{aligned} B &= Y(F) + S(F) + F + W(F) \quad , \\ \textit{where } Y(F) &= 0.01 \\ S(F) &= 0.02 \\ W(F) &= BA \quad , \end{aligned} \tag{A.16}$$

where B is bread, Y is dry yeast, S is shortening, F is flour, W is water, and BA is bakery absorption (Moore et al., 1994).

The third group of exogenous variables refers to flour purchase costs. The flour price was linked between the bakery and milling activities (Figure A.10, row 57). The second exogenous procurement variable converted flour procurement to a unit of bread basis (Figure A.10, row 58). This variable was found by dividing the flour price by 100 pounds, a hundredweight, and multiplying it by the pounds of flour required to produce a unit of bread.

The fourth exogenous variable for the bakery module was sales price for a pound of bread (Figure A.10, row 61). A value of \$0.60 per pound was based on calculations from 1992 Census of Manufactures data (U.S. Department of Commerce, 1995) as

$$SP = \frac{TCM}{MCVS} \quad , \tag{A.17}$$

where *SP* is sales price, *TCM* is total cost of materials, and *MCVS* is the materials cost as a percentage of the value shipped.

The final set of exogenous variables relates to logistics costs. Inbound flour transportation and flour transit time were the components of this group of exogenous variables. A single flour railcar tariff rate for a 5,250 cubic feet car reflecting a shipment from Grand Forks, North Dakota, to Chicago, Illinois, was used for the first variable, transportation cost per shipment, in the model (Figure A.10, row 64). The cost of this shipment to the transportation service provider was estimated using the Uniform Rail Costing System (URCS) as was done similarly for the wheat shipment at the elevation stage (Figure A.10, row 65). A value of three days was used in the model for the third variable, transit time (Figure A.10, row 66), and was used to calculate in-transit inventory costs.

Intermediate Variables

Intermediate variables represent the third section of this module. Variables were defined for bakery operating cost, inventory, procurement, and total activity cost. A portion of the module where these variables were calculated has been reproduced in Figure A.11.

The operating cost variables were calculated in two steps. First, a utilization factor was determined (Figure A.11, column C). This factor is based on the current level of utilization and the proportion of each cost item that varies with utilization, which were both specified as decision variables. Second, this factor was multiplied by the operating cost assuming 100 percent utilization (Figure A.11, columns D and E, rows 71 through 78). As a result, operating cost values reflect the specified level of utilization. Finally, a variable was defined as the sum of these operating cost values (Figure A.11, row 79).

The second group of intermediate variables was associated with inventory. The first variable defined, daily white bread production, was found by dividing annual production by annual operating days (Figure A.11, row 82). Next, variables related to flour inventory were defined, followed by variables for bread inventory. Finally, a variable summarizing flour and bread inventory values was defined.

For flour inventory, daily flour requirements were estimated from daily white bread production and the pounds of flour required per pound of bread (Figure A.11, row 85). Then flour requirements for the time period were determined (the time period will be discussed with the summary module) (Figure A.11, row 86). Next, the number of shipments received during the time period and the number of days between shipments were determined (Figure A.11, rows 87 and 88). Fifth, average inventory was calculated as one-half of the shipment size (Figure A.11, row 89). The total flour inventory cost variable was calculated by multiplying average inventory, procurement cost, and carrying cost (Figure A.11, row 90). The per hundredweight (cwt) flour inventory cost variable was calculated by dividing total flour inventory cost by total flour requirements, the product of daily flour requirements and annual operating days (Figure A.11, row 91). The final flour inventory intermediate variable calculated was a conversion of the flour inventory cost from per hundredweight (cwt) to per pound of bread (Figure A.11, row 92).

	B	C	D	E
68	**Intermediate Variables:**			
69				
70	**Operating Cost**			
71	Labor ($/lbs)	1.1000	$106.425	$106.425
72	Electricity ($/lbs)	1.0278	$13.515	$13.515
73	Maint & Repair ($/lbs)	1.1000	$13.420	$13.420
74	Sampling / Testing ($/lbs)	1.0667	$0.000	$0.000
75	Depreciation ($/lbs)	1.1000	$21.670	$21.670
76	Interest ($/lbs)	1.1000	$0.000	$0.000
77	Administration / Misc. ($/lbs)	1.1000	$112.530	$112.530
78	Packaging & Other materials ($/lbs)	1.0167	$155.550	$155.550
79	*Operating Cost ($/lbs)*		$423.110	$423.110
80				
81	**Inventory**			
82	Daily Production (Units)	44.3		
83				
84	Flour Inventory:			
85	Daily Requirements (cwt)		272	271
86	Required Per Time Period (cwt)		8,160	8,138
87	Shipments Received Per Time Period		4.1	4.1
88	Days on Hand		7.4	7.4
89	Flour Inventory (cwt)		1,000	1,000
90	Annual Inventory Cost ($)		$3,414	$3,414
91	Flour Inventory Cost ($/cwt)		$0.041	$0.041
92	*Flour Inventory Cost ($/Bread Unit)*		$0.2510	$0.2510
93				
94	White Bread Inventory:			
95	Days on Hand	3.02		
96	Bread Inventory (lbs)	134		
97	Per Unit Investment ($/Unit)		$507.197	$506.972
98	Annual Inventory Cost ($)		$16,940	$16,932
99	*White Bread Inventory Cost ($/Unit)*		$1.2456	$1.2450
100				
101	*Total Inventory Cost ($/Unit)*		$1.4966	$1.4960
102				
103	**Procurement Cost**			
104	Inbound Material Movement Costs:			
105	Intransit Inventory Cost ($/cwt flour)		$0.0228	$0.0228
106	Inbound Transit Cost ($/cwt flour)		$1.0980	$1.0980
107	*Inbound Material Movement Cost ($/unit)*		$6.8814	$6.8629
108				
109	*Total Procurement Cost ($/unit)*		$90.7174	$90.4735
110				
111	**Total Activity Cost**			
112	*Cost ($/Unit) excluding procurement*		$424.607	$424.606
113	*Cost ($/Unit)*		$515.324	$515.080

Figure A.11. Portion of the model reflecting bakery intermediate variables.

Adapted from Wheat Supply Chain Spreadsheet Model, Bakery Sheet (B68:W113), page 21, Appendix B.

White bread inventory was determined by first computing the number of days' production on hand. This was determined by dividing annual operating days by the turnover of finished goods inventory, both decision variables (Figure A.11, row 95). Next, daily white bread production was multiplied by the number of days on hand to determine average white bread inventory (Figure A.11, row 96). The third variable, per unit investment in inventory, was the sum of procurement, operating, and flour inventory costs on a per pound of white bread basis (Figure A.11, row 97). Multiplying the average inventory quantity by the per unit investment yielded total white bread inventory cost (Figure A.11, row 98). The fifth and final white bread inventory variable, the per pound of white bread inventory cost, was found by dividing total white bread inventory cost by annual white bread production for the bakery (Figure A.11, row 99).

Total inventory cost was defined as the sum of flour inventory costs and white bread inventory costs. This variable was calculated on a per pound of white bread basis (Figure A.11, row 101).

The third group of intermediate variables in the bakery module concerns procurement costs. These costs were associated with the inbound movement and acquisition of flour for the baking activity. In addition to the purchasing cost previously specified, variables for inbound in-transit inventory and transportation were defined. The equation used to determine in-transit inventory costs for the bakery was the same as for the milling activity (Figure A.11, row 105). Unlike the wheat shipment, the inbound flour transportation cost, on a per hundredweight basis, was a constant. It was estimated by dividing the shipment's total transportation cost by the quantity shipped (Figure A.11, row 106).

Inbound procurement costs were summarized in two steps. First, the in-transit inventory and inbound transit costs were summed and converted to a per unit of bread basis (Figure A.11, row

107). Second, the flour purchase cost and associated inbound costs were summed to determine total procurement cost (Figure A.11, row 109).

The final group of intermediate variables in the bakery module concerns total activity cost. The first variable was the sum of the operating and inventory intermediate variables (Figure A.11, row 112). This variable excludes procurement and resembles the value-added by the baking activity. The second variable encompasses all three of the intermediate cost variables: procurement, operating, and inventory (Figure A.11, row 113).

Performance Measures

Performance measures represent the fourth section of this module. Bakery margin was used as the performance measure in the baking module (Figure A.12, row 118). It was found by subtracting the intermediate variable for total activity cost including procurement from the sales revenue exogenous variable for each category.

	B	C	D	E
115	**Performance Measures:**			
116				
117	**Margin**			
118	*Bakery Margin ($/Unit)*		$84.676	$84.920

Figure A.12. Portion of the model reflecting bakery performance measures.

Adapted from Wheat Supply Chain Spreadsheet Model, Bakery Sheet (B115:W118), page 23, Appendix B.

Summary Module

The final component of the spreadsheet model was a summary module. This module summarized the cost and revenue variables for the elevation, wheat transportation, flour milling, flour transportation, and baking activities. The margins for each of the activities also are summarized in this module. All variables were converted to the bakery's unit of measure. This section of the model refers to the supply chain sheet which was reproduced as pages 25 and 26 in Appendix B. A portion of the module where these variables exist was reproduced in Figure A.13.

	A	B	C	D
1	Analysis Time Period (days)			30
2				
3			**Bin Identification**	
4			**< 11.5**	
5			**US 1**	**US 2**
6	**Activity Results:**		($/1000 lbs bread)	
7				
8	**Elevator**			
9	Cost/Unit		$44.8276	$45.1511
10	Revenue/Unit		$45.1566	$45.4823
11	Profit/Unit		$0.3289	$0.3313
12				
13	**Transport**			
14	Cost/Unit		$1.4144	$1.4246
15	Revenue/Unit		$5.0087	$5.0449
16	Profit/Unit		$3.5944	$3.6203
17				
18	**Mill**			
19	Cost/Unit		$74.3255	$73.3246
20	Revenue/Unit		$83.8360	$83.6106
21	Profit/Unit		$9.5105	$10.2860
22				
23	**Transport**			
24	Cost/Unit		$3.0112	$3.0031
25	Revenue/Unit		$6.7417	$6.7236
26	Profit/Unit		$3.7305	$3.7205
27				
28	**Bakery**			
29	Cost/Unit		$515.3244	$515.0800
30	Revenue/Unit		$600.0000	$600.0000
31	Profit/Unit		$84.6756	$84.9200
32				
33	**Total**			
34	Total Cost/Unit		$638.9031	$637.9834
35	Total Revenue/Unit		$740.7430	$740.8614
36	Profit/Unit		$101.8398	$102.8780

Figure A.13. Portion of the model reflecting the supply chain summary calculations.

Adapted from Wheat Supply Chain Spreadsheet Model, Supply Chain Sheet (B1:W36), page 25, Appendix B.

Appendix B

The Wheat Supply Chain Spreadsheet Model

	Decision Variables:			V
2	Wheat Characteristics - Elevator			
		Bin Identification		
5				
			16.5 <	16.84
				388.60
				0.72
				58.98
				31.28
				97.80
				0.98
				0.00
				0.04
				1.02
				1.81
19				0.02
20	Wheat Characteristics - Mill			
	Wheat Data	Bin Identification		
			16.5 <	US 2
				16.60
				367.00
				0.100
				57.800
				30.100
				98.000
				1.300
				0.000
				0.200
				1.500
				1.728
				0.200
				0.003

Figure B.1. Spreadsheet model of the wheat supply chain.

Wheat Prices
(Minneapolis Cash Price 6/12/95, 13% Protein, 14% Protein, 15% Protein)

V

4.67
-0.83
$3.84

44

Wheat Data

Value
($0.75)
($0.60)
($0.57)
($0.54)
($0.51)
($0.48)
($0.45)
($0.42)
($0.39)
($0.36)
($0.33)
($0.30)
($0.27)
($0.24)
($0.21)
($0.18)
($0.15)
($0.12)
($0.09)
($0.06)
($0.03)
$0.00
$0.06
$0.12
$0.18
$0.24
$0.30
$0.36
$0.42
$0.48
$0.54
$0.60
$0.66
$0.72
$0.78
$0.84
$0.90

Figure B.1. continued

			Bin Identification									M
	Decision Variables:											
5	**Utilization**									**< 14.0**		
		90										
		60										
		75										
		25										
		10										
		5										
16	**Operating Characteristics**	10										
		20										
		50										
		600,000										
		2.27										
		307										
		1,000										
Elevator		80										
26	**Operating Costs (100% Utilization)**	20										
		25										
		26										
		$0.034										
		$0.006										
		$0.003										
		$0.001										
		$0.010										
		$0.008										
		$0.030										
		$5.05										($0.15)

Figure B.1. Continued.

2											W
	Decision Variables:										
5	**Utilization**									16.5 <	
	Current Utilization (%)										
	Labor (% Variable)										
	Utilities (% Variable)										
	Maint. & Repair (% Variable)										
	Sampling / Testing (% Variable)										
	Depreciation (% Variable)										
	Interest (% Variable)										
	Admin / Misc. (% Variable)										
	Cleaning (% Variable)										
16											
	Operating Characteristics										
	Turnover (volume)										
	Capacity (bu)										
	Operating Days										
	Cleaner Capacity (bu/hr)										
	Cleaning Cost (%, Vendor)										
Elevator	Cleaning Cost (%, Customer)										
	Inventory Carrying Cost (%)										
	Outbound Shipment Size (100 tons)										
26											
	Operating Costs (100% Utilization)										
	Labor ($/bu)										
	Utilities ($/bu)										
	Maint. & Repair ($/bu)										
	Sampling / Testing ($/bu)										
	Depreciation ($/bu)										
	Interest ($/bu)										
	Administration / Misc. ($/bu)										
	Cleaner Cost ($/hour)										
											($0.15)

Figure B.1. Continued

			Bin Identification									M
	Exogenous Variables:											
39	**Protein Adjustment**										**< 14.0**	
42	**Sales Price**											($0.03)
45	**Logistics Characteristics**											$3.81
		$31,356										
		$8,854										
50	**Intermediate Variables:**											
52	**Procurement Cost**	3										
55	**Operating Cost**											$3.65
												$0.035
												$0.006
												$0.003
												$0.001
Elevator												$0.011
												$0.009
												$0.033
65	**Cleaning Cost**											$0.098
68	**Inventory Cost**											$0.009
												$3.76
												7,228
												$6,790
74	**Total Activity Cost**											$0.0297
												$0.136
												$3.788

Figure B.1. Continued.

											W
2											
	Exogenous Variables:										
39	**Protein Adjustment**									16.5 <	
42	**Sales Price**										$0.84
45	**Logistics**										$4.68
	Rate ($/Shipment)										
	URCS ($/Shipment)										
	Transit Time (Days)										
50	**Intermediate Variables:**										
52	**Procurement Cost**										
55	**Operating Cost**										$4.52
											$0.035
											$0.006
											$0.003
Elevator											$0.001
											$0.011
											$0.009
											$0.033
65	**Cleaning Cost**										$0.098
68	**Inventory Cost**										$0.008
											$4.63
74	**Total Activity Cost**										$61374 / $765
											$0.143
											$4.666

Figure B.1. Continued.

		Bin Identification									M
79	**Performance Measures:** **Margin**									**< 14.0**	
											$0.021

Elevator

Page 7

Figure B.1. Continued.

2 W

Performance Measures:

79 16.5 <

Margin

$0.013

Elevator

Page 8

Figure B.1. Continued.

Flour Mill

			Bin Identification									M
											< 14.0	US 2
6	Decision Variables: Utilization											
17	Operating Characteristics	90 25 75 25 10 10 10 10 25 1,800,000 46.30										
25	Operating Costs (100% Utilization)	307 1,000 25 20										
35	Wheat Product Specifications	$0.86 $0.25 $0.25 $0.00 $0.42 $0.20 $0.47 $6.00										
												0.1 001

Figure B.1. Continued.

Flour Mill

2			W
	Decision Variables:	16.5 <	US 2
6	**Utilization**		
	Current Utilization (%)		
	Labor (% Variable)		
	Utilities (% Variable)		
	Maint. & Repair (% Variable)		
	Sampling / Testing (% Variable)		
	Depreciation (% Variable)		
	Interest (% Variable)		
	Admin / Misc. (% Variable)		
	Wheat Cleaning (% Variable)		
17	**Operating Characteristics**		
	Finished Goods Inventory Turnover		
	Annual Production (cwt)		
	Operating Days		
	Cleaner Capacity (bu/hour)		
	Inventory Carrying Cost (%)		
	Intransit Inventory Carrying Cost (%)		
25	**Operating Costs (100% Utilization)**		
	Labor ($/cwt)		
	Utilities ($/cwt)		
	Maintenance & Repair ($/cwt)		
	Sampling / Testing ($/cwt)		
	Depreciation ($/cwt)		
	Interest ($/cwt)		
	Administration / Misc ($/cwt)		
	Cleaning Cost ($/hour)		
35	**Wheat Product Specifications**		
			0.001

Figure B.1. Continued.

			Bin Identification									M
	Exogenous Variables:										< 14.0	US 2
41	Milled Wheat Characteristics											12.79
												369
												2103
												0.4215
48	Mill Efficiency											36.52
												68.79
52	Ch53aracteristics of Flour Sold											2.46
												0.000
56	Proportions:											12.8
												1.000
60	Flour Mill											0.000
												369
												2103
												0.4215
65	Purchase Cost											36.52
												$3.81
												$9.3839
70	Sales Price											38
		$14.00										-0.2767
												$13.723

Figure B.1. Continued.

		Bin Identification									W
	Exogenous Variables:										US 2
41	Milled Wheat Characteristics									16.5 <	
											14.95
											376 3219 0.4126
48	Mill Efficiency										43.47
											66.04
52	Ch53aracteristics of Flour Sold										2.62
											14.94554 0.000
56	Proportions:										
											1.000
60	Flour Mill										0.000
											376 3219 0.4126
65	Purchase Cost										43.47
											$4.68 $12.2573
70	Sales Price										38
	Base Flour Pirce ($/cwt)										
											0.968563
											$14.969

Figure B.1. Continued.

			Bin Identification									M
											< 14.0	US 2
	Intermediate Variables:											
77	Operating Cost											
												$0.93
												$0.26
												$0.27
												$0.00
												$0.46
												$0.22
												$0.52
												$2.66
87	Cleaning Cost											
												$0.0218
90	Inventory											
93	**Flour Mill**											
	Wheat Inventory Cost:	5,863										
												14,447
												433,422
												5 44,073 6.1
												$41,961
												$0.0095
												$0.0233

Figure B.1. Continued.

		Bin Identification									W
	Intermediate Variables:									16.5 <	US 2
77	Operating Cost										
											$0.00
											$0.46
											$0.22
											$0.52
87	Cleaning Cost										$2.66
											$0.0232
90	Inventory										
	Daily Flour Production (cwt)										
93	Wheat Inventory Cost:										
Flour Mill											15,361
											460,833
	Shipments Received Per Time Period										
											5
											44,983 39
											$52,613
											$0.0112
											$0.0292

Figure B.1. Continued.

			Bin Identification									M
	Flour Inventory:										< 14.0	US 2
	Average Flour Inventory (cwt flour)	6.63 38,877										
	Annual Inventory Cost ($)											$12.087 $117,481
110												$0.065
112												$0.089
	Procurement Costs											
	Inbound Material Movement Costs:											
												$0.0063
	Inbound Transit Cost ($/bu wheat)											$0.364
118 Flour Mill												$0.9136
												$10.2976
120	Total Activity Cost											
												$2.7688
124												$13.066
	Performance Measures:											
126	Margin											
												$0.657

Figure B.1. Continued.

		Bin Identification									W
	Flour Inventory:									16.5 <	US 2
	Days Production on Hand										
	Average Flour Inventory (cwt flour)										$14.968
	Annual Inventory Cost ($)										$145,479
110											$0.081
112											$0.110
	Procurement Costs										
	Inbound Material Movement Costs:										
											$0.0078
	Inbound Material Movement Cost ($/cwt)										$0.356 $0.9522
118	**Flour Mill**										
	Total Procurement Cost ($/cwt)										$13.2095
120											
	Total Activity Cost										
											$2.7917
											$16.001
124											
	Performance Measures:										
126											
	Margin										
											-$1.033

Figure B.1. Continued.

Bakery

			Bin Identification									M
	Decision Variables:										**< 14.0**	**US 2**
7	**Utilization**	1,000										
18	**Operating Characteristics**	90 10 75 10 40 10 10 10 85 101.80 13,600,000 1.90										
27	**Operating Costs (100% Utilization)**	307 25 1,000 **20** $12.90 $0.0629 $12.20 $0.00 $19.70 $0.0230 $153.00										7.5 209.1

*includes other ingredients such as sweetners, yeasts, and fats and oils and packaging and other materials

Figure B.1. Continued.

2											W
	Decision Variables:									16.5 <	US 2
	Unit (in lbs)										
7											
	Utilization										
	Current Utilization (%)										
	Labor (% Variable)										
	Electricity (% Variable)										
	Maint & Repair (% Variable)										
	Sampling / Testing (% Variable)										
	Depreciation (% Variable)										
	Interest (% Variable)										
	Admin / Misc (% Variable)										
	Packaging & Other materials (% Variable)										
18											
	Operating Characteristics										
	Inventory Turnover (Times/Yr)										
	Throughput Time (Days)										
	Annual Production (lbs)										
	Operating Days										
	Inventory Carrying Cost (%)										
	Intransit Inventory Carrying Cost (%)										
Bakery	Inbound Shipment Size (cwt)										
27											
	Operating Costs (100% Utilization)										
	Labor ($/hr)										
	Electricity ($/kwh)										
											7.5
	Maint & Repair ($/lbs)										209.1
	Sampling / Testing ($/lbs)										
	Depreciation ($/lbs)										
	Interest ($/lbs)										
	Admin / Misc. ($/lbs)										
	Other Materials ($/lbs)*										

*includes other ingredients such as sweetners, yeasts, and fats and oils and packaging and other materials

Figure B.1. Continued.

			Bin Identification									M
	Flour Product Specifications										< 14.0	US 2
		12.50										
		260										
		63										
46												
	Exogenous Variables:	7										
		25										
48												
	Dough Characteristics											
												62.01
52												
	Bakery Efficiency											
												29
												606.0216
55												
	Purchase Cost											
												13.72326
Bakery												$83.1660
59												
	Sales Price											
62		$0.6000										
	Logistics Characteristics											
		$2,196.00										
		$980.85										

3

Figure B.1. Continued.

2											**W**
	Flour Product Specifications									**16.5 <**	**US 2**
	Protein										
	Falling Number										
	Farino: Absorption										
	Farino: Peak Time										
	Farino: Mixing Tolerance										
46											
	Exogenous Variables:										
48											
	Dough Characteristics										
											65.48
52											
	Bakery Efficiency										
	Lbs Flour Required / Bread Unit										5 593.5380
55	**Bakery**										
	Purchase Cost										
											14.96856
											$88.8441
59											
	Sales Price										
	White Bread Price ($/lb)										
62											
	Logistics Characteristics										
	Rate ($/Shipment)										
	URCS ($/Shipment)										
	Transit Time (Days)										

Figure B.1. Continued.

			Bin Identification									M
67												US 2
	Intermediate Variables:										< 14.0	
69												
	Operating Cost											
												$106.425
												$13.515
												$13.420
												$0.000
												$21.670
												$0.000 $112.530
												$155.550
												$423.110
80												
	Inventory											
83		44.3										
	Flour Inventory:											
												268 8,054
	Bakery											4.0
												7.4 1,000
												$3,431
												$0.042
93												$0.2523
	White Bread Inventory:											
		3.02										
		134										$506.529
												$16,917
100												$1.2439
102												$1.4962
	Procurement Cost											

Figure B.1. Continued.

2			W
67	**Intermediate Variables:**	**16.5 <**	**US 2**
69	**Operating Cost**		
			$106.425
			$13.515
			$13.420
			$0.000
			$21.670
			$0.000
			$112.530
			$155.550
80			$423.110
	Inventory		
	Daily Production (Units)		
83			
	Flour Inventory:		
			263
			7,888
	Bakery		3.9
			7.6
			1,000
			$3,742
93			$0.046
			$0.2752
	White Bread Inventory:		
	Days on Hand		
	Bread Inventory (lbs)		
			$512.230
			$17,108
100			$1.2579
102			$1.5331
	Procurement Cost		

Figure B.1. Continued.

			Bin Identification									M
	Inbound Material Movement Costs:										< 14.0	US 2
	Intransit Inventory Cost ($/cwt flour)											$0.0229
	Inbound Transit Cost ($/cwt flour)											$1.0980
	Inbound Material Movement Cost ($/unit)											$6.7927
108	*Total Procurement Cost ($/unit)*											$89.9587
110	**Total Activity Cost**											
	Cost ($/Unit) excluding procurement											$424.607
												$514.565
114	**Performance Measures:**											
Bakery	**Margin**											$85.435

Figure B.1. Continued.

2											**W**
	Inbound Material Movement Costs:									**16.5 <**	**US 2**
	Intransit Inventory Cost ($/cwt flour)										$0.0249
	Inbound Transit Cost ($/cwt flour)										$1.0980
	Inbound Material Movement Cost ($/unit)										$6.6651
108											
	Total Procurement Cost ($/unit)										$95.5092
110											
	Total Activity Cost										
	Cost ($/Unit) excluding procurement										$424.644
											$520.153
114											
	Performance Measures:										
116	**Bakery**										$79.847

Figure B.1. Continued.

Row	Supply Chain	30		L
2		Bin Identification		
		($/1000 lbs bread)	< 14.0	US 2
7	Elevator			$56.5625 $56.8688 $0.3063
12	Transport			$1.5367 $5.4419 $3.9052
17	Mill			$79.1851 $83.1660 $3.9809
22	Supply Chain Transport			$2.9721 $6.6541 $3.6820
27	Bakery			$514.5654 $600.000 $85.4346
32	Total			$654.821 $752.130 $97.3091

Figure B.1. Continued.

		16.5 <	V US 2
7	Activity Results: Elevator		$72.5505 $72.7518 $0.2013
12	Transport		$1.5617 $5.5304 $3.9687
17	Mill		$94.9730 $88.8441 -$6.1289
22	Supply Chain Transport		$2.9109 $6.5170 $3.6062
27	Bakery		$520.1528 $600.0000 $79.8472
32	Total		$692.1488 $773.6433 $81.4945

Figure B.1. Continued.

	Elevator Formulas		
A	**B**	**C**	**D**
4	**Decision Variables:**		
5			
6	**Utilization**		
7	Current Utilization (%)	90	
8	Labor (% Variable)	60	
9	Utilities (% Variable)	75	
10	Maint. & Repair (% Variable)	25	
11	Sampling / Testing (% Variable)	10	
12	Depreciation (% Variable)	5	
13	Interest (% Variable)	10	
14	Admin. / Misc. (% Variable)	20	
15	Cleaning (% Variable)	50	
16			
17	**Operating Characteristics**		
18	Turnover (volume)	2.27	
19	Capacity (bu)	600000	
20	Operating Days	307	
21	Cleaner Capacity (bu/hr)	1000	
22	Cleaning Cost Passed On (%)	100	
23	Inventory Carrying Cost (%)	25	
24	Average Inventory	42500	
25			
26	**Operating Costs (100% Utilization)**		
27	Labor ($/bu)	0.0335	
28	Utilities ($/bu)	0.00584	
29	Maint. & Repair ($/bu)	0.00277	
30	Sampling / Testing ($/bu)	0.001	
31	Depreciation ($/bu)	0.00995	
32	Interest ($/bu)	0.0082	
33	Admin. / Misc. ($/bu)	0.0303	
34	Cleaner Cost ($/hour)	5.05	
35	Gross Margin ($/bu)		-0.15
36			
37	**Exogenous Variables:**		
38			
39	**Protein Adjustment**		
40	Adjustment ($/bu)		=VLOOKUP(('Wheat Data'! C6), 'Wheat Data'!$D$44:$E$66, 2,TRUE)
41			

Figure B.2. Spreadsheet formulas for the elevator activity.

42	**Sales Price**		
43	Price ($/bu)		='Wheat Data'!$D41+D40-($C22/100*D61)
44			
45	**<u>Intermediate Variables:</u>**		
46			
47	**Procurement Cost**		
48	Price ($/bu)		=D43+D35
49			
50	**Operating Cost**		
51	Labor ($/bu)	=((1/($C$7/100)) * (1-(C8/100))) + (C8/100)	=$C27*$C51
52	Utilities ($/bu)	=((1/($C$7/100)) * (1-(C9/100))) + (C9/100)	=$C28*$C52
53	Maint. & Repair ($/bu)	=((1/($C$7/100)) * (1-(C10/100))) + (C10/100)	=$C29*$C53
54	Sampling / Testing ($/bu)	=((1/($C$7/100)) * (1-(C11/100))) + (C11/100)	=$C30*$C54
55	Depreciation ($/bu)	=((1/($C$7/100)) * (1-(C12/100))) + (C12/100)	=$C31*$C55
56	Interest ($/bu)	=((1/($C$7/100)) * (1-(C13/100))) + (C13/100)	=$C32*$C56
57	Admin. / Misc. ($/bu)	=((1/($C$7/100)) * (1-(C14/100))) + (C14/100)	=$C33*$C57
58	*Operating Cost ($/bu)*	=((1/($C$7/100)) * (1-(C15/100))) + (C15/100)	=SUM(D51:D57)
59			
60	**Cleaning Cost**		
61	*Cleaning Cost ($/bu)*		=IF(('Wheat Data'!C8)>'Flour Mill'!$D$38, ($C34*$C58)/((0.7449-(0.1019*('Wheat Data'! C8)) + (0.3882*('Flour Mill'!$D$38))) *$C$21),0)
62			
63	**Inventory Cost**		
64	Per Unit Investment		=D48+D58+D61
65	Average Inventory (bu)		=$C24*'Wheat Data'!C17
66	Annual Inventory Cost ($)		=D65*($C$23/100)*D64
67	*Inventory Cost ($/bu)*		=D66/(($C$19*$C$18)*'Wheat Data'!C17)

Figure B.2. Continued.

68			
69	**Total Activity Cost**		
70	*Cost ($/bu) excluding procurement*		=D58+D61+D67
71	*Cost ($/bu)*		=D70+D48
72			
73	**<u>Performance Measures:</u>**		
74			
75	**Margin**		
76	*Elevator Margin ($/bu)*		=D43-D71

Figure B.2. Continued.

	Flour Mill Fomulas		
A	**B**	**C**	**D**
5	**Decision Variables:**		
6			
7	**Utilization**		
8	Current Utilization (%)	90	
9	Labor (% Variable)	25	
10	Utilities (% Variable)	75	
11	Maint. & Repair (% Variable)	25	
12	Sampling / Testing (% Variable)	10	
13	Depreciation (% Variable)	10	
14	Interest (% Variable)	10	
15	Admin. / Misc. (% Variable)	10	
16	Wheat Cleaning (% Variable)	25	
17			
18	**Operating Characteristics**		
19	Finished Goods Inventory Turnover (Times/Yr)	46.3	
20	Annual Production (cwt)	1800000	
21	Operating Days	307	
22	Cleaner Capacity (bu/hour)	1000	
23	Inventory Carrying Cost (%)	25	
24	Intransit Inventory Carrying Cost (%)	20	
25	Inbound Shipment Size (100 tons)	26	
26			
27	**Operating Costs (100% Utilization)**		
28	Labor ($/cwt)	0.86	
29	Utilities ($/cwt)	0.25	
30	Maintenance & Repair ($/cwt)	0.25	
31	Sampling / Testing ($/cwt)	0	
32	Depreciation ($/cwt)	0.42	
33	Interest ($/cwt)	0.2	
34	Admin. / Misc ($/cwt)	0.47	
35	Cleaning Cost ($/hour)	6	
36			
37	**Wheat Product Specifications**		
38	Dockage Procured (%)		0.1
39	Dockage Prior to Milling (%)		0.001
40			
41	**Exogenous Variables:**		

Figure B.3. Spreadsheet formulas for the flour mill activity.

42			
43	**Milled Wheat Characteristics**		
44	Protein		=IF('Wheat Data'! C35 > 0, 1.8+('Wheat Data'!C24*0.7919),0)
45	Falling Number		=IF('Wheat Data'!C35>0, 93.51 +('Wheat Data'! C25 * 0.7689), 0)
46	Amylograph Peak Viscosity		=IF('Wheat Data'!C35>0,(-3060.3167 +(14.3858*'Wheat Data'!C25)),0)
47	Flour Ash		=IF('Wheat Data'!C35>0, (0.2098+ (0.008*'Wheat Data'! C32)+ (0.1164*'Wheat Data'!C34)),0)
48	Wet Glutten		=IF('Wheat Data'!C35>0, (4.1963+ (2.5871*'Wheat Data'!C24)+(-0.01* 'Wheat Data'!C25))+(D60*65), 0)
49			
50	**Mill Efficiency**		
51	Extraction Rate		=IF('Wheat Data'!C35>0, 90.6211- (0.1173*'Wheat Data'!C27)+(0.0132* 'Wheat Data'!C29)-(1.1505*Wheat Data'!C24),0)
52	Bushels Wheat = 1 cwt Flour		=IF('Wheat Data'!C27>0,(1/(D51/100)) /('Wheat Data'! C27/100),0)
53			
54	**Characteristics of Flour Sold**		
55	Added Protein		=IF('Wheat Data'!C35>0,IF(D44< Bakery!$C$40,Bakery!$C$40-D44,0),0)
56	Net Flour Protein		=D44+D55
57			
58	Proportions:		
59	Milled Wheat		=1/(1+(D55/65))
60	Wheat Glutten (65% protein)		=(D55/65)/(1+(D55/65))
61			
62	Falling Number		=D45
63	Amylograph Peak Viscosity		=(D59*D46)+(D60*$X46)
64	Flour Ash		=(D59*D47)+(D60*$X47)
65	Wet Glutten		=(D59*D48)+(D60*$X48)
66			
67	**Procurement Cost**		
68	Wheat Price ($/bu)		='Wheat Data'!$D$41+(VLOOKUP (('Wheat Data'!C24),'Wheat Data'! $D$44:$E$70,2,TRUE))
69	Glutten Price ($/cwt)		38
70	*Procurement Cost ($/cwt flour)*		=D68*D59*D52+D69*D60
71			
72	**Sales Price**		

Figure B.3. Continued.

73	Base Flour Pirce ($/cwt)	14	
74	Flour Protein Adjustment ($/cwt)		=$X$52*VLOOKUP((D56+0.5), 'Wheat Data'!$D$44:$E$70, 2, TRUE)
75	*Price Received ($/cwt flour)*		=$C73+D74
76			
77	**Logistics Characteristics**		
78	Rate ($/Shipment)	31356	
79	Transit Time (Days)	3	
80			
81	**<u>Intermediate Variables:</u>**		
82			
83	**Operating Cost**		
84	Labor ($/cwt)	=((1/($C$8/100)) * (1-(C9/100))) + (C9/100)	=$C28*$C84
85	Utilities ($/cwt)	=((1/($C$8/100)) * (1-(C10/100))) + (C10/100)	=$C29*$C85
86	Maintenance & Repair ($/cwt)	=((1/($C$8/100)) * (1-(C11/100))) + (C11/100)	=$C30*$C86
87	Sampling / Testing ($/cwt)	=((1/($C$8/100)) * (1-(C12/100))) + (C12/100)	=$C31*$C87
88	Depreciation ($/cwt)	=((1/($C$8/100)) * (1-(C13/100))) + (C13/100)	=$C32*$C88
89	Interest ($/cwt)	=((1/($C$8/100)) * (1-(C14/100))) + (C14/100)	=$C33*$C89
90	Admin. / Misc. ($/cwt)	=((1/($C$8/100)) * (1-(C15/100))) + (C15/100)	=$C34*$C90
91	*Operating Cost ($/cwt flour)*	=((1/($C$8/100)) * (1-(C16/100))) + (C16/100)	=SUM(D84:D90)
92			
93	**Cleaning Cost**		
94	*Wheat Cleaning Cost ($/cwt flour)*		=IF(D38<=D39, 0, ($C35*$C91)/((0.7449-(0.1019*(D38))+(0.3882*(D39)))*$C$22)* (D52*D59))
95			
96	**Inventory**		
97	Daily Flour Production (cwt)	=C20/C21	
98			
99	Wheat Inventory Cost:		
100	Daily Requirements (bu)		=$C$97*D59*D52

Figure B.3. Continued.

101	Required Per Time Period (bu)		=D100*'Supply Chain'!$D$1
102	Shipments Received Per Time Period		=(D101*'Wheat Data'!C27/2000)/($C$25*100)
103	Days Between Shipments		='Supply Chain'!$D1/'Flour Mill'! D102
104	Average Wheat Inventory (bu)		=($C25*200000/'Wheat Data'! C27)/2
105	Annual Inventory Cost ($)		=D104*D68*($C23/100)
106	Wheat Inventory Cost ($/bu)		=D105/(D100*$C21)
107	*Wheat Inventory Cost ($/cwt flour)*		=D106*D59*D52
108			
109	Flour Inventory:		
110	Days Production on Hand	=C21/C19	
111	Average Flour Inventory (cwt flour)	=C97*C110	
112	Per Unit Investment ($/cwt)		=D70+D91+D94+D107
113	Annual Inventory Cost ($)		=$C$23/100*$C$111*D112
114	*Flour Inventory Cost ($/cwt)*		=D113/$C$20
115			
116	*Total Inventory Cost ($/cwt)*		=D114+D107
117			
118	**Total Activity Cost**		
119	*Cost ($/cwt) excluding procurement*		=D91+D94+D116
120	*Cost ($/cwt)*		=D119+D70
121			
122	**Logistics Cost**		
123	Inbound Transportation:		
124	Cost ($/bu wheat)		=$C78/(($C25*200000)/'Wheat Data'!C27)
125	*Cost ($/cwt flour)*		=D124*D59*D52
126			
127	Intransit Wheat Inventory:		
128	Cost ($/bu wheat)		=(($C79/('Supply Chain'!$D1*($C25*200000/'Wheat Data'!C27)/D101))*($C25*200000/'Wheat Data'!C27)*D68*(($C24/100)/360*'Supply Chain'! $D1))/D101
129	*Cost ($/cwt flour)*		=D128*D59*D52
130			
131	*Inbound Logistics Cost ($/cwt)*		=D129+D125
132			
133	**Performance Measures:**		
134			
135	**Margin**		
136	*Mill Margin ($/cwt)*		=D75-(D120+D131)

Figure B.3. Continued.

	Bakery Formulas		
A	**B**	**C**	**D**
5	**Decision Variables:**		
6			
7	**Utilization**		
8	Current Utilization (%)	90	
9	Labor (% Variable)	10	
10	Electricity (% Variable)	75	
11	Maint & Repair (% Variable)	10	
12	Sampling / Testing (% Variable)	40	
13	Depreciation (% Variable)	10	
14	Interest (% Variable)	10	
15	Admin. / Misc (% Variable)	10	
16	Packaging & Other materials (% Variable)	85	
17			
18	**Operating Characteristics**		
19	Inventory Turnover (Times/Yr)	101.8	
20	Throughput Time (Days) ????	1.9	
21	Annual Production (lbs)	13600000	
22	Operating Days	307	
23	Inventory Carrying Cost (%)	25	
24	Intransit Inventory Carrying Cost (%)	20	
25	Inbound Shipment Size (cwt)	2000	
26			
27	**Operating Costs (100% Utilization)**		
28	Labor ($/hr)	12.9	
29	Labor (hr/lbs)		0.0075
30	Electricity ($/kwh)	=143.3/2278.6	
31	Electricity (kwh/lbs)		0.2091
32	Maint & Repair ($/lbs)	0.0122	
33	Sampling / Testing ($/lbs)	0	
34	Depreciation ($/lbs)	0	
35	Interest ($/lbs)	0	
36	Admin. / Misc. ($/lbs)	0	
37	Packaging & Other materials ($/lbs)	0.0255	
38			
39	**Flour Product Specifications**		
40	Protein	12.5	
41	Falling Number	260	
42	Farino: Absorption	63	

Figure B.4. Spreadsheet formulas for the baking activity.

43	Farino: Peak Time	7	
44	Farino: Mixing Tolerance	25	
45			
46	**Exogenous Variables:**		
47			
48	**Dough Characteristics**		
49	Baking Absorption		=IF('Wheat Data'!C35>0, (53.1165+(-19.9217*'Flour Mill'! D64)+(0.4735* 'Flour Mill'!D65)),0)
50	Mixing Tolerance Index		=IF('Wheat Data'!C35>0, (125.2171-(10.5102*'Flour Mill'!D56)+(0.269* 'Flour Mill'!D62)-(0.029*'Flour Mill'!D63)),0)
51			
52	**Bakery Efficiency**		
53	Lbs Flour Required / Lb Bread		=IF('Wheat Data'!C35>0, (1/(1.03+(D49/100))),0)
54			
55	**Procurement Cost**		
56	Flour Price ($/cwt)		='Flour Mill'!D75
57	*Procurement Cost ($/lbs)*		=D56/100*D53
58			
59	**Sales Price**		
60	White Bread Price	0.4985	
61			
62	**Logistics Characteristics**		
63	Rate ($/Shipment)	2196	
64	Transit Time (Days)	3	
65			
66	**Intermediate Variables:**		
67			
68	**Operating Cost**		
69	Labor ($/lbs)	=((1/($C$8/100)) * (1-(C9/100))) + (C9/100)	=D29*$C$28*$C69
70	Electricity ($/lbs)	=((1/($C$8/100)) * (1-(C10/100))) + (C10/100)	=D31*$C$30*$C70
71	Maint & Repair ($/lbs)	=((1/($C$8/100)) * (1-(C11/100))) + (C11/100)	=$C32*$C71
72	Sampling / Testing ($/lbs)	=((1/($C$8/100)) * (1-(C12/100))) + (C12/100)	=$C33*$C72
73	Depreciation ($/lbs)	=((1/($C$8/100)) * (1-(C13/100))) + (C13/100)	=$C34*$C73

Figure B.4. Continued.

74	Interest ($/lbs)	=((1/($C$8/100)) * (1-(C14/100))) + (C14/100)	=$C35*$C74
75	Admin. / Misc. ($/lbs)	=((1/($C$8/100)) * (1-(C15/100))) + (C15/100)	=$C36*$C75
76	Packaging & Other materials ($/lbs)	=((1/($C$8/100)) * (1-(C16/100))) + (C16/100)	=$C37*$C76
77	*Operating Cost ($/lbs)*		=SUM(D69:D76)
78			
79	**Inventory**		
80	Daily Production	=C21/C22	
81			
82	Flour Inventory:		
83	Daily Requirements (cwt)		=$C80*D53/100
84	Required Per Time Period (cwt)		=D83*'Supply Chain'!$D1
85	Shipments Received Per Time Period		=D84/$C25
86	Days on Hand		='Supply Chain'!$D1/D85
87	Flour Inventory (cwt)		=D86*D83/2
88	Annual Inventory Cost ($)		=D87*D56*($C23/100)
89	Flour Inventory Cost ($/cwt)		=D88/(D83*$C22)
90	*Flour Inventory Cost ($/lbs bread)*		=D89/100*D53
91			
92	White Bread Inventory:		
93	Days on Hand	=C22/C19	
94	Bread Inventory (lbs)	=C93*C80	
95	Per Unit Investment ($/lbs)		=(D89/100*D53)+D77+D57
96	Annual Inventory Cost ($)		=$C94*D95*($C23/100)
97	*White Bread Inventory Cost ($/lbs)*		=D96/$C21
98			
99	*Total Inventory Cost ($/lbs)*		=D97+D90
100			
101	**Total Activity Cost**		
102	*Cost ($/lbs) excluding procurement*		=D99+D77
103	*Cost ($/lbs)*		=D99+D77+D57
104			
105	**Logistics Cost**		
106	Inbound Transportation:		
107	Cost ($/cwt flour)		=$C63/($C25*100)
108	*Cost ($/lbs bread)*		=D107/100*D53

Figure B.4. Continued.

109			
110	Intransit Flour Inventory:		
111	Cost ($/cwt flour)		=(($C64/('Supply Chain'!$D1 *$C25/ D84))*$C25*D56*(($C24/ 100)/ 360*'Supply Chain'!$D1))/ D84
112	*Cost ($/lbs bread)*		=D111/100*D53
113			
114	*Inbound Logistics Cost ($/lbs)*		=D112+D108
115			
116	**<u>Performance Measures:</u>**		
117			
118	**Margin**		
119	*Bakery Margin ($/lbs)*		=$C60-(D103+D114)

Figure B.4. Continued.

	Supply Chain Formulas		
A	**B**	**C**	**D**
1	Analysis Time Period (days)		30
2			
3		**Bin Identification**	
4		**A**	
5		**US 1**	
6	**Activity Costs:**	($/1000 lbs bread)	
7			
8	**Elevation**		
9	Procurement	=((Elevator!D48*'Flour Mill'!$D$52*'Flour Mill'!$D$59)/100*Bakery!$D$53)*1000	
10	Operating	=(((Elevator!D58+Elevator!D61)*'Flour Mill'!$D$52*'Flour Mill'!$D$59)/100*Bakery!$D$53)*1000	
11	Inventory	=((Elevator!D67*'Flour Mill'! $D$52*'Flour Mill'!$D$59)/ 100*Bakery!$D$53)*1000	
12	Subtotal	=SUM(C9:C11)	
13			
14	Transportation	=('Flour Mill'!D125/100*Bakery!D53)*1000	
15	Intransit Inventory	=('Flour Mill'!D129/100*Bakery!D53)*1000	
16	Subtotal	=SUM(C14:C15)	
17			
18	**Milling**		
19	Procurement	=('Flour Mill'!D70/100*Bakery!D53)*1000	
20	Operating	=(('Flour Mill'!D91+'Flour Mill'!D94)/100*Bakery!D53)*1000	
21	Inventory	=('Flour Mill'!D116/100*Bakery!D53)*1000	
22	Subtotal	=SUM(C19:C21)	
23			
24	Transportation	=(Bakery!D108)*1000	
25	Intransit Inventory	=(Bakery!D112)*1000	
26	Subtotal	=SUM(C24:C25)	
27			
28	**Bakery**		
29	Procurement	=(Bakery!D57)*1000	
30	Operating	=(Bakery!D77)*1000	
31	Inventory	=(Bakery!D99)*1000	
32	Subtotal	=SUM(C29:C31)	
33			
34	*Total ($/1000 lbs bread)*	=C12+C16+C22+C26+C32	
35			
36	**Activity Margins:**		

Figure B.5. Spreadsheet formulas for the supply chain summary.

37		
38	Elevation	=((Elevator!D76*'Flour Mill'!D52*'Flour Mill'!D59)/100*Bakery!D53)*1000
39		
40	Milling	=('Flour Mill'!D136/100*Bakery!D53)*1000
41		
42	Bakery	=(Bakery!D119)*1000
43		
44	*Total ($/1000 lbs bread)*	=SUM(C38:C42)

Figure B.5. Continued.