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COST AND QUALITY COMPARISONS OF FIVE
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TECHNIQUES AT TWO LEVELS OF CAPACITY

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COST AND QUALITY COMPARISONS OF FIVE ALTERNATIVE CORN DRYING AND STORAGE TECHNIQUES AT TWO LEVELS OF CAPACITY

By

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ABSTRACT

COST AND QUALITY COMPARISONS OF FIVE
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An economic analysis of five alternative on-farm corn drying and storage systems was performed at two size levels - 30,000 bushels and 80,000 bushels annually. The systems studied were the automatic batch system, the in-bin counterflow system, the automatic batch/dryeration system, the automatic batch/low temperature system, and the automatic batch/natural air system. The quality of grain resulting from each type of drying system was compared to the cost of the system.

The least-cost options proved to be the in-bin counterflow and automatic batch/dryeration systems. The automatic batch/natural air and automatic batch/low temperature systems produce slightly better quality corn than the automatic batch/dryeration system, but at a considerably higher cost. Although the in-bin counterflow system competes well with the automatic batch/dryeration system with respect to cost, it produces poorer quality grain. The automatic batch/dryeration system appears to be the most attractive option when considering both cost and quality.

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CHAPTER 1

INTRODUCTION AND OBJECTIVES OF THESIS

1.1 Corn Production in the U.S. and Michigan

The amount of corn produced in the United States has been growing steadily over the past decade. From the marketing year 1974/75 to the marketing year 1984/85, U.S. production has increased from 4.7 billion bushels to 7.5 billion bushels. This represents a 60 percent increase. The average production for this period was 6.9 billion bushels. The annual rate of growth averaged 8.3 percent per year over this period.

Paralleling the rise in production was a significant increase in corn exports. Between 1974/75 and 1984/85, exports as a proportion of production averaged 28.2 percent with a high of 35 percent and a low of 22 percent. The annual rate of growth averaged 7.9 percent (USDA, 1974-84).[1]

Development and adaptation of new technology has helped make possible this significant increase in production of corn in the United States. Illustrative of harvesting technology to increase farm capacity are the combine with corn head and high temperature drying of high moisture corn (Kline, 1972).

[1] The 1983/84 marketing year was excluded from this presentation because of reduced production due to the Payment in Kind (PIK) Program

For example, in Michigan, 64.1 percent of all corn grain was harvested by a combine with a corn head in 1975. By 1979, 79 percent was harvested in this manner. Likewise, in 1975, 51 percent of Michigan corn was artificially dried on the farm. This fraction grew to 75 percent by 1979 (Michigan Department of Agriculture, 1979).

Of the 75 percent of corn in Michigan which is artifically dried on the farm, most is dried in high temperature automatic batch dryers (180-230^{0}F) or batch-in-bin systems (110-140^{0}F) (Kalchik et al., 1979). High temperature drying has been shown to have a detrimental effect on the ability of the corn kernel to withstand damage from handling, transporting, and invasion by molds. Furthermore, high temperature drying is responsible for approximately 60 percent of the energy requirements for on-farm corn production (Issacs, 1973). Kalchik (1979) estimated that drying the 1979 Michigan corn crop required 400 million gallons of liquid propane.

The above events have led to a growing concern about the quality of corn in domestic as well as foreign markets. Concerns regarding low quality corn have been raised in recent years. Wet millers and dry millers have complained of poor yields of products and low millability. Handlers complain of increased costs due to significant amounts of broken corn and the increased risk of dust explosions in handling facilities. Lower nutritional value of corn dried at high temperatures as well as an increased susceptibility to mold have been noticed by some feed processors. Importers of U.S. corn have found that the quality of corn they receive has deteriorated significantly from the time the grade certificate was issued in the United States.

Corn damaged from mold, insect infestation, and broken corn and foreign material represents from three to five percent of corn that actually goes to market (Liebenow, 1972).

Hill (1975) identified four major problems with corn quality:

1. Identification of those characteristics of corn considered to reflect quality and value.
2. Genetically producing corn possessing those qualities which will maximize returns to productive resources.
3. Finding techniques to permit rapid and accurate description of quality characteristics.
4. Developing equipment, facilities, and marketing systems that will maintain the maximum quality that is economically feasible.

It is possible to increase the level of corn quality on the marketplace by using alternative drying technologies. By reducing the temperature of the drying air and increasing the residence time in the dryer, the quality of the grain can be improved. In addition, energy efficiency of the drying operation is increased. Combining high temperature and low temperature dryers to dry the grain to a safe storage level has been shown to improve grain quality as well as energy efficiency. Combination techniques require more management expertise compared to most automatic high temperature systems (Kalchik et al, 1981).

1.2 Objectives of Thesis

This study establishes ownership and operating costs for five different on-farm grain drying and storage systems at two levels of capacity. These systems are compared with respect to cost and the quality of grain produced. There are five major objectives:

1. Specify five alternative corn drying and storage systems for two different size farms.

2. Use the capital budgeting/net present value approach to determine and analyze the ownership and operating costs for each of these systems.

3. Perform a sensitivity analysis with respect to energy prices and risk levels.

4. Describe the quality of grain maintained by each system through the use of kernel breakage susceptibility scores and kernel stress crack levels.

5. Compare cost to quality and determine the cost to achieve increased levels of quality in corn dried and stored on the farm.

The goal in constructing the five alternative drying and storage facilities is to produce a practical, representative system which parallels those found on today's modern farms. Each facility should be able to perform the following functions:

- prepare the harvested grain for drying
- dry the grain
- move dry grain from the dryer to the storage facility
- store the grain
- remove the grain from storage facility

To determine the existence and consistency of the economies of size phenomenon, two different size facilities will be modeled.

The fulfillment of the first objective is achieved by using a economic-engineering approach. The use of this method allows the inputs for each system to be "synthesized" using engineering data. Assumptions are made concerning the volume of corn dried and the percentage points of moisture removed. The major categories of inputs are fixed durable inputs (e.g. dryers and storage bins) and variable inputs (e.g. liquid propane, electricity, and labor).

Accomplishment of the second objective will generate realistic costs of owning and operating each facility. Ownership costs associated with the investment in a grain drying and storage system are interest expense on borrowed funds, opportunity cost of equity capital used, insurance, and maintenance charges. Operating costs include liquid propane, electricity, and labor charges. Other factors which are considered to be important in financial decision-making are the time value of money, relative size and timing of cash flows, and the effects of depreciation, interest, and other expenses on income tax obligations. A capital budgeting model is used to determine the costs of each system.

The third objective involves performing a sensitivity analysis using the capital budgeting model. The effects of relative increases in the price of energy inputs as well as changes in the risk level (discount rate) are analyzed.

Objective number four is concerned with grain quality from the respective drying systems. Data collected by the Michigan State University Agricultural Engineering Department in conjunction with Steve Kalchik at Kalchik Farms in northern Michigan is used. These tests generated data on amounts of broken corn and foreign material (BCFM), corn breakage susceptibility, and kernel stress cracks for each system. The drying techniques analyzed at Kalchik Farms in Bellaire, Michigan are the same ones studied in this thesis. This data will be used as a basis for comparing the cost of each different drying technology with their respective impact on grain quality.

To attain objective number five, the physical data on grain quality is combined with the capital budgeting results to economically evaluate the systems. From this comparison a measure of the cost of increasing the quality of corn dried and stored on the farm can be obtained.

1.3 Topics Covered in the Following Chapters

The next chapter in this study is a review of the various on-farm grain drying and storage methods presently in use. It discusses the differences between technologies as well as their relative advantages and disadvantages.

Discussed in Chapter 3 are the quality measures of corn including broken corn and foreign material (BCFM), breakage susceptibility, and stress cracks. In addition, the chapter covers the effects of high temperature drying on corn quality and the impact low quality corn has on the feed industry, dry and wet millers, and the handlers and exporters of corn. Results of other studies on the costs of drying and storing corn are also summarized in this chapter.

Chapter 4 is a discussion of the analytical methods used. In the first part, the economic-engineering approach is discussed as a way to obtain the physical inputs required to own and operate drying and storage systems. The second section describes the capital budgeting model as a way to generate realistic costs for ownership and operation of the investments.

Chapter 5 is devoted to a discussion of the procedures used in this thesis. It tells how the drying and storage systems were "synthesized," how cost data were obtained, and how it was incorporated into the capital budgeting model. Also, the sensitivity analysis is discussed.

The results of the analysis are reported in Chapter 6. System comparisons on a cost and quality basis as well as the effect on cost of increasing energy and risk levels are the major topics of this chapter. Also included are additional considerations and suggestions for future research.

CHAPTER 2

DESCRIPTION OF DRYING SYSTEMS

In recent years, corn drying systems have evolved from the widely adopted method of crib storage of ear corn using natural air flow to dry the corn, to artificially dried shelled corn relying on fossil fuels as energy sources for forcing heated air through the corn. With the onset of artificial drying systems a number of different drying methods have emerged. This chapter gives a summary of drying systems currently in use in the United States.

Drying systems can be divided into three different categories. These are:

1. High temperature systems, which require relatively large amounts of fossil fuel to achieve high drying temperatures, high airflow rates, and high bushel capacity drying rates.

2. Low temperature systems, whose requirements for fossil fuel are relatively smaller resulting in lower drying temperatures. They use lower airflow rates and have relatively low bushel capacity drying rates.

3. Combination or hybrid systems, which use both high and low temperature technology.

2.1 High Temperature Systems

High temperature systems (HT) employ high temperatures (150-250°F) and relatively high airflow rates (40 to 130 cubic feet per minute (CFM) per bushel) (Madsen et al., 1976). Therefore, these systems are able to dry more grain in a short period of time. However, this type of drying technique is responsible for low energy efficiency, high fossil fuel consumption, and low product quality (Madsen et al., 1976; Silva, 1980). Three examples of high temperature grain dryers are batch dryers, continuous flow dryers, and batch-in-bin dryers.

Batch dryers are dryers which dry grain in batches or cycles. They are popular on many small and medium-sized farms in the United States. The drying period in some batch dryers can be divided into two steps or stages. Initially, ultra-high temperature air (216-235^{o}F) is supplied during the first part of the cycle and lower temperature air (175-182^{o}F) in the second part (Silva, 1980). These dryers, known as two stage dryers, are usually more fuel efficient than single stage dryers.

Continuous flow dryers dry grain on a continual basis. They are used mainly by large farms and commercial drying operations because of their high capacity. They can be divided into two categories--concurrent flow and counterflow.

In concurrent flow drying, the grain and the drying air move in the same direction. The advantages of this method include lower energy usage with respect to the automatic batch system, high grain quality, lower pollution, and discharge of grain at a uniform moisture content (Brooker, 1978).

In counterflow dryers, the grain and the drying air move in opposite directions. An example of this is the in-bin continuous flow dryer known as the "Shivvers System." In this system, wet grain is placed in a bin and hot air (160^{O}F) is forced up through a perforated floor. As the grain is dried, it is removed by means of a sweep auger. Since the grain is removed while it is hot, it can be placed in a storage bin at a moisture content 1 to 2 percent higher than the desired final moisture content. The advantage of this type of high temperature system is its higher energy efficiency, over the automatic batch system, assuming the grain bed depth is sufficient to absorb all the drying potential of the heated air (Brooker, 1978).

The batch-in-bin dryer operates on the same principle as a batch dryer except drying takes place inside a bin. Batches usually take 3 to 10 hours to dry. Temperatures and airflow rates are relatively lower than other batch dryers (120-140^{o}F and 15-30 CFM per bushel). The advantages of this system are the modest investment costs and its relatively high drying efficiency (Silva, 1980). It can also be used as a storage facility when drying is not taking place (Schwart and Hill, 1977). However, since the system is not automatic, additional labor and management is required throughout the drying process. In addition, the grain in the bottom of the batch-in-bin dryer is usually 3 to 5 percentage points dryer than the grain on top.

The advantages of automatic batch and continuous flow dryers include less labor and management because they are automatic. They also can be moved from place to place. However, these systems are not cost competitive at low volumes and are not readily adaptable for expanding to larger operations (Schwart and Hill, 1977).

2.2 Low Temperature Systems

Low temperature systems (LT) are characterized by lower airflow rates (1-3 CFM per bushel) and little or no additional heat. Although drying time is increased substantially with this system, improvement in energy efficiency is considerable. In low temperature systems, wet grain is placed directly in the bin where it will be stored. Air is then blown through the grain and after a period of time the whole bin is dry. The airflow rate is dependent upon initial moisture, harvesting date and geographic location (Silva, 1980).

Two common types of low temperature systems are the natural air system and the low temperature system. The natural air system relies totally on the ability of atmospheric air for drying (except for approximately 2^{o}F of heat from the fan motor). Low temperature systems rely on an additional 5-9^{o}F heat from another source to aid in drying (Shove, 1978). Propane or electricity are examples of these sources of additional heat.

Bartsch and Finner (1976) found that 27 percent moisture corn could be dried safely using the low temperature technique even during unfavorable weather conditions if air flows of 3.21 to 4.57 CFM per bushel were provided.

Pierce and Thompson (1978) claimed that airflow rate is the single most important factor when designing natural air and low temperature systems. In addition, they found that 2 CFM per bushel may be a higher airflow than is needed. Using 2 CFM per bushel was satisfactory 84 percent of the time in order to keep dry matter decomposition below 0.5 percent in low temperature systems.

The low temperature and natural air systems combine the drying and storage functions in one facility. In addition, they are usually more energy efficient than high temperature systems. Low temperature and natural air systems result in better quality grain with fewer stress cracks and reduce the reliance on propane and natural gas (Schwart and Hill, 1977).

A major disadvantage encountered by natural air and low temperature systems is that harvest must be delayed until average daily temperatures fall below 50^{o}F. Moisture content of the grain must be below 26 percent and all bins are limited to 16 feet in height in order to achieve sufficient airflow (Schwart and Hill, 1977). Other disadvantages include a spoilage risk due to bad weather. Overdrying of the grain in the bottom half of the bin can occur with low temperature systems (Silva, 1980).

2.3 Combination or Hybrid Systems

Hybrid or combination systems (HT/LT) are drying systems which combine techniques from both low and high temperature methods. These systems generally use a high temperature dryer to remove the first few points of moisture from the grain. Then the grain is transferred to the low temperature phase of the system (Shove, 1978).

One example of combination drying is known as dryeration. This technique was developed by Foster (1964) and involves drying and aeration of the grain. In dryeration, the corn is removed from a high temperature dryer, without cooling, at a moisture content 2-3 percent above the desired final level. After steeping in a tempering tank for 6 to 10 hours, the grain is cooled at low airflow rates (0.5 to 1.0 CFM per bushel) (Brooker, 1978; Schwart and Hill, 1977).

Another example of a hybrid grain drying system is combining a high temperature dryer with a low temperature or natural air drying facility. This technique is similar to dryeration except corn is usually discharged from the high temperature dryer into the storage bins, without tempering, at a higher moisture content (18 to 22 percent). Drying is then completed with low temperature or natural air methods (Shove, 1978; Brooker, 1978; Schwart and Hill, 1977).

A main advantage of the combination process is the improvement in grain quality. Gustafson et al. (1976) and Shove and White (1977) showed that susceptibility to breakage was reduced substantially by eliminating rapid cooling of hot grain and rapid moisture content decreases through the 18-15 percent range.

Foster (1964) discovered that dryeration prevents most of the stress cracks associated with high temperature drying and reduces breakage susceptibility by 50 percent. Other advantages include increased fuel efficiency and increased drying capacity (Brooker et al., 1978; Kalchik et al., 1981).

2.4 Summary of Drying Systems

High temperature dryers use high airflow rates and high drying air temperatures to dry corn to a safe storage level in a relatively short period of time. The two predominate types of high temperature dryers are the batch and the continuous flow systems. The main advantages of these systems are their speed and low labor and management requirements. The disadvantages are the high energy requirements and the negative effects they have on corn quality.

Alternatively, low temperature drying systems use low airflow rates and low drying air temperatures. However, these systems require the grain to remain in the dryer for extended periods of time. Two examples of this method are the low temperature and natural air systems. The advantages of these systems are low energy requirements and high grain quality. The disadvantages are the low drying capacity and high labor and management requirements.

Hybrid or combination systems use techniques from both the low and high temperature methods. They are generally composed of a high temperature and a low temperature dryer. An example of this is the dryeration technique. Combination systems produce better quality grain then the high temperature systems and have a faster drying rate than the low temperature systems.

CHAPTER 3

REVIEW OF LITERATURE ON CORN QUALITY AND ECONOMICS OF GRAIN DRYING

As the production of corn in the United States has grown, so has the complexity of the marketing channels. Increased specialization on farms has resulted in many farmers marketing their entire crop commercially. The increase in volume of the export market has led to a growing number of intermediaries between the farm and the final user. Therefore the need has arisen for methods to quickly and accurately measure the quality of corn as it passes through market channels.

3.1 Measures of Corn Quality

Of the many measures of corn quality, broken corn and foreign material (BCFM) is one of the most commonly used in commercial trade. Albert (1975) defines BCFM as pieces of corn, fines, and cob fragments. Also included may be a few weed seeds and soybeans. It is the level of BCFM in corn that directly affects its quality. Broken kernels increase susceptibility to attack by insects and molds. Corn fines tend to cause stored grain to compact, blocking air movement in the grain and contribute to internal heating when moisture levels are high (Albert, 1975). High levels of BCFM also increase the chances of dust explosions (Hill et al., 1976).

Breakage tests are also used to measure corn quality. Determined in these tests are the susceptibility of the corn kernel to breakage during handling. By subjecting the sample to a predetermined loading or impact condition, the probable damage during handling can be predicted (Silva, 1980). Sieving the sample after performing this test gives the percentage of broken corn due to mechanical damage.

A third measure of corn quality is stress cracks. According to Thompson and Foster (1963), stress cracks are fissures in the endosperm or starchy inside of the kernel in which the seed coat is not ruptured. Hamilton et al. (1972) agree with this definition and add that stress cracks increase the susceptibility to breakage during handling, storing and processing. Stress cracks can be observed easily when illuminated from below, a method similar to candling eggs (Roberts, 1972).

3.2 Methods of Testing Corn Quality

The amount of BCFM in a sample is a measure of the level of physical damage that has occurred. Ways of measuring this include sieving and fast green dye tests. Equations to predict the amount of kernel damage have also been developed.

The growing need for information concerning the likelihood of corn breakage during handling and shipping has led to the development of a number of corn breakage testers. The purpose of these devices is to measure the chance of kernel breakage during handling. The Stein Breakage tester is the predominate method of determining this quality parameter.

Stress cracks as a measure of corn quality are not used as often as breakage tests or BCFM levels. This is due to the tedious and relatively more subjective techniques used to determine the level of stress cracked kernels in samples (Watson et al., 1983).

3.2.1 Measures of Physical Damage

According to the Official U.S. Standards for Grain, BCFM is measured by determining the relative fraction of kernels and pieces of kernels of corn and all matter other than corn which passes readily through a 12/64 inch sieve, and all matter other than corn which remains in the sieved sample (USDA, 1975).

Methods other than sieving have been used to determine levels of broken corn. In 1982 Paulsen et al. used fast green dye tests to determine pericarp damage to kernels after impact. Kernels with small pericarp cracks that absorbed the dye and those with broken pieces of endosperm were considered damaged.

Chowbury and Buchele (1976) used a similar method involving fast green dyes. In their study, a colorimeter was used to measure the amount of dye absorbed by damaged kernels.

Damage indices have also been developed to measure broken kernels. Foster and Holman (1973) found breakage to be an exponential function of velocity. The equation is of the form:

$$B = cV^n$$

where: B = percentage breakage

V = velocity in feet per minute

and: "c" and "n" equal constants related to the kind of grain, its moisture content and temperature

Chowbury and Buchele (1976) developed a damage index that categorized several levels of corn kernel damage and used a weighted average to measure the overall damage level. This equation is presented below.

$$DI = \frac{D_1 d_1 + D_2 d_2 + D_3 d_3 + D_4 d_4 + D_5 d_5}{10}$$

where: DI = damage index

$D_1 = D_2 = 10$

$D_3 = 6$

$D_4 = 2$

$D_5 = 1$

and: d_1 = percent broken kernels and fine material passing through a 12/64 inch sieve.

d_2 = percent broken, chipped, and crushed kernels (more than one third of the whole kernel missing).

d_3 = percent kernels with open cracks, chipped, and severe pericarp damage.

d_4 = percent kernels with hairline cracks and spots of pericarp missing

d_5 = percent whole kernels

The authors claimed this index produced qualitative and quantitative measurements of damage.

Although measures of broken corn are able to show the levels of BCFM at a specific point in time, BCFM is not useful as a predictor of the susceptibility of corn to damage during handling and shipping. It is important for grain handlers and users to be able to predict the increase in levels of broken corn kernels.

3.2.2 Breakage Testers

One of the more common breakage testers is the Stein Breakage Test. This machine uses both impact and abrasion to measure a kernel's ability to withstand mechanical damage (Watson et al., 1983). It is usually run for 2 or 4 minutes. The 4 minute tests produce breakage scores approximately twice that of the 2 minute test (Paulsen et al., 1980). By sieving the samples after testing, the percentage increase in broken corn can be determined.

Stephen and Foster (1976) showed a good correlation between breakage of market corn due to handling and predicted results from the Stein tester. They cautioned, however, that wide variations in grain properties, without compensating test procedures, often lead to inconsistent or irreproduceable results. Hill and Paulsen (1976) used a Stein tester to show that corn unloaded from barges and emptied into concrete bins showed a 100 percent increase in breakage susceptibility over the level when the barges were initially loaded.

Although the Stein tester has been used for about 20 years, it has not been adopted to any extent in grain elevators for assessing corn breakage susceptibility. The probable reason is the length of time required for analysis and the large number of manipulations required (Watson et al., 1983).

Other breakage testers are also used regularly. Sharda and Herum (1977) developed a centrifugal impactor. This device used a rotating impeller to impact the kernels against a stationary metal shroud. In 1977, Sharda and Herum claimed the centrifugal impactor was more sensitive than the Stein. However, in 1981, Herum and Blaisdel compared a centrifugal impactor, a Stein tester, and a modified Stein tester and found no single test superior. Paulsen and Hill (1980) showed that the coefficients of variation were lower for the centrifugal impactor than for the 2 and 4 minute Stein test.

In 1980, six recently developed breakage testers were compared against the Stein tester. Four of these devices had coeffecients of variation (CV) of six percent or less. In 1981, four of these devices had CVs of five percent or less, half that of the Stein. A device developed by the University of Wisconsin consistently showed the lowest CV in both years (Watson et al., 1983). Other less common methods have also been used to determine breakage susceptibility. Thompson and Foster (1963) used three different testers- a commercial breakage tester, a peanut splitter, and a modified food blender.

The condition of the grain at the time it is being tested is an important consideration no matter which test is being used. Moisture content and temperature of the sample appear to be the most important parameters influencing the outcome of the breakage tests. Foster and Holman (1973) showed that a decrease of only a little more than two percent in the moisture level at which the corn was handled resulted in a threefold increase in breakage. They also claimed that handling corn near $80^{O}F$ rather than near $40^{O}F$ reduced breakage nearly 50 percent.

Thompson and Foster (1963) stated that moisture content and temperature of the grain at the time the test is made may influence the breakage even more than the usual variations in drying methods.

3.2.3 Measurements of Stress Cracks

Testing corn kernels for stress cracks is another way of measuring quality in corn. For the most part stress cracks _per se_ do not cause quality problems although manufacturers of grits do complain of lower yields of large grits from kernels with multiple stress cracks (Thompson and Foster, 1963). It is the correlation between stress cracks and breakage from handling that interests most corn users and handlers.

Thompson and Foster (1963) evaluated kernels under a bright light to determine the number of stress cracks. They found that stress crack evaluation can be useful not only in detecting corn that has been dried rapidly, but also in predicting increases in the material that may be expected from breakage during handling.

Chrowbury and Kline (1978) used a candling method to determine the number and extent of stress-cracked kernels. Their tests showed four types of stress cracks were common (See Figure 1).

3.3 The Corn Grain Quality Problem

Research results on the effects of high temperature drying on corn quality are cited in this section. As drying temperatures increase, breakage susceptibility of the corn kernel increases and stress cracks appear in the endosperm. A result of increased breakage susceptibility and stress cracks is a buildup of broken corn as repeated handling occurs.

Kline (1972) established a definite link between high temperature drying and reduced quality corn. He noted a substantial increase in broken corn after drying at high temperatures. The results of the breakage test before drying showed 5.5 percent broken corn. This figure rose to 12.7 percent after drying. Because drying with heated air increases the amount of broken corn during the breakage test, Kline stated that the amount of broken kernels may be expected to increase with multiple handling of artificially dried corn in market channels.

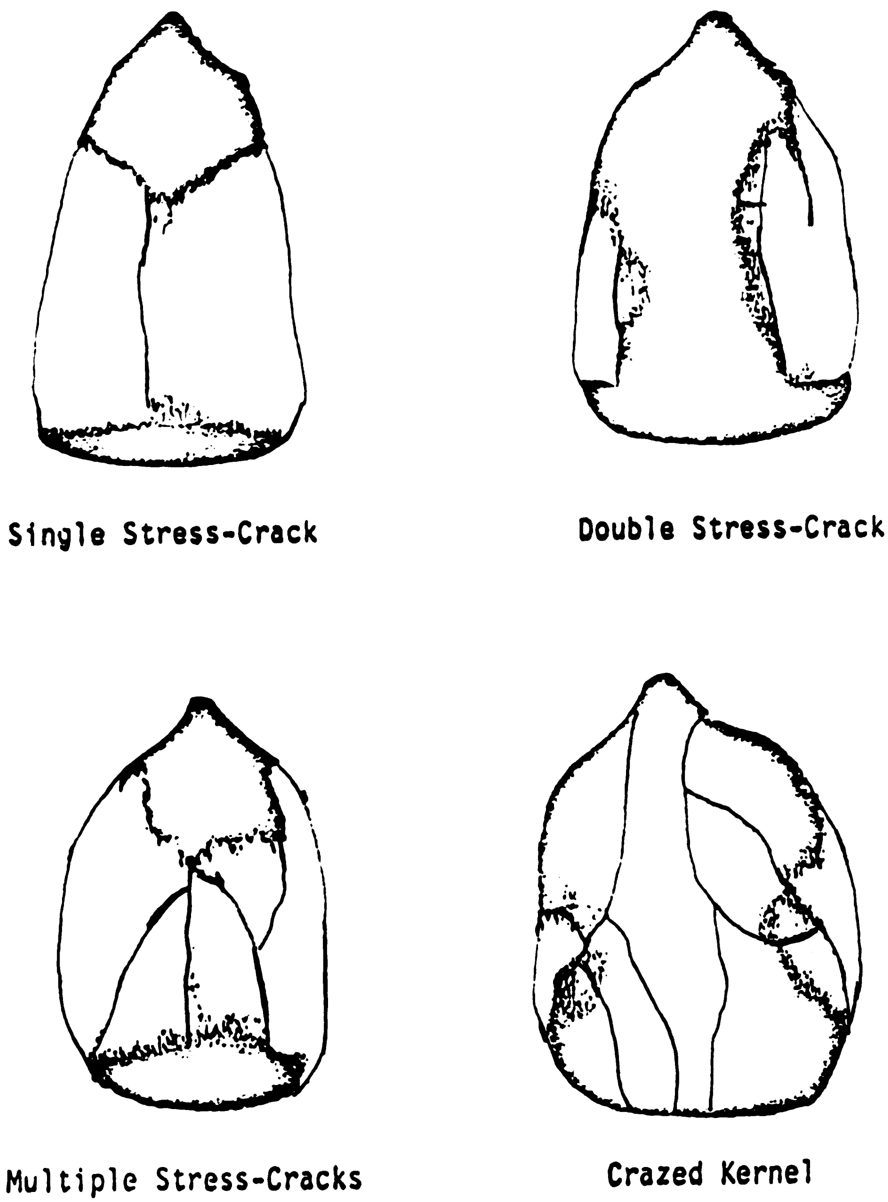

Figure 1: Four common types of stress cracks. From Chowbury and Kline, 1978.

By using a Stein Breakage Tester, Shove (1978) showed a distinct difference in breakage susceptibility between corn dried with natural air and corn dried artifically at high temperatures. Differences in breakage of up to 11 percent by weight were obtained.

Hurburgh and Moechnig (1982) found that BCFM, breakage susceptibility, and kernel damage increased through the continuous-flow drying and related handling procedures at country elevators in Iowa and Nebraska. They found a fourfold increase in breakage susceptibility and a twofold increase in physical kernel damage after drying.

Thompson and Foster (1963) showed that shelled corn dried at 140-240°F was two to three times more susceptible to breakage than the same corn dried with unheated air. In addition, they asserted that high temperature drying caused stress cracks which appeared to account for much of the increased susceptibility to breakage. They claimed that the most significant factor leading to stress crack development was drying speed expressed in terms of moisture loss in percentage points per hour. The majority of the stress cracks developed when the corn was dried through the 18-15 percent moisture content range. Rapid cooling increased the number of stress cracks while delayed cooling had an opposite effect (Thompson and Foster, 1963; Hamilton et al., 1972).

Foster and Holman (1973) found that 80-85 percent of the kernels they studied had stress cracks resulting from rapid drying or machine harvesting or both.

According to Leath (1983), Purdue researchers have found that high temperature drying increased the corn kernel's susceptibility to mold invasion. If the temperatures were high enough to kill the kernel's viability, the kernel attracted and absorbed moisture from the air.

Increased moisture made the grain mass vulnerable to invasion by molds during storage.

Another experiment compared corn dried at high temperature (HT) with corn dried at low temperature (LT). The samples were stored at 84 percent relative humidity. Mold was found to develop much faster on the HT samples than on the LT samples.

Temperature of the air used to dry corn is not the only factor in reducing quality. In 1978, Gustafsen et al. concluded that drying to a final moisture content above 18 percent does not necessarily cause a significant increase in breakage susceptibility. In fact, the product of heating time and change of moisture content appeared to be the best predictor of change in breakage.

Ross and White (1972) included drying rate, drying systems, initial moisture content, and cooling rate as possible reasons for stress crack formation.

In summary, it is evident that high temperature drying plays an important role in the deterioration of corn quality. Silva (1980) stated that although drying *per se* does not directly affect the number of broken kernels, drying at high temperatures physically and physiologically damages grain. This can be expected to increase the grain's susceptibility to handling damage.

3.4 Physical Problems With Low Quality Corn

The effects of high temperatures during the drying process has been shown. It is worthwhile, therefore, to mention the effects that poor quality corn has on the eventual users of corn. Four areas that will be discussed are:

- the feed industry
- the dry milling industry
- the wet milling industry
- grain handlers and exporters

3.4.1 Feed Industry Problems

A large portion of corn grown in the U.S. is used for animal feed. It is therefore necessary to look at the effects of corn quality on feed processors and users. Van Wormer (1972) stated that some feed quality control workers would like to be able to detect overheated or overdried corn because they experienced problems with palatability of the feed as well as an increase in shattering during the production of coarse ground corn in the feed mill. He also cited mold susceptibility and heat damage as two major quality problems confronting the feed industry.

In 1952, Hathaway et al. showed the effects of heat damage on corn. Drying temperatures above 140°F significantly decreased energy and palatability levels as measured by feeding trials with rats.

Jensen (1978) showed that roasting corn at 14 percent and 23 percent moisture reduced lysine availability at 302°F and 261°F. Pyroxidine availability was significantly reduced when 14 percent moisture corn was dried at 320°F, but niacin levels remained unchanged.

Sullivan (1975), however, argues that a decrease in the commercial grade of corn grain due to drying at high temperatures may not correspond to a decrease in value as an animal feed, even though heat has a definite effect on the nutritional value of corn.

Drying corn at 140°F, 180°F, and 219°F had no deleterious effects on the nutritive value of corn for swine, as measured by growth rate and feed use (Jensen et al., 1960).

Despite the disagreement on the actual effects of heat damage on corn used for animal feed, most researchers agree that drying temperature does affect physical and chemical characteristics such as consistency, energy content, palatability, color, moisture, and protein and amino acid profiles (Williamson, 1975).

A problem on the horizon concerning corn quality in the feed industry is the presence of molds capable of producing toxins. Aflatoxin in peanut meal caused the death of large number of turkeys in England in 1960 (VanWormer, 1972). Cracked and broken kernels make aeration difficult and invite attacks by molds, according to Anderson (1972).

3.4.2 Quality Problems in the Dry Milling Industry

There are three major quality problems which affect dry millers directly. These are mold damage, heat damage, and mechanical damage. It has been shown that an intact pericarp is a major line of defense against invasion of molds. There is an increased risk of mold formation when high levels of broken corn or stress cracks, which enhance the susceptibility of corn to breakage, are present. Dry millers are opposed to mold and the associated mycotoxins it can produce because the major portion of their production (e.g. low fat grits, meals and flours, and corn oil) is sold to food and brewing industries (Roberts, 1972).

Low yield of prime products is the most obvious effect of mechanical damage in a dry milling operation. Broken kernels must be screened out prior to the actual milling operation thereby reducing yield per bushel (Roberts, 1972).

Stress cracks, a form of mechanical damage, are also bad for dry millers. Kernels with multiple stress cracks appreciably lower the yield of large flaking grits, a valuable product for dry millers (Roberts, 1972).

Brekke et al. (1973) showed that yields from the first break (fractions over 5W and 7W screens) were 14 percent and 4 percent, respectively, for 90^{o}F and 289.9^{o}F dried corn.

According to Leath (1983), researchers at Purdue developed a mill evaluation factor (MEF) to indicate desirable dry milling characteristics (high yields to total endosperm products and large flaking grits). The results showed that high temperature drying (201^{o}F) reduced kernel density and MEF values for all corn samples. Low temperature drying (100^{o}F) resulted in higher MEF scores.

Heat damage causes dry millers concern because it lowers the levels of fermentable carbohydrates. Brewing and fermentation industries use dry milled corn as sources of fermentable carbohydrates and any reduction of carbohydrates lowers the value to them (Roberts, 1972).

Stress cracks lower end-use values in dry milling because the yield of large flaking grits is reduced and the fat content of all grits is increased above desired levels.

3.4.3 Quality Problems in the Wet Milling Industry

According to Freeman (1972), there are four main problems in the wet milling industry caused by low quality corn. They are:

- poor millability

- low oil recovery
- low starch viscosity
- low pigment content of the corn gluten

Millability is a measure of the ease with which starch and protein can be separated from the endosperm and purified by normal processes. Drying, claims Freeman, has the greatest effect on reducing millability

The quantity of oil which can be recovered by wet milling of corn significantly influences the value of the corn. Mold grow preferentially on the germ depleting it of its oil and reducing potential oil yield.

Drying corn from 30 to 15 percent moisture in one pass caused a 25 percent reduction in grind capacity, poor dewatering of course fiber, increased starch in gluten with a correspondingly lower starch yield per bushel of corn, higher protein content of isolated starch, and low starch viscosity or thickening power. (Freeman, 1972)

Liebenow (1972) also complained of problems associated with poor quality corn in the wet milling industry. Heat and mold damage of the germ causes oxidation and the formation of free fatty acids which lower the yield and quality of the oil extracted.

Secondly, mechanically damaged kernels are more susceptible to molds and fungi invasion which degrade oil and may result in development of mycotoxins. Mechanically damaged and stress cracked kernels also lead to substantial losses in the cleaning and screening operations. Such raw materials can only be used for non-feed products.

In addition, heat damaged corn sometimes makes it difficult to separate the protein from the starch and changes the viscosity. Lastly, damaged corn increases losses due to insect infestation.

3.4.4 Quality Problems Affecting Grain Handlers and Exporters

Poor quality corn not only affects the final user or processor but it has negative effects on firms which store and handle the corn between the farm and the final users. Quality problems in export markets are also becoming increasingly important to the U.S. corn industry. Butz (1975) argued that the U.S. has forced its grades on foreign buyers because it has enjoyed a seller's market. This is changing, however, as competition is increasing in world corn production. He asserted that the U.S. may have to give more market service in order to keep its competitive advantage.

Anderson (1975) cited many problems with poor quality corn as it affects grain handlers. Field shelled corn is typically 3 to 5 pounds lower in test weight. This leads to lower kernel density and inefficient use of storage space because of a lower weight of corn per volume measure of storage space. Also this corn has a greater repose angle so bins can not be filled as full. In fact, he claimed that the capacity of elevating legs at the Maumee, Ohio terminal is about 3 to 6 percent less with field-shelled artifically dried corn than with naturally dried corn.

Anderson also complained about the accumulation of broken corn beneath filling spouts. Removal of these fines is required in order to obtain satisfactory aeration of the corn in the bin. He estimated losses at one percent of capacity in addition to an increase in the amount of air needed for aeration. Another problem involving the handling of broken corn is the increased chance of dust explosions. Martin and Stephens (1977) showed a build up in fine dust emission when corn is handled and found it remained constant during repeated handlings. Seventy percent of the dust they collected was fine dust.

Broken corn and other materials which are screened out of corn before it is put in storage bins also creates a problem for handlers. Screenings are lower in price, harder to handle and store, and require more room per pound to store and transport. Anderson estimates screenings cause a loss on the average of 10 percent in storage capacity. Other losses experienced are losses of dry weight, additional housekeeping costs, and in some cases, pollution.

A fundamental problem that affects handlers and exporters is the effect of repeated handling on corn. Foster and Holman (1973) found that the amount of kernel breakage was cumulative and constant each time the same lot of corn was handled, regardless of whether the broken material was removed.

Anderson (1972) claims that these losses in quality, even through invisible, are passed on to the next recipient. The problems with export corn is further aggravated because of the unloading of export vessels by pneumatic equipment, which develop high kernel speeds and tend to shatter the brittle kernels.

Hill and Paulsen (1976) reported in one instance, pneumatic suckers and associated unloading procedures increased BCFM by approximately 3.1 percentage points and decreased whole kernels by 2.6 percentage points. In contrast, hand unloading procedures increased BCFM by only 0.75 percentage points with no decrease in whole kernels.

In order to illustrate the problem of quality deterioration in the export industry, Hill and Paulsen (1977) followed a shipment of corn from a Peoria, Illinois elevator down the Mississippi River to Mexico. They claimed the most important quality change in corn during handling and transportation was the increase in percentage of BCFM. In fact, they showed that average BCFM increased from 1.2 percent at origin to 5.3 percent at destination.

Stein breakage tests and stress crack tests showed a less visible, but important change. Corn at Peoria had an initial Stein breakage reading of 3.07 percent. Multiple stress cracks were found in 13.6 percent of the kernels. By the time the corn had been loaded into storage bins at New Orleans, the breakage test reading had increased to 32.1 percent. They concluded, therefore, that handling and transporting did more than just increase BCFM; it also led to a weakening in kernel structure and an increased susceptibility to breakage.

In a similar study, Hill et al. (1979) followed a shipment of corn from two elevators in Indiana and Illinois to Manchester, England. They showed that at the origin, the shipment consisted of 13,922 tons of corn of which 13,525 tons was clean corn and 397 tons (2.9%) was BCFM. At the final destination, the shipment weighed 13,260 tons of which 12,345 tons was clean corn and 915 tons (6.9%) was BCFM. The loss in total weight was 622 tons, the loss in clean corn was 1,180 tons. BCFM increased 4.0 percent despite the removal of 621 tons of screenings.

In a more recent study by Hill et al. (1981) eleven export vessels were sampled at origin and destination. Increases in BCFM ranged from 1.8 to 6.9 percentage points. The lowest increase, 1.8 percent, was linked to vessels listed in a "gentle handling" category. The average increase for all vessels was 3.6 percentage points. Origin grade for all vessels was No. 3 yellow corn while destination grade ranged from No. 4 to sample grade. The factor determining grade in all cases was broken corn and foreign material.

The Agricultural Attache for the U.S. Embassy in London, England summarized the problem of low quality corn in export markets. Following are excerpts from his report.

> The Embassy has received numerous complaints from the U.K. grain trade on the high percentage of dust and broken kernels in U.S. corn in the past two to three years... In all cases the content of broken corn, foreign material (including dust), damaged kernels and heat damaged kernels exceeds the tolerances of the U.S. Official Grain Standards... We hope the FAS/W will get the word to U.S. corn industry from farmer to shipper that present methods of marketing U.S. corn, no matter how efficient they might seem, are not serving the U.S.'s longer term export interests here in the U.K. (Kline, 1972).

3.5 Economic Impact of Quality Problems

It is clear that quality problems in corn do affect users and handlers of corn. Problems such as mold contamination during storage to reduced yields of prime products during milling are readily quantifiable and have been documented. However, in any industry where profit is a primary motive, the economic impact of these problems should be assessed. Although reliable data on costs of low quality corn in industry are not readily available (Anderson, 1975), an attempt to roughly define these costs is worthwhile.

In the export market, it is reasonable to assume that as corn quality declines, its demand at any given price will decline, all other factors being equal. Anderson (1975) maintained that total domestic disappearance of U.S. grain is relatively insensitive to its price while export disappearance is relatively sensitive to its price. In his study, Anderson assumed a domestic demand elasticity of -0.7 and an export demand of elasticity of -2.0. A 3.0 percent decrease in price of of all U.S. corn would increase total domestic disappearance by about 2 percent, while the same change would increase total export disappearance by about 6 percent. Furthermore, he assumed quality and price are closely related, a decrease in quality should have a similar effect on quantity demanded. Therefore, the domestic market should be relatively insensitive to quality differences and the export market should be relatively sensitive to quality differences.

The impact of broken corn at elevators and grain terminals was estimated by Anderson (1975) at their Maumee and Toledo terminals to be 3/4 cent per bushel. This cost was primarily due to the discount on corn screenings and thus was dependent on the sale price of corn screenings and the amount of screenings removed. Furthermore, the price difference between high quality Argentine corn and U.S. No. 2 was about 2.2 cents per bushel in May 1970, so the total cost for physical damage in corn was about 3 cents per bushel. He maintained, however, that the 3 cents per bushel was underestimated because:

- it ignores the loss in quality from the European receiving point (in this instance Rotterdam) to the point of final use
- properly maintained, U.S. corn may be superior to Argentine corn
- the 3/4 cents per bushel does not include other storage and handling costs associated with damaged corn

Dobbs (1972) estimated that screenings decreased the value of corn 10 to 20 cents per 56 lb. bushel depending on the seasonal demand for animal feed and the availability of substitute feed ingredients. Inefficient use of space and uneven cooling of grain resulted in wider margins by handlers in order to cover anticipated losses.

Hill et al. (1982) showed that the price of screenings as a percentage of the price of corn varied from 69 to 77 percent with an annual average of 72 percent between October, 1975 and September, 1976.

In 1979, Hill et al. estimated that corn grain decreased in value by 12.2 cents per bushel between the time it was graded and loaded at a U.S. port and received by the final users in England. They arrived at this figure by assuming that each percentage point of BCFM above 3 percent reduces the corn's value by 2 percent according to 1977 prices and discounts. This estimate, however, did not include other costs of broken corn such as the cost of cleaning and blending, additional aeration required, increased risk of mold damage and dust explosions, and physical loss from dust associated with broken kernels.

As noted earlier, Anderson estimated storage losses due to broken corn at about 3 to 6 percent of capacity. Assuming a storage charge of 3 cents per bushel per month, a storage facility whose capacity is one million bushels loses between $900 and $1,800 per month during times when storage space is needed because of poor quality corn.

Roberts (1972) made an attempt to estimate the cost in the milling industry attributable to damaged and broken corn. He estimated that a miller loses about 17 cents on each bushel of screening removed assuming a $6 per ton difference between cash corn price and the selling price of hominy feed. A 30,000 bushel per day mill operating 300 days annually with 3 percent screenings would lose $45,000 per year.

Anderson (1975) summarizes some of the costs associated with low quality corn. Although not quantifiable, these costs are probably recognized by many participants throughout the corn marketing channels.

Cost to Marketers: These include losses due to differences in value between corn and all corn screenings removed from the corn, losses of dry weight due to mechanical damage and physiological processes and from insects, rodents, and birds, dirty and dusty facilities and increased hazards of fire and explosion, and increased aeration fan running time.

Cost to Farmers: These include losses of dry weight during and after harvest from mechanical and physiological processes and from insects, rodents, and birds.

Unknown and Potential Costs: These include risk of contamination by aflatoxins and other known mycotoxins of storage fungi due to concentrated handling at grain elevators and blending higher moisture corn with lower moisture corn. Also included are costs attributable to pollution of the environment by corn dust and the release of fungal spores into the air.

3.6 Cost Evaluation of Different Drying Systems

Many studies have been done attempting to show the cost to own and operate corn drying and storage facilities. Following is a summary showing the economic costs of owning and operating grain drying and storage systems.

In 1970, Hill used linear programming to compare the alternatives of drying corn on the farm or drying commercially at the elevator. He analyzed a batch-in-bin dryer at 300 hours of operation per season and an average moisture reduction of ten percentage points. Total annual ownership and operating costs were shown to be .78 cents per bushel per point of moisture removed. Hill claimed that the profitability of on-farm drying relative to drying at the elevator was dependent on farm size. As larger capacity dryers are used, the price per bushel of capacity decreases. In addition, labor requirements per bushel dried declines rapidly as dryer capacity increases.

Scott (1970) used an economic-engineering approach to determine the costs of drying and storing corn on the farm. He found the initial investment cost of a batch-in-bin dryer and storage facility ranged from 61.6 cents per bushel for a 310 acre (31,000 bu.) farm to 48 cents per bushel for a 700 acre (69,900 bu.) farm. The total annual costs for drying and storage of corn from harvest to mid July ranged from 1.78 to 1.62 cents per bushel per point of moisture removed from the 310 acre and 700 acre farms, respectively.

In 1975, Loewer et al. assembled a list of purchase prices and incorporated them into the computer design simulation BNDZN in order to compare purchase and annual costs for layer, batch-in-bin, and portable batch drying and storage facilities. This study showed that purchase and annual cost per bushel decreased rapidly for capacities up to 20,000 bushels per year and then tended to decrease at a lesser but more uniform rate. The results also showed that layer drying had an economic advantage for capacities up to 10,000 bushels per year. Batch-in-bin and portable batch drying were competitive in purchase price at all capacities but batch-in-bin systems showed significantly less annual cost due to increased fuel efficiency and less investment in the "dryer equipment" category.

Schwart and Hill (1977) compared six different corn drying and storage facilities over a range of farm capacities. The different dryers studied were batch-in-bin dryers, bin dryers with stirring devices, low temperature (electric) dryers, automatic batch dryers, and continuous flow dryers. The results of this study showed that the batch-in-bin dryers were the most economical for volumes ranging from 5,000 to 20,000 bushels. For volumes ranging from 20,000 to 80,000 bushels per year a batch-in-bin with a stirring device was the least cost alternative. Automatic batch and continuous flow dryers were more cost effective than the batch-in-bin systems at volumes of 80,000 and 100,000 bushels per year. The low temperature drying system produced better quality grain but its cost was consistently above all other systems at volumes exceeding 10,000 bushels per year. The high costs of this system were due mainly to the increased number of bins because bin height is limited to 16 feet on low temperature systems.

Smith and Baldwin (1975) obtained cost data on five different corn drying and storage systems at various volume levels. The systems studied were:

- natural air drying and crib storage
- continuous flow drying
- automatic batch drying
- batch-in-bin drying
- low temperature drying

At an annual volume of 20,000 bushels, they reported the automatic batch process to be the least costly. The batch-in-bin, low temperature, and continuous flow facilities ranked second, third, and fourth, respectively.

However, the batch-in-bin system became the best alternative at the 40,000 bushel production level. After this, expense increased from automatic batch to low temperature to continuous flow systems.

At the 60,000 bushel production level, the batch-in-bin system was shown to be the most economical. The second least expensive system was the automatic batch facility followed by the continuous flow and low temperature systems.

Skees et al. (1979) used a computer model to perform a capital budgeting cost analysis on three different on-farm grain drying systems at various capacities. The systems included low temperature drying, batch-in-bin drying, and portable batch drying. The results of this study showed the batch-in-bin system at 30,000 bushels annually to be the least expensive (30.43 cents per bushel). The other corn drying systems were ranked as follows: portable batch (53,000 bushels), 34.23 cents per bushel; low temperature (6,000 bushels), 35.28 cents per bushel; and low temperature (10,000 bushels), 40.28 cents per bushel.

Madsen et al. (1976) analyzed the effects of volume and increasing energy prices for three classes of corn drying and storage systems. Systems analyzed included high temperature systems that rely on relatively large amounts of fossil fuel, low temperature systems that rely mainly on electrical power, and hybrid systems which combine both high and low temperature methods. The capacity levels at which the systems were evaluated were 10,000, 20,000, 40,000 and 60,000 or more bushels per year.

At a farm production level of 10,000 bushels per year, the most economical method was the low temperature system. After allowing the "modest" and "significant" energy price increases, this technique still remained the most economical.

Under a "modest" energy price increase scenario at the 20,000 bushel per year level, the batch-in-bin system had a slight edge over the low temperature and automatic batch/dryeration systems. In the case of a "significant" energy price increase, the low temperature system became more cost effective.

Dryeration with an automatic batch dryer was shown to be most economical at 40,000 bushels during periods of "modest" energy price increases. During periods of "significant" increase in energy prices, the low temperature system became the least-cost method due to its heavier reliance on electricity as an energy source.

In all cases, the continuous flow/dryeration system was most economical at farm production levels exceeding 60,000 bushels per year.

In a report written by Schwart (1982), four drying systems were analyzed for ownership and operating costs at varying volumes. At annual volume levels of 10,000 and 25,000 bushels, the batch-in-bin system proved to be the most economical. Following in order of increasing cost were: batch-in-bin with a stirring device, automatic batch drying and continuous flow drying.

At production levels of 50,000 bushels per year, the batch-in-bin with a stirring device replaced the batch-in-bin system without a stirrer as the least-cost system. The automatic batch and continuous flow systems placed third and fourth, respectively.

At annual production levels exceeding 75,000 bushels, the batch-in-bin with a stirrer was still the most economical method. However, the continuous flow dryer showed slighlty better cost performance than the automatic batch dryer. The batch-in-bin system without a stirrer was still only slightly more costly than the batch-in-bin with a stirrer.

The above studies showed that grain drying and storage costs decrease as volume increases. This is due to lower per bushel investment costs. Some researchers also showed that low temperature systems were cost effective at low volume, but became relatively more expensive as capacity was increased. The batch-in-bin system seemed to be cost effective choice in many situations although automatic batch and continuous flow dryers remained cost competitive. Madsen et al. showed that drying systems that rely heavily on fossil fuel for an energy source lose some of their cost effectiveness as energy prices increase.

CHAPTER 4

METHODOLOGY

An important objective of this study is to analyze the economics of alternative drying and storage techniques. Discussed in this chapter are the methods used in this analysis. The economic-engineering approach is used to establish the equipment requirements and other physical inputs. A capital budgeting model entitled "Capital Investment Model--Including Buy or Custom Hire," Telplan 3, Version 4 is employed to perform the cost analysis of each system.

4.1 The Economic-Engineering Approach

The economic-engineering approach is used to provide the physical design specifications of the alternative systems. Each system is designed to replicate as closely as possible realistic farm situations. The economic-engineering technique, also known as the building block approach, the engineering approach, or the synthetic approach, estimates production functions from engineering data. This method produces a descriptive layout of all the hardware needed to dry and store corn using five alternative technologies. It also determines inputs required to operate the facilities (e.g., LP gas, electricity, labor).

There are three primary uses for the economic-engineering approach. Finding optimal firm or plant size can be accomplished by developing cost structures for a number of different size plants and choosing the most cost efficient one. Comparing the cost efficiency of different production methods is useful in deciding on which method of production is most profitable and should therefore be adopted. Finally, the economic-engineering approach can be used to generate descriptive and definitive cost models (French, 1977).

According to French, the economic-engineering method has four basic steps. They are:

1. System description. In this step the system or production process is described. It requires familiarity of the researcher with the technical aspects of the production methods.

2. Specification of alternative production techniques. This step focuses on the different means of production which are being compared. Different production techniques within a firm as well as different sizes of firms can be studied.

3. Estimation of the production function. This step requires determining the input-output relationships. Engineering data is important in this step.

4. Synthesis of the cost function. This is the final step which produces the results. Factor prices are applied to the previously developed production function to obtain a cost function.

A major strength of the economic-engineering approach surfaces when accounting data are not available. Since the foundation of this technique rests on calculating from engineering data all inputs which contribute to cost, there is no requirement for accounting records.

Similarily, this approach can generate cost functions for multi-product firms because of its dependence on engineering data. In the same way, variation in length of operations can be addressed.

High research costs are the major limitation of the economic-engineering method. The high costs are usually the result of generating enough engineering data to make the study possible. Another weakness is the possibility of overlooking some aspect of cost, particularly on larger models (French, 1977).

The economic-engineering method will benefit this study because of the building block approach it employs. In order to accomplish the goal of comparing corn drying and storage costs to quality parameters, the type of equipment used must be similar to the equipment used on the Kalchik farm where the quality data was generated. The economic-engineering approach gives the researcher control in formulating the type and size of equipment to be studied.

It is argued that high research costsare an obstacle when using the economic-engineering method. In this study, however, it is felt that the high cost normally associated with the economic-engineering method will not be a factor. Much of the information regarding the physical layout of the drying facilities and investment costs are available from agricultural engineers and equipment dealers. Other engineering information, including input-output relationships, is available in many of the engineering studies done on corn drying and storage.

4.2 Description of Alternative Drying and Storage Systems

The five drying and storage systems under consideration in this study are composed of two high temperature systems and three combination systems. More specifically, these systems are:

1. the automatic batch system
2. the in-bin counterflow system
3. the automatic batch/dryeration system
4. the automatic batch/low temperature combination system
5. the automatic batch/natural air combination system

The drying and storing techniques described are modeled after those studied by Kalchik et al. (1979) at Bellaire, Michigan.

1. Automatic batch system. The main components in this system are the automatic batch dryer and the storage bins. All the grain drying and cooling takes place in the dryer. The sole function of the storage bins is to store and maintain the condition of the grain. The dryer is a high temperature, two-stage batch dryer (219-239^{O}F; 180^{O}F). The dryer reduces the moisture content of the grain from 26 percent to 15.5 percent.

2. In-bin counterflow (Shivvers) system. This grain drying system consists of a Shivvers dryer and storage bins. Grain drying temperature is approximately 160^{O}F. This system differs from the automatic batch system in that hot grain is delivered from the dryer into the storage bins. Therefore, the storage bins provide both the cooling function as well as storing and maintaining the grain. Consequently, the grain can be moved to the storage bins when the moisture content is about 3 percent above the desired level (15.5%).

3. Automatic batch/dryeration system. This system consists of three main components--an automatic batch dryer, a tempering or steeping bin, and storage bins. In this system grain is partially dried from 26 percent to 20 percent in the automatic batch dryer and then transferred to a tempering bin where it remains without aeration for

8 to 12 hours. The tempering bin holds the amount of corn dried in one full day. After tempering, the grain moves to the storage bin where final cooling, drying and storage occurs. Airflow rate required during the cooling phase in the storage bin is 1 cubic foot per minute (CFM) per bushel.

4. Automatic batch/low temperature combination system. This technique requires an automatic batch dryer and a low temperature drying/storage bin. The grain is dried to 23 percent moisture content in the automatic batch dryer. It is then transferred without cooling to the low temperature bin. Here the grain is further dried with heated air (3^{o} to 5^{o}F above ambient air temperature) until the desired moisture level is reached (15.5%). The airflow rate for the low temperature bin it is approximately 2.0 CFM per bushel.

5. Automatic batch/natural air combination system. This system is similar to the automatic batch/low temperature combination system. However, instead of a low temperature drying/storage bin, a natural air bin is used. No heated air (except for approximately 2^{o}F from the fan motor) is applied to the grain after it is transferred from the batch dryer. Air is blown through the grain at a rate of 2.5 CFM per bushel until the grain reaches the desired moisture level (15.5%). It is important to note that with the low temperature and natural air systems, the bin drying phase may be postponed until spring if daily ambient air temperatures average 35^{o}F or below as long as the grain has been cooled to the ambient air temperature (Silva, 1980).

4.3 The Capital Budgeting/Net Present Value Cost Model

The capital budgeting/net present value cost model will be used because it is flexible enough to handle the time value of money, income tax effects due to owning and operating capital items, and uneven distribution of cash flows during the economic lifetime of each system.

Skees et al. (1979) used a capital budgeting/net present value cost model in their study of grain drying systems. They said this type of model would benefit their analysis because it accounts for net present value of alternative investments, allowing for comparison of investments with different annual cash flows of expenses or income as well as factors such as interest rate and life of loan, depreciation life and schedule chosen, marginal tax rate, investment tax credits, and possible inflation of variable costs.

The time value of money is an important aspect to consider. When analyzing the cost of a long term investment such as a grain drying and storage system, it is generally agreed that money received or spent today is worth more than an equivalent amount of money received or spent in the future. Having money today provides the holder with the option of spending, saving, or investing it. There is an opportunity cost associated with having money tied up until some time in the future. This concept can be called the time preference for money and it exists even in periods of stable money values (zero inflation).

Another aspect concerning the time value of money is the difference between the present purchasing power of money versus its future purchasing power. During inflationary periods, the purchasing power of money declines as time goes by. Thus a premium, in addition to, the time preference for money, must be paid to an investor to reward him for the erosion of purchasing power of his invested funds. A model which discounts future cash flows eliminates relative differences due to the time preference of money and to changes in purchasing power due to inflation or deflation.

The net present value method uses a discounting procedure to find the present value of future dollars. The equation for the present value of a stream of returns is:

$$V = \sum_{n=1}^{N} R_n / (1+i)^n \tag{4.1}$$

where: R_n = monetary amount received in time period

i = rate of interest per time period

and N = number of time periods during the lifetime of the investment

The discount rate measures the opportunity cost of money used in the investment plus some measure of the riskiness of the investment (Harsh et al., 1981).

Inflation of revenues and expenses generated by an investment can be handled quite easily by the capital budgeting method. During an inflationary period, revenues and expenses, in nominal dollars, realized from an investment can be expected to increase. This increase is offset, however, by a decrease in purchasing power of money. By including in the discount rate a component which exactly equals the expected inflation rate the effects of inflation can be negated when analyzing the investment because the discounting procedure transforms all cash flows, present and future, into present value cash flows of equal purchasing power.

The capital budgeting model also incorporates the impact of the investment on income tax liabilities. Since most investments generate tax deductible expenses, it is important to include the reduction of tax liabilities in the cost analysis. Two important expense categories which have an effect on income taxes are the non-cash expense of depreciation, and cash expenses, including interest.

Depreciation reduces the taxable income of the business. In this way depreciation serves as a tax shield. It is used to spread the cost of a durable investment over a number of years. Since depreciation is not a cash expense, its only effect is to reduce the tax obligation. Therefore it can be treated as a positive cash flow to the extent it reduces income tax liabilities. The amount of after-tax "income" can be measured by the following equation (Casler, et al., 1984).

$$TS = AD * t \tag{4.2}$$

where: TS = tax savings

AD = annual depreciation

and t = marginal income tax rate between 0 and 1

Cash expenses including interest on loans also have effects on income tax liability. Only the interest portion of loan payments is tax deductible, therefore it has the effect of reducing the tax burden. Cash expenses incurred in the production process are also tax deductible. Unlike the non-cash expense of depreciation, interest and other expenses are cash outflows and remain cash outflows even after the effect of income taxes is taken into consideration (Casler, et al., 1984). The impact of interest payments and other cash expenses on income tax liabilities is measured by the equation:

$$ATE = BTE * (1-t) \tag{4.3}$$

where: ATE = after-tax expense

BTE = before-tax expense

and t = marginal income tax rate between 0 and 1

Similarily, investments also generate taxable revenues. A capital budgeting approach adjusts revenues to an after-tax basis using the same method as above (Casler, et al., 1984).

$$ATI = BT * (1-t) \tag{4.4}$$

where: ATI = after-tax income

BTI = before-tax income

and t = marginal income tax rate between 0 and 1

Because the capital budgeting method handles uneven annual cash flows and the income tax effects of an investment, it is very useful in comparing alternative investments. Using the concepts mentioned above, a capital budgeting model calculates a figure known as the net present value (NPV) of an investment. This number is the discounted sum of all the cash flows (positive and negative) generated by the investment. A positive NPV indicates that the investment will produce a return on the investment greater than the desired rate of return or discount rate. The investment can be considered profitable and worthwhile. A negative NPV means the return on the investment is less than the desire rate of return or discount rate and the investment is not profitable. By standardizing the NPVs of several investments using a common unit of measure (e.g., \$/bushel or \$/acre), several investments can be analyzed and the investment which will generate the most after-tax net income or operate for the least cost can be determined.

CHAPTER 5

EXPERIMENTAL DESIGN AND PROCEDURES

5.1 Basic Assumptions

To evaluate the ownership and operating cost of five grain drying and storage facilities for two different farm sizes, certain qualifying assumptions were made in order to clarify some of the parameters affecting the cost of owning and operating a grain drying and storage facility.

1. In this analysis, two different farm sizes were used. Each different system was evaluated on a 30,000 bushel per year farm and an 80,000 bushel per year farm. Prior research has shown that as volume changes, the relative ranking by cost of different drying technologies changes (Schwart and Hill, 1977; Madsen et al., 1978). It is important, therefore, to evaluate these systems at two different volumes. Corn volumes of 30,000 and 80,000 bushels annually were chosen to represent medium and large size cash grain farms in Michigan according to 1982 Telfarm data (Brown and Kelsey, 1981).

2. Measurements of energy usage (LP gas and electricity) came primarily from the data collected by Kalchik et al. (1981). Although information on energy use by grain drying and storage systems was available elsewhere, it was felt that this data is the most representative for two reasons. First, since the drying techniques being evaluated in this study closely resembled those studied by Kalchik at Bellaire, Michigan, it was assumed that the amount of energy needed per

bushel is a reasonable estimate of the true amount. Furthermore, since the systems were evaluated under northern Michigan conditions, these systems should operate feasibly for all of Michigan.

3. The moisture content of corn generally varies throughout the harvest period. That is, it is relatively high at the start of harvest and decreases as the harvest progresses. With this in mind, it is important to establish the amount of moisture to be removed by the corn drying systems. It was assumed in this study that initial moisture content of the corn is 26 percent and final moisture content for storage is 15.5 percent. Since all quality and energy data from the Bellaire project were standardized to this moisture range, this range was chosen for this analysis.

4. Temperature of the drying air and airflow rates are important parameters when measuring the performance of grain drying and storage systems. For purposes of this study, it was assumed that all dryers and storage bins were operated similar to the ones studied by Kalchik et al. (1979). Table 1 shows the important operating conditions that were used in Bellaire and were assumed here.

5. It was assumed that the throughput or drying rate of each system is limited to the high temperature drying stage. The high temperature drying stage is considered to be the bottleneck in each system because the corn has to continually be removed in order to make room for freshly harvested corn. Low temperature drying is done in the storage structure so there is no need to be concerned about removing the corn to allow harvesting to continue. The drying rates for each system are as follows:

Table 1. Drying temperatures and aeration rates for the five corn drying and storage systems in Bellaire, MI (Kalchik et al., 1979)

Type of Systems	Moisture Loss - HT phase	Drying Temper. - HT phase	Moisture Loss - LT phase	Drying Temper. - LT phase	Airflow in bins
Automatic Batch (HT)	26.15.5% MC	219^{o}F 1st stage 180^{o}F 2ndstage	---	---	0.3 CFM
In-bin Counterflow (HT)	26-18% MC	160^{o}F	18-15.5% MC	ambient air	0.4 CFM
Automatic Batch/ Dryeration (HT/LT)	26-20% MC	219^{o}F 1st stage 180^{o}F 2nd stage	20-15.5% MC	ambient air	1.0 CFM
Automatic Batch/ Low Temperature (HT/LT)	26-23% MC	219^{o}F 1st stage 180^{o}F 2nd stage	23-15.5% MC	ambient air $+5^{o}$F	2.0 CFM
Automatic Batch/ Natural Air (HT/LT)	26-23% MC	219^{o}F 1st stage 180^{o}F 2nd stage	23-15.5% MC	ambient air $+2^{o}$F	2.5 CFM

NOTE: MC stands for moisture content of the grain. CFM stands for cubic feet per minute. HT stands for high temperature and LT stands for low temperature.

-All 30,000 bu. systems have a drying rate of 70 bushels per hour when ten points of moisture are removed.

-All 80,000 bu. systems have a drying rate of 140 bushels per hour, except the automatic batch system, which has a drying rate of 325 bushels per hour when ten points of moisture are removed.

6. In this analysis, it was assumed that the entire drying and storage system is purchased at once. There was no allowance for existing structures (e.g. already standing grain bins) because of the difficulties in establishing the proper exceptions for existing structures. The assumption does not impair a relative ranking by cost of the systems.

7. The final assumption involves the period of time the grain will be stored. For purposes of this study, this period was six months. Drying must be discontinued with the low temperature and natural air systems when daily average temperatures approach 32^{o}F. Therefore, a six-month storage period gives adequate time to ensure that all the grain in all the systems has been dried to the proper moisture content even though the grain in the automatic batch/natural air and automatic batch/low temperature systems may not be dried until early spring. If the analysis is done when drying is not complete in some systems, a fair assignment of cost cannot occur.

5.2 Physical Requirements for the Drying and Storage Systems

The physical components of the grain drying and storage systems were assembled by enlisting the aid of Mr. Ken Mokoma of Hamilton Distributing Co., Hamilton, Michigan and Mr. Mark Doyle of Aerovent Fan and Equipment Co., Lansing, Michigan. Mr. Mokoma provided information on the grain bins, automatic batch dryers, and associated equipment while Mr. Doyle provided information on the electric heaters for the automatic batch/low temperature systems. The complete listing of the equipment components for each drying and storage system is found in Appendix A.

5.2.1 Development of Energy Inputs

As mentioned before, energy inputs were taken directly from data compiled and reported by Kalchik et al., (1981). However, these figures include only energy needed for the drying phase. Aeration of the grain during storage also requires energy. The three systems that require aeration are the automatic batch, the in-bin counterflow, and the automatic batch/dryeration systems. In this study the automatic batch/natural air and automatic batch/low temperature system needed no aeration because it was assumed the grain will be removed shortly after drying is completed in these systems.

The amount of energy needed for aeration is a function of the hours of fan operation and the horsepower of the aeration fan. The hours of fan operation for one cooling cycle can be estimated by using the following equations and data (McKenzie and Van Fossen, 1980):

$$\text{Hours} = \frac{15\ \text{hrs/(CFM/BU)}}{\text{CFM/bu}} \quad \text{(fall)} \qquad (5.1)$$

$$\text{Hours} = \frac{20\ \text{hrs/(CFM/BU)}}{\text{CFM/bu}} \quad \text{(winter)} \qquad (5.2)$$

$$\text{Hours} = \frac{10\ \text{hrs/(CFM/BU)}}{\text{CFM/bu}} \quad \text{(spring)} \qquad (5.3)$$

where: CFM = cubic feet of air per minute

The following number of cooling cycles were used in this study: fall -- 2.5; winter -- 1.0; and spring -- 1.0. Although more than one cycle is usually required in the spring, previous assumptions state that grain will be removed early in the spring, therefore only one spring cycle was used. Total aeration hours were calculated by multiplying each of the above equations by the appropriate number of cooling cycles and adding the results together.

Electricity requirements were then found by using the following equation (ASAE, 1982):

$$KWH = HP * hours * .746 \text{ killowats/HP} \qquad (5\ 4)$$

where: HP = horsepower of electric motor
hours = total aeration hours
KWH = kilowatt hours of electricity

The complete energy required to operate each drying and storage system is the total of the drying and aeration phase. These figures have been itemized in Table 2. Energy needed to operate grain augers and other assessories was assumed to be minimal in relation to other energy requirements and was not included in this study. Detailed coverage of energy requirements is found in Appendix B, Tables B.1 through B.4.

5.2.2 Development of Labor Input

The labor requirement to operate and manage grain drying and storage systems was broken into two phases for this study--grain drying and grain management and supervision.

Hours of labor required for drying are a function of the number of hours the drying unit is in operation. This number depends upon the

Table 2: Energy and labor requirements per 100 bu. for alternative drying and storage techniques.

	LP gas (gal)	Electricity (kwh)	Labor (hrs)
	30000 bu.		
Auto. Batch (HT)	27	14.57	0.25
In-bin Count. (HT)	15	39.98	0.67
A. Batch/Dryer. (HT/LT)	11	36.45	0.18
A. Batch/L. Temp. (HT/LT)	7	177	0.16
A. Batch/Nat. Air. (HT/LT)	7	124	0.19
	80000 bu.		
Auto. Batch (HT)	27	15.59	0.06
In-bin Count. (HT)	15	39.28	0.10
A. Batch/Dryer. (HT/LT)	11	36.76	0.12
A. Batch/L. Temp. (HT/LT)	7	177	0.13
A. Batch/Nat. Air (HT/LT)	7	124	0.17

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

dryer's capacity and the number of bushels dried per season. The amount of labor required for drying was estimated according to equation used by Schwart and Hill (1977).

High temperature dryers:

$$LH = .1667 * DH \qquad (5.5)$$

Low temperature dryers:

$$LH = .1667 \text{ hour/bin/drying day} \qquad (5.6)$$

where: LH = labor hours
and DH = dryer operation (hours)

Hours of dryer operation were determined by:

$$DH = BD/DR \qquad (5.7)$$

where: DH = hours of dryer operation
DR = drying rate (bu/hr)
and BD = bushels dried per season

For the combination systems, it was assumed that the labor hours attributable to high temperature phase is proportional to the amount of moisture (in percentage points) removed during that phase. The hours of dryer operation for the low temperature phase of the combination systems were obtained from Silva (1980). The labor requirements for the drying phase are summarized in Appendix B, Table B.5.

Labor is also needed to supervise and manage the grain during the storage phase. McKenzie and Van Fossen (1980) recommend bins be checked every two weeks during storage. Assuming ten minutes of labor are required per bin to check the condition of the grain, each bin requires .33 hours per month of storage. Appendix B, Table B.5 shows the hours of labor needed for management of stored grain for each system. Total labor requirement per 100 bushels is shown in Table 2.

5.3 The Capital Investment Model -- TELPLAN 3

The capital budgeting/present value model used in this analysis is entitled "Capital Investment Model--Including Buy or Custom Hire." It is a Telplan computer program available to the farmers of Michigan. The primary objective of this model is to obtain the net present value of an investment in order to aid in decision-making. The Telplan system is a collection of computer-aided economic decision models which can be accessed by farmers through their county extension office or over their own telephone if they have either a computer terminal or micro-computer with a modem available to them. Telplan 3 was initially developed by Dr. Stephen Harsh in 1972, but was updated and expanded by Dr. Harsh and the author prior to this analysis to reflect income tax law changes effective in 1984 and before.

The model is composed of three distinct steps or functions. They are:

- Enter data describing the investment
- Processing the data
- Reporting the processed data in a useful form

The data to be entered into the model includes all information on the investment's income and cost savings, expenses, information relevant to income taxes (e.g. depreciation schedules), loan information, required rate of return (discount rate), and size and amount of usage of the investment over its lifetime.

An investment is usually undertaken by a farm business to increase income or reduce cost. An income-generating investment produces additional income by expanding the size of the farm (e.g., adding 40 acres of land or 20 head of cattle). A cost-reducing investment is aimed at reducing the costs of production (e.g., purchasing a more efficient tractor) without necessarily increasing farm size. Telplan 3 can analyze both types of investments. Income from an investment is calculated using gross income generated by the investment measured in dollars per unit and the size of the investment (units/year). A cost-saving investment uses an estimation of cost savings (e.g., elimination of expenses for custom work) as a gross income figure. Subroutines are used to calculate loan payments, the depreciation schedule, Section 179 deduction, investment tax credit, repairs, and the salvage value. The subroutine for loan payments provides a yearly description of the interest and principal payments using the equal payment per year method. Telplan 3 allows the use of all the present depreciation methods, but limits the life of the investment to 25 years. The model also will calculate, if desired, the optimal depreciation schedule and investment tax credit option according to which options produce the highest net present value (NPV) for the investment. The alternative depreciation techniques are the Accelerated Cost Recovery System (ACRS) method or the Alternative ACRS (straight line) method. The choices for the investment tax credit method are a ten percent tax credit and a consequent lower cost basis for depreciation or an eight percent tax credit allowing the original cost basis for depreciation. The repair subroutine calculates annual repairs according to the type of machine and the amount of usage it receives. The salvage value is calculated according to the initial value of the investment and the amount of use it receives over its lifetime, but has no effect on the annual depreciation cost-recovery expense.

Using the above subroutines and the information entered directly, the model calculates annual and total cash expenses and subtracts them from the corresponding income or cost savings figures. These values are then adjusted to an after-tax basis.

Income tax savings due to depreciation and Section 179 deductions, cash flows due to principal payments, salvage value, and investment tax credit are compiled. These adjustments are added to after-tax cash income to obtain after-tax net income on an annual and total basis. The discounting procedure is used to get the total and annual net present value of the investment.

The output for Telplan 3 is divided into two parts--a summarized report and a detailed report. The summarized report consists of the first four lines of output (See Figure 2). While lines two and three are self-explanatory, lines one and four need further explaining.

Line one gives the net present value (NPV) of the investment. The NPV is the total net return expected from the investment in discounted dollars. It is this figure which tells the manager whether the investment can be expected to return a profit. If it is positive, the investment is profitable. If the NPV is negative, it is advisable to forgo the investment.

Also included in the first output line is the breakeven return (BER) per unit. This number represents the primary income or cost savings that must be obtained in year one if the investment is expected to breakeven. It is allowed to grow with inflation. If the BER is less

```
1. ECONOMIC SAVINGS (DISCOUNTED DOLLARS) OVER PERIOD OF USE
    IF INVESTMENT IS MADE = $     -15556
   ANNUALIZED BREAKEVEN RETURN PER UNIT = $       0.52
   OWNERSHIP COST AS A PERCENTAGE OF BREAKEVEN RETURN =  42.9

2. NUMBER OF UNITS ON WHICH ANALYSIS WAS MADE =       30000

3. DEPRECIATION METHOD USED IN ANALYSIS
    IS ALTERNATIVE ACRS (STRAIGHT LINE METHOD).

   INVESTMENT TAX CREDIT(ITC) IS CALCULATED BY USING ADJUSTED ITC
    AND ORIGINAL COST BASIS.


4. NUMBER OF YEARS AFTER-TAX TOTAL INCOME IS POSITIVE =  4
     MAXIMUM ANNUAL AFTER-TAX TOTAL INCOME = $    9346

   NUMBER OF YEARS AFTER-TAX TOTAL INCOME IS NEGATIVE =  7
     MINIMUM ANNUAL AFTER-TAX TOTAL INCOME = $   -5248

   DO YOU WANT TO SEE DETAILED ANALYSIS ?

Response options are as follows:  Y = yes;  N = no

Enter desired option.
```

Figure 2: Summarized Report of Telplan 3 Output

than the per unit primary income or cost savings from the investment, the NPV will be positive. If the BER is greater than the primary income that can be expected from the investment, the investment will not break-even and the NPV is negative.

A third figure found in line one is the cost of ownership as a percentage of the breakeven return. It represents the fraction of the breakeven income or cost savings that is used to cover the fixed costs of the investment and inflates at the same rate as the primary income. This is an important piece of information for managers because it gives them an indication of the expense of the investment that must be met every year regardless of how much the investment is used. For example, given alternative investments with equal NPVs, it would be better to choose the investment with the lower cost of ownership because it would allow the manager greater discretionary control over expenses.

Line four shows the number of years after-tax net income is positive and the number of years it is negative. It also includes the largest positive and largest negative value for after-tax net income over the life of the investment. This output line summarizes the profitability of the investment on an annual basis.

The second portion of the output is devoted to a detailed analysis of the cash flows generated by the investment. This information is in tablular form and shows annual as well as total figures (See Figure 3). This section can be used to identify how individual costs contribute to the total cost structure of the investment. It can also be used to analyze the yearly cash flow requirements of the investment.

5. BEFORE TAX INCOME OR COST SAVINGS

YR	PRIMARY INCOME REDUCTION	SECONDARY INCOME REDUCTION	TOTAL
1	0	0	0
2	12324	0	12324
3	12657	0	12657
4	12998	0	12998
5	13349	0	13349
6	13710	0	13710
7	14080	0	14080
8	14460	0	14460
9	14851	0	14851
10	15252	0	15252
11	15663	0	15663
TOTAL	139344	0	139344

6. BEFORE TAX CASH EXPENSES

YR	INT.	REPAIRS	FUEL+ LUB.	LABOR	SUP- PLIES	HOUSING	PR TAX+ INSUR.	TOTAL
1	4648	0	0	0	0	125	174	4947
2	4207	42	8086	432	347	115	160	13389
3	3706	114	8239	457	352	105	148	13121
4	3139	209	8396	485	356	97	136	12818
5	2495	325	8555	514	361	89	125	12464
6	1766	463	8718	545	366	82	115	12055
7	938	621	8884	578	370	76	106	11573
8	0	801	9052	612	375	70	98	11008
9	0	1005	9224	649	380	64	90	11412
10	0	1232	9400	688	385	59	83	11847
11	0	1485	9578	729	390	54	76	12312
TOTAL	20899	6297	88132	5689	3682	936	1311	126946

Figure 3: Detailed Report of Telplan Output.

7. BEFORE TAX SUMMARY

YR	B-T TOT INCOME	B-T TOT EXPENSES	B-T NET INCOME	NET CAP GAIN OR LOSS	TAX RATE	A-T NET INCOME
1	0	4947	-4947	0	30	-3462
2	12324	13389	-1065	0	30	-745
3	12657	13121	-464	0	30	-324
4	12998	12818	180	0	30	126
5	13349	12464	885	0	30	620
6	13710	12055	1655	0	30	1159
7	14080	11573	2507	0	30	1755
8	14460	11008	3452	0	30	2416
9	14851	11412	3439	0	30	2407
10	15252	11847	3405	0	30	2384
11	15663	12312	3351	10000	30	-654
TOTAL	139344	126946	12398	10000		5682

NOTE: After tax(a-t) net income is equal to before tax(b-t) net income multiplied by (1-(tax rate/100)) minus net capital gain or loss multiplied by (tax rate/100).

8. CASH FLOWS RESULTING FROM DOWNPAYMENT OR SALVAGE VALUE, PRINCIPAL PAYMENTS, AND INVESTMENT TAX CREDIT

YR	DWNPMT OR SAL VAL	PRINC-CIPAL	INV TAX CREDIT	TOTAL
0	9783	0	0	9783
1	0	3293	3558	-265
2	0	3734	0	3734
3	0	4235	0	4235
4	0	4802	0	4802
5	0	5445	0	5445
6	0	6175	0	6175
7	0	7003	0	7003
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	10000	0	0	-10000
TOTAL	0	34687	3558	30912

Figure 3. (continued)

9. TAX SAVINGS DUE TO DEPRECIATION AND SECTION 179 DEDUCTION

YR	DEPREC-IATION	SEC 179 DEDUCT	TAX RATE	TAX SAVINGS
1	4447	0	30	1334
2	8894	0	30	2668
3	8894	0	30	2668
4	8894	0	30	2668
5	8894	0	30	2668
6	4447	0	30	1334
7	0	0	30	0
8	0	0	30	0
9	0	0	30	0
10	0	0	30	0
11	0	0	30	0
TOTAL	44470	0		13340

NOTE: Tax savings due to depreciation and Section 179 deduction are calculated by multiplying each one by (tax rate/100).

10. DISCOUNTED ANALYSIS OF INVESTMENT

YR	A-T NET INCOME (A)	A-T INV CASH FLOW (B)	TAX SAVINGS (C)	A-T TOTAL (D)	DISC RATE (E)	DISCD VALUES (F)
0	0	9783	0	-9783	0.0	-9783
1	-3462	-265	1334	-1863	0.9066	-1688
2	-745	3734	2668	-1811	0.8220	-1488
3	-324	4235	2668	-1891	0.7452	-1408
4	126	4802	2668	-2008	0.6756	-1356
5	620	5445	2668	-2157	0.6125	-1320
6	1159	6175	1334	-3682	0.5553	-2044
7	1755	7003	0	-5248	0.5035	-2641
8	2416	0	0	2416	0.4565	1103
9	2407	0	0	2407	0.4138	996
10	2384	0	0	2384	0.3752	894
11	-654	-10000	0	9346	0.3402	3179
TOTAL	5682	30912	13340	-11890		-15556

NOTE: Column (D) is equal to columns (A-B+C).
Column (F) is equal to columns (D*E).

Figure 3. (continued)

Table 5 in Figure 3 is an annual summary of the gross income or cost savings of the investment. Table 6 in Figure 3 is an annual summary of the before-tax cash expenses of the investment. It provides annual totals as well as a total for all cash expenses over the lifetime of the investment.

Table 7 of the Telplan 3 output (See Figure 3) brings the annual totals from Tables 5 and 6 to obtain a before-tax net cash income. It also presents expected capital gain or loss when the investment is sold and then displays all figures on after-tax basis.

Table 8 in Figure 3 shows the downpayment and expected salvage value of the investment, principal payments, and investment tax credit and totals these cash flows.

Table 9 of the Telplan 3 output (See Figure 3) displays the depreciation schedule and Section 179 deduction and the resultant tax savings.

The last table of the Telplan 3 output (Figure 3) combines the after-tax net cash income from Table 7, the investment cash flows from Table 8, and the tax savings from Table 9 and shows the resulting after-tax net income. These totals are multiplied by the appropriate discount rate and presented on a present value basis. The total of the discounted values (Column F) is equal to the value in line one of the output form (See Figure 2).

5.4 Establishing Prices and Inflation Rates for Inputs

This section covers the value assigned to the inputs used in the analysis. The prices reflect existing conditions at the time of analysis. (Spring 1984) Prices for all the equipment used in constructing the five grain drying and storage systems are included in Table 3. A detailed listing is found in Appendix A. Table A.1 through A.10.

The inflation rate for new machine purchase prices, needed to determine ending salvage value was chosen to be 10.0 percent per year based on data from the Handbook of Agricultural Charts (USDA, 1983).

The prevailing LP gas price at the time of this analysis was $.85 per gallon. The price of electricity was 7.8 cents per kilowatt hour. Since 1977, fuel and energy prices, used as a proxy for LP gas prices, have inflated at an annual rate of 10.6 percent (USDA, 1984). Electricity prices over the same period have increased 9.3 percent annually (USDA, 1983).

The interest rate on borrowed funds was obtained by consulting the local Production Credit Association office. At the time of the analysis, loans less than $100,000 were charged an interest rate of 13.4 percent and loans greater than $100,000 were charged an interest rate of 12.7 percent. To determine the size of the loan for each grain drying and storage system, it was assumed $10,000 was available for the 30,000 bu. systems as a downpayment and $20,000 downpayment was available for the 80,000 bu. systems.

The cost of labor (wage rate) used in this analysis was assumed to be $5.50 per hour. Data collected by the Michigan Agricultural Statistics Department showed machine operators on Michigan farms received an average of $4.22 per hour in 1980 (Michigan Department of Agriculture, 1983). It was assumed that $5.50 per hour would accurately reflect current wage conditions. The labor inflation rate used for this analysis was 6.0 percent per year (USDA, 1983).

Repairs were assumed to total one percent of the initial price of the investment over the ten-year period after consulting with

Table 3: Purchase price, downpayment, and interest rate on borrowed funds used in analysis.

	Purchase Price ($)	Downpayment ($)	Interest Rate (%)
	30000 bu.		
Auto. Batch (HT)	44472	10000	13.4
In-bin Count. (HT)	57121	10000	13.4
A. Batch/Dryer. (HT/LT)	66793	10000	13.4
A. Batch/L. Temp (HT/LT)	85933	10000	13.4
A. Batch/Nat. Air (HT/LT)	99996	10000	13.4
	80000 bu.		
Auto. Batch (HT)	96597	20000	13.4
In-bin Count. (HT)	103368	20000	12.7
A. Batch/Dryer. (HT/LT)	152900	20000	12.7
A. Batch/L. Temp (HT/LT)	214721	20000	12.7
A. Batch/Nat. Air (HT/LT)	235356	20000	12.7

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

Mr. Ken Mokoma. Since a direct measure of an inflation rate for repairs was not found, the rate for new machine purchase price (10.0 percent per year) was used.

Insurance and property tax were assumed to be 2.0 percent of the annual value of the investment. There was no charge for housing included in this analysis. A summary of all input prices and inflation rates is presented in Tables 3 and 4.

As mentioned before Telplan 3 chooses the optimal depreciation schedule and investment tax credit option for the investment. In this analysis Telplan 3 was allowed to calculate optimal depreciation schedules and investment credit for each grain drying and storage system. In each case the alternate Accelerated Cost Recovery System (ACRS) depreciation schedule (similar to straight line) was chosen. Each system was depreciated over a period of six years. The model also selected an investment tax credit equal to eight percent of the full cost basis over ten percent of a reduced cost basis as the most beneficial option.

This option was chosen because it produced the lowest total cost for all the systems analyzed. Lowering the investment tax credit and depreciating a larger cost basis in future years proved to be more profitable under the particular circumstances and assumptions used in this analysis.

5.5 Choosing a Marginal Income Tax Rate

The choice of a marginal tax rate on income is important when analyzing investments because of the effect on determining the difference between before-tax and after-tax cash flows. As mentioned before, the tax bracket determines the actual cost of expenses and

Table 4: Input prices and inflation rates for base run of analysis.

Input	Price	Inflation Rate
1. Equipment	varies with syst.	10.0%
2. Liquified Propane	$ 0.85 per gal.	10.6%
3. Electricity	$ 0.078 per kwh.	9.3%
4. Labor	$5.50 per hour	6.0%
5. Repairs	1% of purchase price over ten years	10.0%
6. Insur. and prop. tax	2.1% of annual value	---

NOTES: 1. The marginal income tax rate used in the base run is 30 percent.

2. The after-tax discount rate used in the base run is 10.3 percent.

determines the adjustment for noncash expenditures such as depreciation and Section 179 deductions.

In this study, the marginal rate of taxation was chosen to be 30 percent. In Minnesota, cash grain farmers usually fall into the 30-35 percent range (Fuller, 1977). It was assumed that similar conditions exist in Michigan.

Although Telplan 3 allows for three different tax rates in any one analysis (tax rate in the first year, tax rate during the first half of the investment, and tax rate over last half of the investment), this study assumed a constant marginal tax rate throughout the life of the investment.

5.6 Choosing a discount rate

The discount rate or present value factor is an important parameter when evaluating investments using the net present value approach. The present value factor determines how heavily future dollars are discounted in order to make them equivalent to dollars spent or received today. For most investments, an appropriate choice for the discount rate is the after-tax opportunity cost of investment funds plus some measure of risk.

To find a realistic measure of risk, yields on corporate bonds maturing in ten years were compared with the yield of United States Treasury bonds maturing in ten years. According to Moody's Bond Survey (1984), for the first quarter of 1984 bonds with a risk rating of "A" averaged approximately two percentage points above similar government securities. Bonds with a risk rating of "B" had an average yield of four percentage points above similar government securities. The "A" rating shows that Moody's has more confidence in that issue than in the

"B" issue. United State Treasury securities are considered to be the best estimate of a riskless investment (Bierman and Schmid, 1975). The return on ten-year U.S. Treasury securities was considered to be the risk-free return for an investment in this analysis. At the time of the analysis, ten-year Treasury bonds were yielding 12.7 percent per annum. The before-tax discount rate is the sum of the yield of ten-year Treasury bonds and the risk premiums mentioned above.

Since Telplan 3 discounts after-tax dollars, the opportunity cost of investment funds and the risk premium must be considered on an after-tax basis. This can be calculated by the following equation:

$$ATR = BTR * (1 - t) \tag{5.8}$$

where: ATR = after-tax discount rate
BTR = before-tax discount rate
t = a marginal income tax rate between 0 and 1

The effect of possible changes in the discount rate will be discussed more thoroughly in the section on sensitivity analysis.

The investment period, or number of years over which the grain drying and storage facilities were analyzed, was ten years. This period was chosen because it represents the expected lifetime of the grain dryers. The expected lifetime of all the other equipment was 20 years. At present, Telplan 3 does not allow for replacement of a capital item during the investment period.

5.7 Sensitivity Analysis Methods

Although the input prices used in this analysis represented prevailing conditions at the time the study was done, it is important to realize that as the economic environment changes, so will the actual and possibly the relative cost of the grain drying and storage systems.

For this reason, a sensitivity analysis was performed in order to assess what happens to ownership and operating costs as certain input parameters change.

The two factors to be addressed by the sensitivity analysis are energy prices (i.e. LP gas and electricty) and risk levels. These two parameters were chosen because they play a major role in the decision to purchase a grain drying and storage system. The cost of energy is a significant contributor to the cost of a grain drying and storage system. For this reason, changing energy prices were analyzed.

Another important parameter in the decision to invest in a grain drying and storage system is the level of risk involved. Risk affects the rate of return a manager requires on an investment. Generally, the greater the risk, the greater the required rate of return. In this analysis, the discount rate was used to measure risk implications. A higher discount rate was used to simulate a management strategy that is relatively risk-averse. A lower discount rate would simulate a management strategy that would be willing to assume relatively more risk.

5.7.1 Layout of Sensitivity Analysis

A total of four different analyses were performed on each grain drying and storage system. The base run (E1, R1) used the original inputs for energy prices and the risk level (See Table 4). A second run analyzed the effect of increased energy prices using the original risk level (E2, R1). Energy prices were increased by increasing the inflation rates of LP gas and electricity. E1 designates original energy price inflation rates. E2 designates increased energy price inflation rates. A third run showed the affects of increasing the risk premium while holding energy prices at their original level (E1, R2). The risk level was increased by increasing the risk premium attached to the discount rate. R1 designates the original risk premium. R2 designates an increase in the risk premium. Finally, a last run analyzed the effects of increasing both the energy prices and the risk level (E2, R2).

In the initial run, (E1, R1), LP gas price was inflated by 10.9 percent annually while price of electricity was inflated at a rate of 9.3 percent per annum. In order to measure the sensitivity of cost to increasing energy prices, the price of LP gas was inflated by 16 percent annually. Michigan Agricultural Statistics data show the price farmers have paid for electricity has gone up .81 percentage points for every one percent increase in LP gas price over the past five years. Therefore, the price of electricity was inflated by 13.9 percent per year for the alternative run (E2, R1).

The discount rate was used as a way to measure changing risk levels in this analysis. The discount rate is composed of the rate of return for a risk-free investment plus a premium relating to the riskiness of the investment. As previously mentioned, a proxy for a risk-free investment is a United States Treasury Bond. Corporate bonds that were rated "A" by Moody's were yielding two percentage points above Treasury bonds and corporate bonds rated "B" were yielding four percentage points above Treasury bonds in the spring of 1984. The base run (E1, R1) used the return for a riskless investment (U.S. Treasury bond) of 12.7 percentage plus a risk premium of two percent to get to the before-tax discount rate. The after-tax discount rate can be calculated as follows:

$$ATR = BTR * (1 - t)$$

or

$$ATR = 14.7 \times 0.7$$

$$= 10.3$$

The after-tax discount rate used in the base run is 10.3 percent. In order to analyze the effect of increased risk on cost, four percentage points were used as a risk premium in the alternative run, (E1, R2).

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Results of Base Runs

The results of the grain drying system cost analysis are presented in this chapter. The first part of the chapter is devoted to a discussion of costs of ownership and operation for all the grain drying and storage systems studied. All cost figures represent annualized cost per bushel in before-tax dollars.

The second part of Chapter 6 covers the results of the sensitivity analysis. The effect of rising energy prices on cost is discussed. In addition, the effect of changing risk levels on cost is also analyzed.

The final section of this chapter deals chiefly with quality/cost comparison among the different drying and storage systems. A quality rating system is set up to compile breakage test and stress crack scores. Comparisons are then made on the basis of cost and quality. An attempt is made to place an economic value on the change in corn quality which takes place during the drying and storage process.

6.1.1 Total Cost of Grain Drying and Storage Systems

The output of the initial runs is presented in Table 5. The cost figure shown is the breakeven return (BER) calculated by Telplan 3. As discussed in the previous chapter the BER is the amount of income (or cost savings) required by the investment in the first year to

Table 5: Annual costs of drying and storing shelled corn -- base run (E1,R1).

	Total Cost (cents/bu)	Energy Cost (cents/bu)	Lab. & Rep. (cents/bu)	Fix. Cost (cents/bu)
		30000 bu.		
Auto. Batch (HT)	40	24	2	14
In-bin Count. (HT)	35	16	1	18
A. Batch/Dryer. (HT/LT)	35	12	2	21
A. Batch/L. Temp (HT/LT)	49	19	2	28
A. Batch/Nat. Air (HT/LT)	50	15	3	32
		80000 bu.		
Auto. Batch (HT)	37	24	1	12
In-bin Count. (HT)	29	16	1	12
A. Batch/Dryer. (HT/LT)	32	12	2	18
A. Batch/L. Temp (HT/LT)	46	19	2	25
A. Batch/Nat. Air (HT/LT)	45	15	2	28

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

breakeven. To provide a specific example, the BER is the cost per bushel a farmer would use when comparing the purchase of an on-farm drying and storage facility to drying and storing his crop at a commercial elevator. The BER is presented on a before-tax basis.

For the 30,000 bu. systems, two facilities have the same cost. The in-bin counterflow system shows a total annualized cost of 35 cents per bushel of capacity and the automatic batch/dryeration system also shows a cost of 35 cents per bushel. The automatic batch system has a total cost of 40 cents per bushel and the automatic batch/low temperature and automatic batch/natural air systems show costs of 49 and 50 cents per bushel, respectively.

When ranking the five systems by cost, it is impossible to distinguish between the in-bin counterflow and automatic batch/dryeration systems. There is also very little cost difference between the automatic batch/low temperature and automatic batch/natural air systems (1 cent per bushel). It would be unlikely that this small difference is significant considering the total expense incurred by each system. However, a general statement can be made that the in-bin counterflow and automatic batch/dryeration systems have a definite cost advantage over the automatic batch system. Also, the automatic batch/natural air and automatic batch/low temperature systems are each more costly than the automatic batch/dryeration system.

The 80,000 bu. systems follow a similar pattern. The in-bin counterflow and automatic batch/dryeration systems are again the most cost effective choices. In this instance, however, the in-bin counterflow system shows a distinct cost advantage over the automatic batch/dryeration system (29 vs. 32 cents per bushel). The automatic batch facility costs 37 cents per bushel. At an 80,000 bu. annual capacity, however, the automatic batch/natural air system holds a small cost advantage over the automatic batch/low temperature system (45 vs. 46 cents per bushel).

When comparing systems with regard to volume, it is apparent that economies of size do exist. In each case, the 80,000 bu. system is more cost effective than the equivalent 30,000 bu. system. The differences in cost range from 3 cents per bushel for the automatic batch, automatic batch/dryeration, and automatic batch/low temperature systems to 6 cents per bushel for the in-bin counterflow system. The mean cost advantage for the larger volume system is 4 cents per bushel.

6.1.2 Energy Costs

Energy costs comprise a large part of the total cost of a grain drying and storage system. These costs are presented in Table 5. Of the 30,000 bu. systems, the automatic batch technique proved to be the most energy intensive with a total energy cost of 24 cents per bushel. The system which is most energy efficient with respect to energy cost is the automatic batch/dryeration system. The total cost for energy in this system is 12 cents per bushel. The automatic batch/natural air and in-bin counterflow systems show similar energy costs: 15 and 16 cents per bushel, respectively. The automatic batch/low temperature system has energy costs equal to 19 cents per bushel.

The 80,000 bu. systems show the same per bushel energy cost. There are no per bushel energy cost differences between equivalent systems at different capacities because energy requirements per bushel for drying are assumed to be the same at all capacities. For example, per bushel propane and electricity requirements for the automatic batch dryer at 30,000 bu. per year are assumed to be the same for the 80,000 bu. automatic batch dryer. This assumption was made because energy data obtained from Kalchik et. al (1981) was given on a per bushel basis with no allowance for different size dryers.

6.1.3 Fixed Costs

Fixed costs are an important part of the total cost of a grain drying and storage system. The Telplan 3 program measures fixed costs as a percentage of the return needed to breakeven (See Chapter 5.4). Multiplying this percentage by the breakeven return will result in the fixed cost per bushel in the first year. For the detailed listing of the breakeven return per bushel, the percentage of this return which is attributable to fixed costs, and the fixed cost per bushel, see Appendix C, Table C.6.

The fixed cost per bushel is included in Table 5. The 30,000 bu. automatic batch system has the lowest fixed cost (14 cents per bushel). The in-bin counterflow and the automatic batch/dryeration systems have slightly higher fixed costs - 18 and 21 cents per bushel, respectively. The automatic batch/low temperature and automatic batch/natural air systems have considerably higher fixed costs. The automatic batch/low temperature system requires 28 cents per bushel and the automatic batch/natural air system requires 32 cents per bushel to cover fixed costs.

The fixed costs for the 80,000 bu. systems followed the same pattern as the smaller systems. The automatic batch and the in-bin counterflow system are inexpensive systems to own requiring 12 cents per bushel. The ranking for the other systems is the same as above. The automatic batch/dryeration system has fixed costs of 18 cents per bushel. The fixed costs for the automatic batch/low temperature and automatic batch/natural air systems are 25 and 28 cents per bushel, respectively.

It is apparent that economies of size do exist with respect to fixed costs. When comparing the automatic batch system at two different capacities, fixed cost decreases by 2 cents per bushel between the 30,000 bushel and the 80,000 bushel systems. The in-bin counterflow system fell from 18 to 12 cents per bushel. Fixed costs for the automatic batch/dryeration systems from 21 to 18 cents per bushel and the automatic batch/low temperature system from 28 to 25 cents per bushel. Fixed costs for the automatic batch/natural air system decreased from 32 to 28 cents per bushel when annual capacity is increased from 30,000 to 80,000 bushels.

6.1.4 Labor and Repair Costs

The expense for labor and repairs makes up only a small portion of the total cost of drying and storing corn. In reference to the 30,000 bushel systems, the labor and repair costs ranged from 1 cent per bushel to 3 cents per bushel for the in-bin counterflow and automatic batch/natural air systems, respectively (See Table 5).

The automatic batch and in-bin counterflow systems had the lowest cost for labor and repairs among the 80,000 bushel system -- 1 cent per bushel. The highest charge for labor and repairs at this capacity belonged to the automatic batch/dryeration and automatic batch/low temperature systems. Because labor and repair cost is only a small fraction of total cost it will not be considered in detail any further in this analysis.

6.2 Sensitivity to Change in Energy Prices

To test the effect of rising energy prices on the cost of the grain drying and storage systems, the annual inflation rate of LP gas was increased to 16 percent from 10.6 percent and the electricity inflation rate was increased from 9.3 percent to 13.9 percent. The results for the 30,000 bu. systems are shown in Table 6.

As would be expected, an increase in energy prices caused an increase in the total cost of drying and storing corn. However, the increase also caused a change in the relative ranking of four systems with respect to cost. The least-cost system at the 30,000 bu. annual usage level became the automatic batch/dryeration method as the in-bin counterflow system became relatively more costly (38 vs. 39 cents per bushel). This reflects the role energy costs play in the total cost structure of each system. The positions of the two lower temperature systems were also reversed. The automatic batch/low temperature system became the most costly option replacing the automatic batch/natural air system (54 vs. 53 cents per bushel). This is due to the heavier reliance on electricity for heat by the automatic batch/low temperature system. The automatic batch system retained its relative position with a cost of 46 cents per bushel.

At the 80,000 bu. capacity, the increase in energy prices caused no change in the relative cost ranking of the systems. The in-bin counterflow system remained the least-cost system at 33 cents per bushel. The automatic batch/dryeration and automatic batch systems showed annual costs of 35 and 43 cents per bushel, respectively. The automatic batch/natural air and automatic batch/low temperature systems showed the highest costs (49 and 51 cents per bushel, respectively).

An important point to consider is the actual increase in cents per bushel precipitated by rising energy prices. The analysis showed that those systems with proportionally high initial energy cost had a larger

Table 6: Annual costs of drying and storing shelled corn after increasing energy prices (E2,R1).

	Total Cost (cents/bu)	Energy Cost (cents/bu)	Lab. & Rep. (cents/bu)	Fix. Cost (cents/bu)
	30000 bu.			
Auto. Batch (HT)	46	30	2	14
In-bin Count. (HT)	39	20	1	18
A. Batch/Dryer. (HT/LT)	38	15	2	21
A. Batch/L. Temp (HT/LT)	54	23	3	28
A. Batch/Nat. Air (HT/LT)	53	19	2	32
	80000 bu.			
Auto. Batch (HT)	43	30	1	12
In-bin Count. (HT)	33	20	1	12
A. Batch/Dryer. (HT/LT)	35	15	2	18
A. Batch/L. Temp (HT/LT)	51	23	3	25
A. Batch/Nat. Air (HT/LT)	49	19	2	28

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

energy cost increase. For instance, the automatic batch system had an original total energy cost of 24 cents per bushel. After energy prices were increased, the total energy price was 30 cents per bushel - a rise of 6 cents. On the other hand, the automatic batch/dryeration system with the lowest energy cost experienced a cost increase of only 3 cents per bushel (See Appendix C, Table C.4). Similar patterns emerged with the 80,000 bu. systems which is to be expected because per bushel energy inputs were nearly the same for both size systems.

6.3 Sensitivity to Increased Risk Levels

Although risk is not a cash cost, it is an important component to consider when analyzing an investment. Some investments are inherently riskier than others and this should be taken into consideration when choosing between investment opportunities. In this analysis, the effect of risk is measured by changing the discount rate. Increasing the discount rate means that a higher rate of return on each particular grain drying and storage system is required. As the discount rate is raised, investments which have relatively small start-up costs and relatively large variable costs have an advantage compared to investments with opposite characteristics. This is caused by the effect of the discounting process. Dollars spent today are worth more in relation to dollars spent in the future. Investments with relatively large fixed costs that are paid at the beginning of the investment period do not benefit from the discounting process as much as investments with a relatively large amount of expenses occurring in the future. To measure the effects of risk on costs, the after-tax discount rate is raised from 10.3 percent to 11.7 percent. As mentioned earlier, the discount rate is comprised of the yield of ten-year U.S. Treasury bonds in the spring of 1984 and a risk premium calculated from the difference of "A" and "B" corporate bonds, as rated by Moody's. The sum of these two components is adjusted to an after-tax basis (See Chapter 5.7) to get the after-tax discount rate.

The effects of increased risk on total cost are found in Table 7. Although the total costs changed for each system, there was no change in the relative cost ranking of the systems. The relative differences in cost between systems also remained the same after the discount rate was raised.

As the system's fixed cost increases, so does total cost when the discount rate is raised. The increase in total cost experienced by all the 30,000 bu. systems was 1 cent per bushel.

Different results were obtained from the 80,000 bu. systems. Total cost increases were highest for the in-bin counterflow, automatic batch/low temperature and automatic batch/natural air facilities--1 cent per bushel. The automatic batch and automatic batch/dryeration systems experience no total cost increases as risk levels increase.

When the rate of discount increases, total cost increases are higher for systems where fixed costs make up a greater portion of total costs. Fixed costs must be paid whether or not the system is operated while variable costs are paid only when the system is operated and are dependent on the volume of grain the system handles. A higher proportion of fixed costs to total costs limits the flexibility of the investment. The farmer has less discretionary control over the total cost of the system when fixed costs make up a large percentage of total cost. Once a grain drying and storage facility is purchased, the costs of

Table 7: Annual costs of drying and storing shelled corn after increasing risk level (E1,R2).

	Total Cost (cents/bu)	Energy Cost (cents/bu)	Lab. & Rep. (cents/bu)	Fix. Cost (cents/bu)
	30000 bu.			
Auto. Batch (HT)	41	24	2	15
In-bin Count. (HT)	36	16	1	19
A. Batch/Dryer. (HT/LT)	36	12	2	22
A. Batch/L. Temp (HT/LT)	50	19	4	29
A. Batch/Nat. Air (HT/LT)	51	15	3	33
	80000 bu.			
Auto. Batch (HT)	37	24	1	12
In-bin Count. (HT)	30	16	1	13
A. Batch/Dryer. (HT/LT)	32	12	1	19
A. Batch/L. Temp (HT/LT)	47	19	2	26
A. Batch/Nat. Air (HT/LT)	46	15	2	29

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

ownership must be met every year while variable costs can be changed according to present economic conditions. Therefore, a system with high fixed costs requires that a large portion of its total cost be paid whether or not it is used; hence the flexibility of the investment is reduced.

The effects of increased discount rate on fixed costs are presented in Appendix C, Table C.5. The changes in fixed costs are the same as the changes in total cost mentioned earlier.

It appears from the above information that an increased discount rate is not a critical factor for a differential cost analysis of grain drying and storage systems. It is important, however, to realize the impact of other parameters on the sensitivity of the investment to risk. The degree to which the investment is financed commercially is one crucial factor.

In this analysis, outside financing covers approximately 80 percent of the total purchase price of each drying system. This reduces the effect of increasing risk levels (higher discount rates) because it spreads the purchase cost of the grain drying and storage facility over seven years. Dollars used to service the loan in the future are of less value than dollars used on the down payment. By using a changing discount rate as a measure of risk, the lender assumes a substantial part of the increased risk. If the grain drying and storage systems had been purchased completely with equity funds, the sensitivity to risk would have been more noticeable.

Another point to consider involving the discount rate and financing the investment is the relationship between the discount rate and the investment rate on borrowed funds. In this analysis, the after-tax discount rate (10.3 percent) is greater than the after-tax interest rate

(13.4 percent x 0.7 marginal tax rate = 9.4 percent). Since the after-tax discount rate or opportunity cost is greater than the after-tax interest rate, financing the investment with outside capital becomes advantageous because interest payments in the future become less expensive when measured in today's dollars. If the opportunity cost of equity capital were less than the interest rate, the opposite would be true and it would be more advantageous to finance with equity capital.

6.4 Sensitivity to Increased Energy Prices and Risk Levels

Predictably, when energy prices and risk levels were increased the total cost of all systems rose. This is a reasonable result because as energy prices and the risk level are increased individually, the total cost of all systems increased. Table 8 shows the results of raising both energy prices and the risk level (E2, R2).

At the 30,000 bu. capacity, the lowest cost system is the automatic batch/dryeration system (39 cents per bushel). Next comes the in-bin counterflow system with a per bushel cost of 40 cents. The automatic batch, automatic batch/low temperature, and automatic batch/natural air systems show per bushel costs of 47, 54, and 54 cents, respectively.

The least cost system at the 80,000 bu. level is the in-bin counterflow system with a cost of 33 cents per bushel. The automatic batch/dryeration system shows a cost of 35 cents per bushel. The automatic batch, automatic batch/natural air and automatic batch/low temperature systems show costs of 43, 49, and 51 cents per bushel, respectively.

Table 8: Annual costs of drying and storing shelled corn after increasing energy prices and risk levels (E2,R2).

	Total Cost (cents/bu)	Energy Cost (cents/bu)	Lab. & Rep. (cents/bu)	Fix. Cost (cents/bu)
		30000 bu.		
Auto. Batch (HT)	47	30	2	15
In-bin Count. (HT)	40	20	1	19
A. Batch/Dryer. (HT/LT)	39	15	2	22
A. Batch/L. Temp (HT/LT)	54	23	3	28
A. Batch/Nat. Air (HT/LT)	54	19	2	33
		80000 bu.		
Auto. Batch (HT)	43	30	0	13
In-bin Count. (HT)	33	19	1	13
A. Batch/Dryer. (HT/LT)	35	15	1	19
A. Batch/L. Temp (HT/LT)	51	23	2	26
A. Batch/Nat. Air (HT/LT)	49	19	2	28

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

Table C.3 in Appendix C shows the change in total cost when energy prices and the risk level are increased. It is important to note that the change in total cost due to increasing energy prices and increasing the discount rate separately sometimes add up to more than the change in total cost resulting from increasing both parameters at the same time. Increasing the discount rate while increasing energy prices results in a smaller real increase in energy prices because a larger discount rate discounts future energy prices more heavily and reduces the value of energy costs when measured in present dollars.

6.5 Comparison of Cost Versus Quality

A primary objective of this study is to compare the cost of five different corn drying technologies with the quality of corn each produces. The data on quality are taken from work done at Kalchik Farms in Bellaire, Michigan and presented by Kalchik et al. (1979). The breakage test was a four-minute Stein test using corn with a ten percent moisture content at 75^{O}F. Figures shown represent percent corn passing through a 12/64 inch diameter round hole sieve. Stress crack percentage is the number of kernels with cracks in the endosperm. Broken corn and foreign material (BCFM) is not used as a quality parameter in this analysis because it showed very little response in the quality tests possibly because BCFM levels are more dependent on repeated handling than on the drying method.

Table 9 shows a ranking of the five alternative technologies according to quality. There appears to be a general trend involving drying temperature and quality of corn. Breakage test and stress crack scores increase as drying temperature increases. Also shown in Table 9

Table 9: Breakage test scores and stress crack scores for five alternative drying technologies.

	Breakage test (%)	Stress cracks (%)	Quality index
Auto. Batch (HT)	46.3	87.3	37.3
In-bin Count. (HT)	29.0	64.0	57.0
A. Batch/Dryer. (HT/LT)	13.8	9.0	88.1
A. Batch/L. Temp (HT/LT)	13.1	3.4	90.8
A. Batch/Nat. Air (HT/LT)	11.9	2.8	91.7

NOTE: The quality index is calculated using the following equation:

$$QI = 100 - [(BT * 0.6) + (SC * 0.4)]$$

where: QI = quality index score
BT = breakage test score
and: SC = stress crack score

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

is a quality index. This index was developed in an attempt to consolidate the two quality parameters used by Kalchik et al. - breakage test scores and stress crack scores. Using one index of corn quality makes it easier and more understandable when making the cost versus quality comparison.

The quality index used is only a relative measure of corn quality among the drying systems studied. It is similar to the damage index developed by Chowbury and Buchele (1976) (See Chapter 3.3.1) in that breakage test scores and stress cracks are weighted differently. The different weightings are a result of the different values placed on broken corn and on kernels with stress cracks by corn processors. The breakage test score is given a weighting of 0.6 and the stress crack score is given a weighting of 0.4. The quality index (QI) is as follows:

$$QI = 100 - (BT * 0.6) + (SC * 0.4)$$

where: QI = quality index score
BT = breakage test score
and SC = stress crack score

The possible values for the quality index can range between 0 and 100. Corn of perfect quality (i.e., zero percent breakage test score and zero percent stress cracks) results in a QI score of 100. Corn that is completely damaged (i.e., 100 percent breakage test score and 100 percent stress cracks) results in a QI rating of 0.

The quality index (QI) decreases from 91.7 to 90.8 between the automatic batch/natural air system to the automatic batch/low temperature system (See Table 9). For the 30,000 bushel automatic batch/

natural air and automatic batch/low temperature systems, the cost to own and operate decreases from 50 cents per bushel to 49 cents per bushel, respectively (See Table 5). The systems at an 80,000 bu. capacity show a cost increase as quality decreases - from 45 to 46 cents per bushel. The automatic batch/dryeration systems produce grain with a QI of 88.1 while the in-bin coutnerflow systems show the quality index at 57.0. Between the automatic batch/dryeration and in-bin counterflow systems at both sizes, the total cost stays the same or decreases as quality decreases. It remained at 35 cents per bushel for the smaller size systems and fell from 32 to 29 cents per bushel for the larger systems. There is a sharp fall in the QI score between the in-bin counterflow systems and the automatic batch systems (from 57.0 to 37.3). (See Table 9) This change is accompanied by an increase in total cost from in-bin counterflow system to the automatic batch for both the 30,000 bu. system (from 35 to 40 cents per bushel) and the 80,000 bu. system (from 29 to 37 cents per bushel).

When comparing per bushel energy cost to quality, it can be seen that the system with the lowest energy cost does not produce the best quality corn. The automatic batch/dryeration system has a per bushel energy cost of 12 cents but ranks third in quality (QI = 88.1). The automatic batch/natural air system, with the best quality score (QI = 91.7) has the second lowest energy cost of five techniques - 15 cents per bushel. The in-bin counterflow system has a slightly higher energy cost (16 cents per bushel) but produces corn of much poorer quality (QI = 57.0) while the automatic batch/low temperature system produces better quality corn (QI = 90.8) but has a higher energy cost (19 cents per bushel). The automatic batch system, the most energy intensive system (24 cents per bushel), also has the worst quality rating (QI = 37.3). Since quality ratings are the same for both system sizes and per bushel energy cost is nearly the same, the energy cost from the 30,000 bu. systems is used for the above comparison.

A comparison of fixed cost to quality shows that better corn quality comes at the expense of higher fixed costs. For both system sizes, systems with higher quality ratings show higher per bushel fixed costs. For the 30,000 bu. systems, the automatic batch/natural air system has the highest fixed cost (32 cents per bushel) and the best quality rating (QI = 91.7). On the other hand, the automatic batch facility has the lowest quality rating of 37.3 on the QI and the lowest fixed cost (14 cents per bushel). The 80,000 bu. systems behaved identically except the fixed costs for all systems were lower.

The automatic batch/natural air system is the most attractive option with respect to corn quality. It had the highest QI among all the techniques studied. For this reason the automatic batch/natural air system is used as a benchmark system in an attempt to establish the cost of increasing the quality of corn dried on Michigan farms. This is done by comparing each system to the automatic batch/natural air system and measuring the change in total cost versus the change in the QI. Table 10 shows this comparison among all five drying techniques at both capacity levels.

The column labeled ΔQI in Table 10 is the change in the QI between the automatic batch/natural air system and any of the other systems. The figures in this column are all negative numbers because the automatic batch/natural air system produces the highest quality corn.

Table 10: Total cost (TC) and quality differences between in-bin dryeration and other systems using a quality index (QI).

	QI	TC (cents/bu)	ΔQI	ΔTC (cents/bu)	ΔQI/ΔTC (cents/bu)
		30000 bu.			
Auto. Batch (HT)	37.3	40	-54.4	-10	5.4
In-bin Count. (HT)	57.0	35	-34.7	-15	2.3
A. Batch/Dryer. (HT/LT)	88.1	35	-3.6	-15	0.2
A. Batch/L. Temp (HT/LT)	90.8	49	-0.9	-1	0.9
A. Batch/Nat. Air (HT/LT)	91.7	50	---	---	---
		80000 bu.			
Auto. Batch (HT)	37.3	37	-54.4	-8	6.8
In-bin Count. (HT)	57.0	29	-34.7	-16	2.2
A. Batch/Dryer. (HT/LT)	88.1	32	-3.6	-13	0.3
A. Batch/L. Temp (HT/LT)	90.8	46	-0.9	1	-0.9
A. Batch/Nat. Air (HT/LT)	91.7	45	---	---	---

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

The column with the heading ΔTC represents the change in total cost between the automatic batch/natural air system and any of the other systems. The number is negative in all instances except one because the automatic batch/natural air system is almost always the highest cost system. The 80,000 bu. automatic batch/low temperature system is the only system that shows a higher cost than the automatic batch/natural air system so in this instance the number is positive.

The last column in Table 10 shows the change in the QI per unit change in total cost. This figure represents the increase in the quality index per one cent increase in total cost when switching from any other system to the automatic batch/natural air system. This comparison attempts to show how much the quality index increases with each penny per bushel of increased cost when going from any lower cost system to the automatic batch/natural air system.

Comparing the 30,000 bu. automatic batch/natural air and automatic batch systems, the QI score declines by 54.4 points from the automatic batch/natural air to the automatic batch system. The cost between these two systems also declines by 10 cents per bushel. Therefore the increase in the QI per one cent increase in cost is 5.4. Between the automatic batch/natural air and the in-bin counterflow systems, the QI increases by 2.3 per penny increase in total cost. This factor decreases significantly between the automatic batch/natural air and automatic batch/dryeration systems (0.2 increase in the QI per penny increase in total cost). The QI increases by 0.9 points per one cent increase in total cost between the automatic batch/low temperature and the automatic batch/natural air systems.

The 80,000 bu. systems show results similar to the 30,000 bu. systems. Between the automatic batch and the automatic batch/natural air systems the QI increases by 6.8 points per one cent increase in total cost. A one-cent increase in total cost results in 2.2 point rise in the QI between the in-bin counterflow and the automatic batch/natural air systems. Between the automatic batch/dryeration and the automatic batch/natural air systems a one-cent increase in total cost results in only a 0.3 point increase in the QI because the automatic batch/dryeration system produces grain of nearly the same quality as the automatic batch/natural air system (only a 3.6 QI point difference). Between the automatic batch/low temperature and automatic batch/natural air systems the quality achieved per one-cent increase in cost is negative because the cost of the automatic batch/low temperature system is higher than the automatic batch/natural air system. This fact makes the automatic batch/low temperature system irrelevant for this comparison.

The effect of rising energy prices and risk levels had no major effect on how the systems compared versus corn quality. Rising energy prices, however, do have the effect of changing the cost to achieve better quality discussed above. Those systems whose cost structure is made up largely of energy costs are more susceptible to increased energy prices and show an increase in the quality/cost changes relative to the automatic batch/natural air system. Table C.10 in Appendix C presents a detailed description of the cost to achieve a point increase in the QI score before and after the price of LP gas and electricity is increased.

Changing risk levels also has an effect on how the drying technologies compare with respect to quality. Those systems with higher per bushel fixed costs, the automatic batch/low temperature and automatic batch/natural air system, should be more sensitive to changing risk levels. However, this effect was not observed in this analysis due to the minimal sensitivity total cost showed to an increased discount rate (See Table C.11 in Appendix C).

6.6 Relating Breakage Test Scores to a Reduction in Value of Corn

It was shown earlier in this study that poor quality corn can cause a decrease in value of the corn on the marketplace. In this section an attempt is made to quantify the relationship between corn quality and its economic value.

Using data compiled by Stephens and Foster (1976) an equation was developed using the linear regression technique which estimates the amount of handling damage that can be expected given the value for the breakage test. The equation is as follows:

$$BC = (0.15 * BT) + 0.54 \qquad (6.1)$$

where: BC = broken corn
and BT = breakage test score

The correlation coefficient for this equation is 0.97.

To estimate the loss in value for increased incidence of broken corn, the present (January 1985) penalties for high levels of broken corn were obtained from central Michigan elevators and an equation was developed to calculate the price penalty per percentage point increase in broken corn.

It was found that penalties for broken corn were being assessed at a rate of 1.4 cents per bushel per 1.0 percentage point increase in broken corn above two percent.

Table 11 shows the relationship between breakage test scores and the expected increase in broken corn as a result of handling for each type of drying and storage system. The increase in broken corn is measured relative to the level of broken corn present before it was dried and stored in each system. Also included in Table 11 is the expected economic loss for each system. It can be seen that the high temperature systems cause a larger loss in the value of corn dried and stored in these systems. The automatic batch system shows an increase in broken corn (BC) of 7.5 percentage points and a consequent loss in value of 10.5 cents per bushel. The in-bin counterflow system increased BC by 4.9 percentage points; a loss in value of 6.9 cents per bushel. Broken corn is increased in the automatic batch/dryeration system by 2.6 percentage points. The value of corn lost by this system is 3.6 cents per bushel. The automatic batch/low temperature and automatic batch/natural air systems realized BC increases of 2.5 and 2.2 percentage points, respectively. Respective losses in value for these systems were 3.5 and 3.2 cents per bushel.

Comparing the original total cost of all systems to the total costs of all systems after allowing for the loss in value of the corn dried and stored shows that those systems which cause more damage become relatively less economical. (See Table 12) Before allowing for quality considerations, the 30,000 bu. in-bin counterflow and automatic batch/dryeration systems are tied for the most economical systems at 35 cents per bushel. After penalizing for loss of quality, the in-bin counterflow system losses its competitive ranking (41.9 cents per bushel vs. 38.7 cents per bushel for the automatic batch/dryeration system). Similarily, the automatic batch system now becomes one of the more costly systems.

Table 11: Expected increase in broken corn and associated loss in value.

	Breakage Test Score (%)	Estimated Broken Corn (%)	Expected Loss in Value (cents/bu)
Auto. Batch (HT)	46.3	7.5	10.5
In-bin Count. (HT)	29.0	4.9	6.9
A. Batch/Dryer. (HT/LT)	13.8	2.6	3.6
A. Batch/L. Temp (HT/LT)	13.1	2.5	3.5
A. Batch/Nat. Air (HT/LT)	11.9	2.2	3.2

NOTES: 1. Broken corn increases are calculated using the following equation:

$$BC = 0.15 * BT + 0.54$$

where: BC = broken corn in percent
and: BT = breakage test score

2. HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

Table 12: Total cost of systems after reduction in value of corn is included.

	Total Cost (1) (cents/bu)	Total Cost (2) (cents/bu)
	30000 bu.	
Auto. Batch (HT)	40	50.5
In-bin Count. (HT)	35	41.9
A. Batch/Dryer. (HT/LT)	35	38.7
A. Batch/L. Temp (HT/LT)	49	52.5
A. Batch/Nat. Air (HT/LT)	50	53.2
	80000 bu.	
Auto. Batch (HT)	37	47.5
In-bin Count. (HT)	29	35.9
A. Batch/Dryer. (HT/LT)	32	35.7
A. Batch/L. Temp (HT/LT)	46	49.5
A. Batch/Nat. Air (HT/LT)	45	48.3

NOTES: 1. HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

2. Column 1 represents total cost without considering loss in value due to drying technique. Column 2 represents total cost with loss in value included.

It is separated by only 2.7 cents per bushel from the highest cost system, the automatic batch/natural air system.

At the 80,000 bu. level, the cost rankings changed between the in-bin counterflow and automatic batch/dryeration systems. The automatic batch/dryeration system becomes slightly more economical after quality of corn produced is considered (35.7 vs. 35.9 cents per bushel).

The present premiums paid by the market do not appear to be enough to cause farmers to adopt drying and storage methods which result in the highest quality corn. Movement from the automatic batch system to the automatic batch/dryeration system can be justified purely on economic grounds without regarding the quality of the corn. Movement from the in-bin counterflow system to the automatic batch/dryeration system can be justified almost entirely on the basis of corn quality because of the nearly equivalent cost of the two systems. Movement away from the automatic batch/dryeration system to systems resulting in higher grain qualtly is accompanied by an increase in cost (See Table 5). The value of the gain in corn quality (1.4 cents per percentage point change in broken corn) is not enough to make up for the increased cost of switching to higher quality systems. For example, the amount of estimated broken corn is reduced by 0.4 percentage points when switching from the automatic batch/dryeration system to the automatic batch/natural air system. This is equivalent to 0.56 cents per bushel of increased value of the corn and does not begin to cover the cost of switching from the automatic batch/dryeration system to the automatic batch/natural air system.

6.7 Summary of Results

It is apparent from the above exercises that an increase in quality of corn dried on the farm is tied to an increase in the cost of drying and storing corn. Starting from the best quality system (automatic batch/ natural air) all reductions in the quality-index score are accompanied by a decrease in cost. Although the automatic batch/low temperature and automatic batch/natural air systems give excellent quality results, the automatic batch/dryeration system gives good quality results at a more modest cost. The significant increase in cost required to make further gains in quality may not be justified.

When quality losses due to a particular drying technology are quantified in monetary terms and added into the cost of each drying system, those systems which produce lower quality corn become less competitive (particularly the automatic batch and in-bin counterflow systems). Adding in quality losses on a monetary basis seems to reinforce the choice of the automatic batch/dryeration system as the most attractive method of drying and storing corn on the farm. Present economic premiums enforced by the marketplace do not appear to justify investing in grain drying and storage systems which produce higher quality corn at the sake of higher ownership and operating costs.

Disregarding corn quality as an input in the decision-making process, it appears that the automatic batch/dryeration and in-bin counterflow systems are the drying and storage techniques to choose if cost is the only consideration. There is no significant difference in cost for these two systems at the 30,000 bu. capacity. At the 80,000 bu. annual capacity, the difference grows, however, as the in-bin counterflow method becomes more attractive.

The rate at which energy prices increase play a key role in the cost of each particular system. These systems which are more energy intensive are more sensitive to energy price changes. The automatic batch/dryeration system proved to be the most energy efficient with respect to cost. The automatic batch system is the most energy intensive. Expectations concerning changes in energy price should be a major concern when choosing the type of system to purchase.

The effect of risk levels is tied directly to the amount of money tied up in the facility, or its fixed cost. Those systems with higher fixed costs have a less flexible cost structure. A farmer who owns a system with high fixed costs is less suited to adapt to changing economic conditions such as increasing interest rates or energy prices. Therefore a system with high fixed costs may place a farmer more at risk in an uncertain economic climate. A farmer's willingness to accept a less flexible cost structure should play a role in the investment decision.

6.8 Additional Considerations

Two related considerations that were not dealt with in this analysis pertain to differing risk levels inherent in each drying and storage technology and the possibility of system-dependent storage losses. Risk differences among different corn drying and storage systems were not considered in this study. The automatic batch dryer dries corn in relatively small batches (100-200 bushels). Therefore, the farmer can continually monitor dried grain to ensure the dryer is operating properly. Improper drying would result in the loss of only a small portion of the total grain stored. In systems such as the automatic batch/natural air or other low temperature facilities, grain is dried in large batches (4,000-5,000 bushels). An improperly operating dryer would result in a relatively large amount of grain going out of condition during storage.

Therefore the risk of loss due to grain going out of condition during storage is higher for the automatic batch/dryeration, automatic batch/low temperature, and automatic batch/natural air systems than for the automatic batch and in-bin counterflow systems.

A third consideration concerns the size of the storage bin for the automatic batch/dryeration, automatic batch/low temperature, and automatic batch/natural air systems. The large number of small storage bins in these systems, particularly the latter two systems, was a significant contributor to total cost. This situation was necessary due to the relatively large amount of aeration that was needed during the low temperature drying phase. Pierce and Thompson (1978) state that 2.0 CFM is an adequate airflow rate for an automatic batch/natural air system. If the airflow rate could be reduced during the low temperature drying phase of the high temperature/low temperature combination systems, they may become more cost competitive.

This analysis shows that the least-cost corn drying and storage systems were the automatic batch/dryeration and in-bin counterflow facilities. If this is so, there must be some explanation for the widespread use of automatic batch dryers in the U.S. Three of the possible explanations follow.

Automatic batch systems have the lowest fixed costs of all systems evaluated. For this reason, many farmers may feel the lower fixed costs, and subsequent lower exposure to risk, may outweigh the relatively high operating costs of automatic batch systems.

Another reason for the preponderance of automatic batch dryers over other methods may be differences in management ability requirements. The automatic batch system is relatively simple to operate.

Other systems require more supervision and labor hours to monitor the drying operation. Some farmers may be more comfortable with the ease of operation and the simplicity of the automatic batch system.

A third reason could be that many automatic batch systems were built before the unprecedented increase in energy prices experienced during the 1970's. Since a large part of the total cost of an automatic batch system is made up of energy cost, these systems would be more cost competitive in a climate of lower energy prices.

6.9 Topics for Future Research

It has been shown that there are distinct quality differences between particular grain drying technologies. This analysis attempted to discover the cost differences among drying systems and relate them to quality changes. In making a choice of which system best improves corn quality at a reasonable cost, an important factor to consider may be the end-use of the corn. High breakage test and stress crack counts in corn fed directly to livestock may not be as important compared to corn sold commercially since most grain used for livestock feed is processed (ground or rolled) before it is fed. If the feed value of corn cannot be established using breakage tests or stress crack analyses, then research efforts aimed at finding a quality parameter which measures the feed value of corn that has been artifically dried would be helpful. This quality parameter should result from a quick, reliable test to facilitate its acceptance on the marketplace. A test which can accurately quantify the losses in quality from artifically drying and handling corn that are realized by feed processors, dry and wet millers, and grain handlers and exporters, would simplify the effort of placing an economic value on the deterioration of corn quality between the farmer and the final user.

This study looked only at the drying and storage phase in the corn production process. There are other aspects which influence the cost of drying and storing corn. Including the harvesting system in the cost analysis of a grain drying and storage system should receive further research attention. It is possible to reduce drying expense by delaying harvest and allowing more moisutre loss in the field. Lower drying expenses may outweigh the increase in field and harvesting losses realized when harvest is postponed. Along with these considerations should be an attempt to adjust harvesting and drying capacity to develop an integrated harvesting and drying system.

APPENDIX A

EQUIPMENT AND PRICE LISTS FOR GRAIN DRYING SYSTEMS

Table A.1: Automatic Batch (30000 bushel)

BINS	
One 48 ft. diameter 29000 bushel bin @ $21250	$21250
DRYER	
One A. B. 120	$7500
One 12 ft. diameter 2000 bushel wetholding bin	$4880
- includes auger to fill bin	
TRANSPORT AUGERS	
One 54 ft. x 8 inch auger to fill wetholding bin	$2640
One 60 ft. x 8 inch auger from dryer to bin	$2150
- augers include accessories such as hoppers, supports, etc.	
OTHER COSTS	
Electrician	$2500
Electric panel	$1750
Concrete costs 41 yds. @ $42/yd.	$1722
Fill	$80
- rerod etc. included in erection	
TOTAL	$44472

NOTE: Data was collected in Spring, 1983 from Mr. Ken Mokoma.

Table A.2: In-Bin Counterflow (30000 bushel)

BINS	
One 48 ft. diameter 29000 bushel bin @ $21250	$21250
DRYER	
One Shivvers 2000	$24645
TRANSPORT AUGERS	
One 54 ft. x 8 inch auger to fill wetholding bin	$2640
One 60 ft. x 8 inch auger from dryer to bin	$2150
- augers include accessories such as hoppers, supports, etc.	
OTHER COSTS	
Electrician	$2500
Electric panel	$1750
Concrete costs 50 yds. @ $42/yd.	$2110
Fill	$86
- rerod etc. included in erection	
TOTAL	$57121

NOTE: Data was collected in Spring, 1983 from Mr. Ken Mokoma.

Table A.3: Automatic Batch/Dryeration (30000 bushel)

BINS	
Three 27 ft. diameter 9200 bushel bins @ $11305.	$33915
DRYER	
One A. B. 120.	.$7500
One 12 ft. diameter 2000 bushel wetholding bin	.$4880
- includes auger to fill bin	
TRANSPORT AUGERS	
One 54 ft. x 8 inch auger to fill wetholding bin	.$2640
One 60 ft. x 8 inch auger from dryer to bin.	.$2150
One 60 ft. x 8 inch bin-to-bin auger	.$2294
- augers include accessories such as hoppers, supports, etc.	
TEMPERING BIN	
One 18 ft. 5000 bushel bin	.$6400
OTHER COSTS	
Electrician.	.$2500
Electric panel	.$1750
Concrete costs 63 yds. @ $42/yd.	.$2636
Fill	$118
- rerod etc. included in erection	
TOTAL	$66793

NOTE: Data was collected in Spring, 1983 from Mr. Ken Mokoma.

Table A.4: Automatic Batch/Low Temperature (30000 bushel)

BINS	
Five 30 ft. diameter 5650 bushel bins @ $10640	$53200
DRYER	
One A. B. 120.	.$7500
Five electric heaters.	.$3450
One 12 ft. diameter 2000 bushel wetholding bin	.$4880
- includes auger to fill bin	
TRANSPORT AUGERS	
One 54 ft. x 8 inch auger to fill wetholding bin	.$2640
One 44 ft. x 8 inch auger from dryer to bin.	.$1452
One 66 ft. x 8 inch bin-to-bin auger	.$2524
One 33 ft. x 8 inch bin-to-bin auger	.$1262
- augers include accessories such as hoppers, supports, etc.	
OTHER COSTS	
Electrician.	.$2500
Electric panel	.$1750
Concrete costs 109 yds. @ $42/yd..	.$4578
Fill	$197
- rerod etc. included in erection	
TOTAL	$85933

NOTE: Data was collected in Spring, 1983 from Mr. Ken Mokoma and Mr. Mark Doyle.

Table A.5: Automatic Batch/Natural Air (30000 bushels)

BINS	
Seven 27 ft. diameter 4200 bushel bins @ $9655	$67585
DRYER	
One A. B. 120	$7500
One 12 ft. diameter 2000 bushel wetholding bin	$4880
- includes auger to fill bin	
TRANSPORT AUGERS	
One 54 ft. x 8 inch auger to fill wetholding bin	$2640
One 44 ft. x 8 inch auger from dryer to bin	$1452
One 90 ft. x 8 inch bin-to-bin auger	$3441
One 60 ft. x 8 inch bin-to-bin auger	$2294
- augers include accessories such as hoppers, supports, etc.	
OTHER COSTS	
Electrician	$2500
Electric panel	$1750
Concrete costs 136 yds. @ $42/yd.	$5712
Fill	$242
- rerod etc. included in erection	
TOTAL	$99996

NOTE: Data was collected in Spring, 1983 from Mr. Ken Mokoma.

Table A.6: Automatic Batch (80000 bushel)

BINS	
Two 48 ft. diameter 41320 bushel bins @ $26975.	$53950
DRYER	
One A. B. 500.	$23000
One 15 ft. diameter 3000 bushel wetholding bin	$6500
- includes auger to fill bin	
TRANSPORT AUGERS	
One 54 ft. x 8 inch auger to fill wetholding bin	$2640
One 76 ft. x 8 inch auger from dryer to bin.	$2450
One 51 ft. x 8 inch bin-to-bin auger	$1950
- augers include accessories such as hoppers, supports, etc.	
OTHER COSTS	
Electrician.	$2500
Electric panel	$1750
Concrete costs 73 yds. @ $42/yd.	$3066
Fill	$135
- rerod etc. included in erection	
TOTAL	$96597

NOTE: Data was collected in Spring, 1983 from Mr. Ken Mokoma.

Table A.7: In-Bin Counterflow (80000 bushel)

BINS	
Two 48 ft. diameter 41320 bushel bin @ $26975	$53950
DRYER	
One Shivvers 5000	$35625
TRANSPORT AUGERS	
One 54 ft. x 8 inch auger to fill wetholding bin	$2640
One 76 ft. x 8 inch auger from dryer to bin	$2450
One 51 ft. x 8 inch bin-to-bin auger	$1950
- augers include accessories such as hoppers, supports, etc.	
OTHER COSTS	
Electrician	$2500
Electric panel	$1750
Concrete costs 56 yds. @ $42/yd.	$2352
Fill	$151
- rerod etc. included in erection	
TOTAL	$103368

NOTE: Data was collected in Spring, 1983 from Mr. Ken Mokoma.

Table A.8: Automatic Batch/Dryeration (80000 bushel)

BINS

Nine 27 ft. diameter 9200 bushel bins @ $11305 . . . .$101745

DRYER

One A. B. 250. . . . . $13700

One 15 ft. diameter 3000 bushel wetholding bin $6500

- includes auger to fill bin

TRANSPORT AUGERS

One 54 ft. x 8 inch auger to fill wetholding bin $2640

One 60 ft. x 8 inch auger from dryer to bin. $2150

One 90 ft. x 8 inch bin-to-bin auger $3441

One 120 ft. x 8 inch bin-to-bin auger. $4588

- augers include accessories such as hoppers, supports, etc.

TEMPERING BIN

One 18 ft. 5000 bushel bin $6400

OTHER COSTS

Electrician. $2500

Electric panel $1750

Concrete costs
171 yds. @ $42/yd.. . . . .$7182

Fill $304

- rerod etc. included in erection

TOTAL $152900

NOTE: Data was collected in Spring, 1983 from Mr. Ken Mokoma.

Table A.9: Automatic Batch/Low Temperature (80000 bushel)

BINS

Fourteen 30 ft. diameter 5650 bushel bins @ $10640 . . . . . .$148960

DRYER

One A. B. 250. . . . . $13700

Fourteen electric heaters. $9660

One 15 ft. diameter 3000 bushel wetholding bin $6500

- includes auger to fill bin

TRANSPORT AUGERS

One 54 ft. x 8 inch auger to fill wetholding bin $2640

One 44 ft. x 8 inch auger from dryer to bin. $1452

Two 198 ft. x 8 inch bin-to-bin auger $15141

- augers include accessories such as hoppers, supports, etc.

OTHER COSTS

Electrician. $2500

Electric panel $1750

Concrete costs
290 yds. @ $42/yd.. . . . . $12180

Fill $508

- rerod etc. included in erection

TOTAL $214721

NOTE: Data was collected in Spring, 1983 from Mr. Ken Mokoma and Mr. Mark Doyle.

Table A.10: Automatic Batch/Natural Air (80000 bushels)

BINS

Eighteen 27 ft. diameter 4200 bushel bins @ $9655 . . . . . . $173808

DRYER

One A. B. 250. . . . . $13700

One 15 ft. diameter 3000 bushel wetholding bin $6500

- includes auger to fill bin

TRANSPORT AUGERS

One 54 ft. x 8 inch auger to fill wetholding bin $2640

One 44 ft. x 8 inch auger from dryer to bin. $1452

Two 240 ft. x 8 inch bin-to-bin augers $18352

- augers include accessories such as hoppers, supports, etc.

OTHER COSTS

Electrician. $2500

Electric panel $1750

Concrete costs
335 yds. @ $42/yd.. . . . . $14070

Fill $584

- rerod etc. included in erection

TOTAL $235356

NOTE: Data was collected in Spring, 1983 from Mr. Ken Mokoma.

APPENDIX B

ENERGY AND LABOR REQUIREMENTS

Table B.1: Standardized average energy consumption for the alternative corn drying methods in Michigan on the Kalchik farm tests (1978-1979-1980).

Drying Technique	Electricity (kwh/bu)	Propane (gal/bu)
Automatic Batch (HT)	0.12	0.27
In-bin Counterflow (HT)	0.37	0.15
A. Batch/Dryer. (HT/LT)	0.34	0.11
A. Batch/L. Temp. * (HT/LT)	1.77	0.07
A. Batch/Nat. Air (HT/LT)	1.24	0.07

* Energy consumption data for low temperature systems are from 1978 only.

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

Table B.2: Aeration fan hours required for alternative drying and storage systems.

Drying and Storage Technique (CFM/bu)	No. of bins	Fall (hr)	Winter (hr)	Spring (hr)	Total (hr)
	30000 bushel systems				
Automatic Batch (HT) (.37)	1	121	54	32	207
In-bin Counter. (HT) (.45)	1	100	44	27	171
A. B./Dryer. (HT/LT) (1.0)	3	45	60	36	141
	80000 bushel systems				
Automatic Batch (HT) (.37)	2	321	143	86	550
In-bin Counter. (HT) (.45)	2	204	91	55	350
A. B./Dryer. (HT/LT) (1.0)	9	135	180	108	423

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

Table B.3: Electricity consumption for aeration.

Drying and Storage Technique	Tot. Fan Hours	Elec. (kwh)	Elec. (kwh/100 bu)	Total ($/100 bu)
30000 bushel systems				
Automatic Batch (HT) (.37)	207	772	2.57	0.20
In-bin Counter. (HT) (.45)	171	893	2.98	0.23
A. Batch/Dryer. (HT/LT) (1.0)	141	736	2.45	0.19
80000 bushel systems				
Automatic Batch (HT) (.37)	550	2872	3.59	0.28
In-bin Counter. (HT) (.45)	350	1827	2.28	0.18
A. Batch/Dryer. (HT/LT) (1.0)	423	2209	2.76	0.22

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

Table B.4: Energy consumption and cost per 100 bushel for alternative drying and storage systems.

Drying/Storage Technique	Drying Elec. (kwh)	Drying LP (gal)	Aeration Elec. (kwh)	Total Elec. (kwh)	Total LP (gal)	Cost * Elec. ($)	Cost * LP ($)
			30000 bushel systems				
Auto. Batch (HT)	12	27	2.57	14.57	27	1.14	22.95
In-bin Counter. (HT)	37	15	2.98	39.98	15	3.12	12.75
A. Batch/Dryer. (HT/LT)	34	11	2.45	36.45	11	2.84	9.35
A. Batch/L. T. (HT/LT)	177	7	---	177	7	13.81	5.95
A. Batch/N. A. (HT/LT)	124	7	---	124	7	9.67	5.95
			80000 bushel systems				
Auto. Batch (HT)	12	27	3.59	15.59	27	1.22	22.95
In-bin Counter. (HT)	37	15	2.28	39.28	15	3.06	12.75
A. Batch/Dryer. (HT/LT)	34	11	2.76	36.76	11	2.87	9.35
A. Batch/L. T. (HT/LT)	177	7	---	177	7	13.81	5.95
A. Batch/N. A. (HT/LT)	124	7	---	124	7	9.67	5.95

* Price of electricity is $0.078. Price of LP is $0.85 per gal.

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

Table B.5: Annual labor requirements for alternative drying techniques.

Drying Technique	High Temp. Dry. Hrs (hrs)	Low Temp. Dry. Hrs (hrs)	High Temp Labor (hrs)	Low Temp. Labor (hrs)	Total Labor (hrs)
		30000 bushel systems			
Automatic Batch (HT)	429	---	72	---	72
In-bin Counter. (HT)	110	---	18	---	18
A. Batch/Dryer. (HT/LT)	245	448	41	9	50
A. Batch/L. Temp. (HT/LT)	123	794	21	28	49
A. Batch/Nat. Air (HT/LT)	123	884	21	37	58
		80000 bushel systems			
Automatic Batch (HT)	246	---	41	---	41
In-bin Counter. (HT)	468	---	78	---	78
A. Batch/Dryer. (HT/LT)	326	448	54	28	82
A. Batch/L. Temp. (HT/LT)	163	794	27	77	104
A. Batch/Nat. Air (HT/LT)	163	884	27	111	138

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

Table B.6: Total annual labor requirements and cost per 100 bu. for alternative drying and storage techniques.

Drying and Storage Technique	Tot. Drying Hours	Mgt & Sup Hours	Tot. Labor Hours	Labor Cost ($)
	30000 bushel systems			
Automatic Batch (HT)	72	2	74	1.36
In-bin Counter. (HT)	18	2	20	0.37
A. Batch/Dryer. (HT/LT)	50	9	55	1.01
A. Batch/L. Temp. (HT/LT)	49	8	57	1.05
A. Batch/Nat. Air (HT/LT)	58	8	66	1.21
	80000 bushel systems			
Automatic Batch (HT)	41	4	45	0.31
In-bin Counter. (HT)	78	4	82	0.56
A. Batch/Dryer. (HT/LT)	82	15	97	0.67
A. Batch/L. Temp. (HT/LT)	104	23	127	0.87
A. Batch/Nat. Air (HT/LT)	138	24	162	1.11

NOTE: Wage rate is $5.50 per hour. HT designates a high temperature drying system. HT/LT designates a high temperature/ low temperature combination drying system.

APPENDIX C

RESULTS OF ANALYSIS

Table C.1: Change in total cost as energy prices increase. *

	Total Cost(E1) (cents/bu)	Total Cost(E2) (cents/bu)	Total Cost(Δ) (cents/bu)
	30000 bu.		
Auto. Batch (HT)	40	46	6
In-bin Count. (HT)	35	39	4
A. Batch/Dryer. (HT/LT)	35	38	3
A. Batch/L. Temp. (HT/LT)	49	54	5
A. Batch/Nat. Air (HT/LT)	50	53	3
	80000 bu.		
Auto. Batch (HT)	37	43	6
In-bin Count. (HT)	29	33	4
A. Batch/Dryer. (HT/LT)	32	35	3
A. Batch/L. Temp. (HT/LT)	46	51	5
A. Batch/Nat. Air (HT/LT)	45	49	4

* Measured at risk level one (R1).

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

Table C.9: Breakeven return, percentage fixed cost, and fixed cost with increasing energy prices and risk levels (E2,R2).

	BER (cents/bu)	% Fixed Cost (%)	Fix. Cost (cents/bu)
	30000 bu.		
Auto. Batch (HT)	47	32.1	15
In-bin Count. (HT)	40	48.2	19
A. Batch/Dryer. (HT/LT)	39	57.2	22
A. Batch/L. Temp. (HT/LT)	54	53.3	29
A. Batch/Nat. Air (HT/LT)	54	61.3	33
	80000 bu.		
Auto. Batch (HT)	43	28.4	12
In-bin Count. (HT)	33	38.5	13
A. Batch/Dryer. (HT/LT)	35	53.4	19
A. Batch/L. Temp. (HT/LT)	51	51.0	26
A. Batch/Nat. Air (HT/LT)	49	58.0	28

NOTES: 1. HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

2. BER designates the breakeven return.

Table C.3: Change in total cost as energy prices and risk level increases.

	Total Cost(E1,R1) (cents/bu)	Total Cost(E2,R2) (cents/bu)	Total Cost(Δ) (cents/bu)
	30000 bu.		
Auto. Batch (HT)	40	47	7
In-bin Count. (HT)	35	40	5
A. Batch/Dryer. (HT/LT)	35	39	4
A. Batch/L. Temp. (HT/LT)	49	54	5
A. Batch/Nat. Air (HT/LT)	50	54	4
	80000 bu.		
Auto. Batch (HT)	37	43	6
In-bin Count. (HT)	29	33	4
A. Batch/Dryer. (HT/LT)	32	35	3
A. Batch/L. Temp. (HT/LT)	46	51	5
A. Batch/Nat. Air (HT/LT)	45	49	4

NOTES: 1. HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

2. All cost figures are presented on an annual present value, after-tax basis.

Table C.4: Change in energy cost as energy prices increase. *

	Energy Cost(E1) (cents/bu)	Energy Cost(E1) (cents/bu)	Energy Cost(△) (cents/bu)
	30000 bu.		
Auto. Batch (HT)	24	30	6
In-bin Count. (HT)	16	20	4
A. Batch/Dryer. (HT/LT)	12	15	3
A. Batch/L. Temp. (HT/LT)	19	23	4
A. Batch/Nat. Air (HT/LT)	15	19	4
	80000 bu.		
Auto. Batch (HT)	24	30	6
In-bin Count. (HT)	16	20	4
A. Batch/Dryer. (HT/LT)	12	15	3
A. Batch/L. Temp. (HT/LT)	19	23	4
A. Batch/Nat. Air (HT/LT)	15	19	4

* Measured at risk level one (R1)

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

Table C.5: Change in fixed cost as risk level increases. *

	Fix. Cost(R1) (cents/bu)	Fix. Cost(R2) (cents/bu)	Fix. Cost(△) (cents/bu)
	30000 bu.		
Auto. Batch (HT)	14	15	1
In-bin Count. (HT)	18	19	1
A. Batch/Dryer. (HT/LT)	21	22	1
A. Batch/L. Temp. (HT/LT)	28	29	1
A. Batch/Nat. Air (HT/LT)	32	33	1
	80000 bu.		
Auto. Batch (HT)	12	12	0
In-bin Count. (HT)	12	13	1
A. Batch/Dryer. (HT/LT)	18	19	1
A. Batch/L. Temp. (HT/LT)	25	26	1
A. Batch/Nat. Air (HT/LT)	28	29	1

* Measured at energy price level one (E1)

NOTE: HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

Table C.6: Breakeven return, percentage fixed cost, and fixed cost -- base run (E1,R1).

	BER (cents/bu)	% Fixed Cost (%)	Fix. Cost (cents/bu)
	30000 bu.		
Auto. Batch (HT)	40	35.7	14
In-bin Count. (HT)	35	52.1	18
A. Batch/Dryer. (HT/LT)	35	60.7	21
A. Batch/L. Temp. (HT/LT)	49	56.7	28
A. Batch/Nat. Air (HT/LT)	50	64.5	32
	80000 bu.		
Auto. Batch (HT)	37	31.9	12
In-bin Count. (HT)	29	42.2	12
A. Batch/Dryer. (HT/LT)	32	57.1	18
A. Batch/L. Temp. (HT/LT)	46	54.5	25
A. Batch/Nat. Air (HT/LT)	45	61.3	28

NOTES: 1. HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

2. BER designates the breakeven return.

Table C.7: Breakeven return, percentage fixed cost, and fixed cost as energy prices increase (E2,R1).

	BER (cents/bu)	% Fixed Cost (%)	Fix. Cost (cents/bu)
		30000 bu.	
Auto. Batch (HT)	46	31.0	14
In-bin Count. (HT)	39	47.0	18
A. Batch/Dryer. (HT/LT)	38	56.0	21
A. Batch/L. Temp. (HT/LT)	54	52.2	28
A. Batch/Nat. Air (HT/LT)	53	60.3	32
		80000 bu.	
Auto. Batch (HT)	43	27.4	12
In-bin Count. (HT)	33	37.3	12
A. Batch/Dryer. (HT/LT)	35	52.3	18
A. Batch/L. Temp. (HT/LT)	51	49.9	25
A. Batch/Nat. Air (HT/LT)	49	57.0	28

NOTES: 1. HT designates a high temperature drying system. HT/LT designates a high temperature/low temperature combination drying system.

2. BER designates the breakeven return.

REFERENCES

REFERENCES

Albert, R.L. "Corn Standards: Past, Present, and Future." In Corn Quality in World Markets ed. by L.D. Hill, Interstate Printers, and Publishers, Danville, Illinois, 1975, p. 145.

American Society of Agricultural Engineers. "Agricultural Machinery Management," ASAE, St. Joseph, Michigan, 1982, p. 210.

Anderson, Donald E. "Economic Aspects of Conserving Quality of Export Corn." In Corn and Soybeans Grain Damage Symposium. Department of Agricultural Engineering, The Ohio State University, Columbus, Ohio, 1972, p. 198.

Anderson, Donald E. "Importance of Physical Damage in Export Corn." In Corn Quality of World Markets, ed. by L.D. Hill, Interstate Printers and Publishers, Danville, Illinois, 1975, p. 151.

Anon. Moody's Bond Survey. Investors Service, Inc., New York, 1984, Vol. 76, Nos. 14-18.

Bartsch, J.A. and M.F. Finner. "A Low-temperature Grain Drying Experiment in an Artificially Reproduced Environment." Transactions of the American Society of Agricultural Engineers, 1976, Vol. 19, pg. 37.

Bierman, J., and M. Schmid. The Capital Budgeting Decision, Fourth Edition. McMillan Publishing Co., New York, 1975.

Brekke, O.L., E.L. Griffin Jr., and Gene C. Shove. "Dry Milling of Corn Artificially Dried at Various Temperatures." Trans. ASAE, 1973, Vol. 16, pg. 761.

Brooker, D.B., B.A. McKenzie, and H.K. Johnson. "The Present Status of On-farm Grain Drying." Paper No. 78-3007, ASAE, 1978.

Brown, L.H. and M.P. Kelsey. "Telfarm Business Analysis Summary for Cash Grain Farms." Agricultural Economics Report No. 411, Department of Agricultural Economics, Michigan State University, East Lansing Michigan, 1981.

Butz, D.E. "The Importance of Corn Quality in World Markets." In Corn Quality in World Markets. ed. by L.D. Hill, Interstate Printers and Publishers, Danville, Illinois, 1975, p. 9.

Casler, George L., Bruce L. Anderson and Richard D. Aplin. Capital Investment Analysis; Using Discounted Cash Flows, Third Edition. Grid Publishing Co., Columbus, Ohio, 1984, pp. 37-44.

Chowbury, M.H. and W.F. Buchele. "Coloriometric Determination of Grain Damage." Trans. ASAE, 1976, Vol. 19(5), pg. 807.

Chowbury, M.H. and W.F. Buchele. "Development of a Numerical Damage Index for Critical Evaluation of Mechanical Damage of Corn." Trans. ASAE, 1976, Vol. 19(5), pg. 428.

Chowbury, M.R. and G.L. Kline. "Stress Cracks in Corn Kernels from Compression Loading." Paper No. 78-3541, ASAE, 1978.

Dobbs, William. "Costs of Mechanical Damage in Shelled Corn at Grain Terminals." In Corn and Soybeans Grain Damage Symposium. Department of Agricultural Engineering, The Ohio State University, Columbus, Ohio, 1972, pg. 29.

Foster, G.H. "Dryeration -- A Corn Drying Process." USDA Agricultural Marketing Service Bulletin No. 532, USDA, Washington, D.C., 1964.

Foster, G.H. and L.E. Holman. "Grain Breakage Caused by Commercial Handling Methods." Marketing Research Report No. 968, Agricultural Research Service, USDA, Washington, D.C., 1973.

Foster, George. "Cause and Cures to Physical Damage in Corn." In Corn Quality in World Markets. ed. by L.D. Hill, Interstate Printers and Publishers, Danville, Illinois, 1975, pg. 221.

Freeman, Jere E. "Damage Factors Which Affect the Value of Corn for Wet Milling." In Corn and Soybeans Grain Damage Symposium, Department of Agricultural Engineering, The Ohio State University, Columbus, Ohio, 1972. pg. 49.

French, Ben C. "The Analysis of Productive Efficiency in Agricultural Marketing: Models, Methods, and Progress." In A Survey of Agricultural Economics Literature. ed. by Lee Martin, Vol. 1, AAEE, University of Minnesota Press, Minneapolis, Minnesota, 1977, pp. 136-141.

Fuller, E. "Income Management for Minnesota Farmers." FM 205, Agricultural Extension Service, University of Minnesota, St. Paul, Minnesota, 1977.

Gustafson, R.J., R.V. Morey, C.M. Christensen and R.A. Meromick. "Quality Changes During High-Low Temperature Drying." Trans ASAE, 1978, Vol. 21(1), p. 162.

Hamilton, H.E., I.J. Ross, and G.M. White. "Discoloration and Stress Cracking of White Corn as Affected by Drying." In Corn and Soybeans Grain Damage Symposium, Department of Agricultural Engineering, The Ohio State University, Columbus, Ohio, 1972, p. 134.

Harsh, Stephen B., Larry J. Conner, and Gerald D. Schwab. Managing the Farm Business. Prentice Hall, Inc., Englewood Cliffs, New Jersey, 1981.

Hathaway, I.L., F.D. Yung, and T.T. Kresselbach. "The Effect of Drying Temperature on Nutritive Value and Commercial Grade of Corn." J. Animal Sci., 1952, Vol. 11, p.430.

Hill, L.D. "Adjustments in Drying and Storage Capacity at Farm and Elevator." AERR No. 105, Department of Agricultural Economics, Agricultural Experiment Station, University of Illinois, Urbana-Champaign, Illinois, 1970.

Hill, L.D. Preface. Corn Quality in World Markets. ed. by L.D. Hill, Interstate Publishers and Printers, Danville, Illinois, 1975.

Hill, Lowell D. and Marvin R. Paulsen. "Grain Quality Lossess During Overseas Shipment." Unpublished draft, 1976.

Hill, L.D., M.R. Paulsen, and D. Miller. "Corn Breakage as Affected by Handling During Shipment." Agricultural Experiment Station, University of Illinois, Urbana-Champign, Illinois, 1976.

Hill, Lowell D. and Marvin R. Paulsen. "Changes in Quality of Grain During Overseas Shipment." In Illinois Research, 1977, Vol. 19, No. 1, Agricultural Experiment Station, University of Illinois, Urbana-Champaign, Illinois.

Hill, Lowell D., Marvin R. Paulsen, and Margaret Early. "Corn Quality Changes During Export." Special Publication No. 58, Agricultural Experiment Station, University of Illinois, Urbana-Champaign, Illinois, 1979.

Hill, L.D., M.R. Paulsen, T.L. Mounts, A.J. Heakin, and G.R. List. "Changes in Quality of Corn and Soybeans Between United States and England." Special Publication No. 63, Agricultural Experiment Station, University of Illinois, Urbana-Champaign, Illinois, 1981

Hill, Lowell D., Mack N. Leath, Odette L. Shotwell, Donald G. White, Marvin R. Paulsen, and Phillip Garcia. "Alternative Definitions for the Grade Factor of Broken Corn and Foreign Material." University of Illinois, Agricultural Experiment Station Bulletin No. 776; University of Illinois, Urbana-Champaign, Illinois, 1982.

Hurburgh, C.R. Jr. and B.W. Moechnig. "Corn Quality Changes in Commercial Elevator Operations." Paper No. 82-3547, ASAE, 1982.

Isaccs, G.W. "An Overview of Energy Consumption in Corn Production and Marketing." In Energy for Agriculture Conference, Corn Refiners Association, Inc., Washington, D.C., 1973.

Jensen, A.H., S.W. Terrill, and D.E. Becker. "Nutritive Value of Corn Dried at 140, 180, and 220F for Swine of Different Ages." J.Animal Sci., 1960, Vol. 19, p. 629.

Jensen, A.H. "The Effects of Processing (Roasting) on the Nutritional Value of Corn for Swine." In Proceedings: 1977 Corn Quality Conference, University of Illinois, Urbana-Champaign, Illinois, 1978.

Kalchik, S.J., J.S. Silva, E.N. Mwaura, J.C. Rodriquez, and F. W. Bakker-Arkema. "On-farm Drying Comparison." Paper No. 81-3011, ASAE, 1981.

Kalchik, S.J., J.S. Silva, F.W. Bakker-Arkema, and B.S. Miller. "An Economic-Engineering Comparison of Five Drying Techniques for Shelled Corn on Michigan Farms." Paper No. 79-3518, ASAE, 1979.

Kline, G.L. "Mechanical Damage to Corn During Harvest and Drying." In Corn and Soybeans Grain Damage Symposium, Department of Agricultural Engineering, The Ohio State University, Columbus, Ohio, 1972, p. 79.

Leath, Mack N. "Marketing Quality Grain in Domestic and Foreign Markets: A Summary of NC-151 Activities." ERS Staff Report No. AGES83 0713, National Economics Division, Economics Research Service, USDA, Washington, D.C., 1983.

Loewer, O.J., Jr., T.C. Bridges, and D.G. Overhults. "Facility Costs of Centralized Storage Systems Utilizing Computer Design." Paper No. 75-3511, ASAE, 1975.

Madsen, Jeffrey P., Harald R. Jensen, and Vernon R. Eidman. "Economics of Owning and Operating Corn Drying and Storing Systems with Rising Energy Prices." Economic Report ER 78-5, Department of Agricultural and Applied Economics, University of Minnesota, St. Paul, Minnesota, 1978.

Martin, C.R. and L.E. Stephens. "Broken Corn and Dust Generated During Repeated Handling." Trans. ASAE, 1977, Vol. 20, Pg. 168.

McKenzie, Bruce A. and Larry Van Fossen. "Managing Dry Grain in Storage." AED-20, Midwest Plan Service, Iowa State University, Ames, Iowa, 1980, p. 3.

Michigan Department of Agriculture. Michigan Agricultural Statistics. Michigan Agricultural Reporting Service, MDA, Lansing, Michigan, 1983, p. 9.

Michigan Department of Agriculture. Michigan Agricultural Statistics. Michigan Agricultural Reporting Service, MDA, Lansing, Michigan, 1979.

Paulsen, M.R., L.D. Hill, D.G. White, and G.F. Sprague. "Breakage Susceptibility of Common Corn Belt Genotypes." Paper No. 82-3056, ASAE, 1982.

Pierce, R.O. and T.L. Thompson. "Management of Solar and Low-Temperature Grain Drying Systems." Paper No. 78-3513, ASAE, 1978.

Roberts, Hugh J. "Corn Damage and Its Affect on Dry Milling." In Corn and Soybeans Grain Damage Symposium, Department of Agricultural Engineering, The Ohio State University, Columbus, Ohio, 1972, p. 37.

Ross, I.J. and G.M. White. "Discoloration and Stress Cracking of White Corn as Affected by Overdrying." Trans. ASAE, 1972, Vol. 15(2), Pg. 327.

Schwart, R.B. and L.D. Hill. "Comparative Costs of Conditioning and Storing Corn." AERR 152, Department of Agricultural Economics Agricultural Experiment Station, University of Illinois, Urbana-Champaign, Illinois, 1977.

Schwart, R.B. "Investment, Ownership, and Energy Costs of New Bin Storage and of Hot Air Drying Facilities for Corn." Farm Economics, Facts, and Opinions, Cooperative Extension Service, Department of Agricultural Economics, University of Illinois, Urbana, Illinois, 1982.

Scott, J.T. Jr. "A Comparison of On-farm Drying and Storage Systems and Costs." In Alternatives for Conditioning and Storing Corn at Farm and Elevator, AE 4228, Department of Agricultural Engineering and Agricultural Economics, University of Illinois, Urbana-Champaign, Illinois, 1970, p. 15.

Shove, G.C. "Corn Quality as Affected by Drying Procedures." In Proceedings: 1977 Corn Quality Conference, University of Illinois, Urbana-Champaign, Illinois, 1978.

Shove, G.C. "Corn Drying with Low Temperature, High Temperature Combination Systems." Paper No. 78-305, ASAE, 1978.

Silva, J.S. An Economic-Engineering Comparison of Five Drying Techniques for Shelled Corn on Michigan Farms, Ph.D. Thesis, Michigan State University, East Lansing, Michigan, 1980.

Skees, J.R., M.E. Rister, R.C. Brook, S.B. Harsh, and F.W. Bakker-Arkema. "On-farm Grain Handling Costs -- Engineering and Economic Factors." Paper No. 79-3525, ASAE, 1979.

Smith, Roger W. and E. Dean Baldwin. "Economics of Farm Drying and Storage Systems in Ohio." Ohio State University Cooperative Extension Service, Department of Agricultural Economics and Rural Sociology, The Ohio State University, Columbus, Ohio, 1975.

Stephens, Lyle E. and George H. Foster. "Breakage Tester Predicts Handling Damage in Corn." ARS-NC-49, Agricultural Research Service, USDA, Washington, D.C., 1976.

Sullivan, J.E., P.M. Coster, F.N. Owens, A.H. Jensen, K.E. Wikoff and E.E. Hotfield. "The Effect of Heat on Nutritional Value of Corn." In Corn Quality in World Markets. ed. by L.D. Hill, Interstate Printers and Publishers, Danville, Illinois, 1975, p. 45.

Thompson, R.A. and G.H. Foster. "Stress Cracks and Breakage in Artificially Dried Corn." USDA Marketing Research Report No. 631, USDA, Washington, D.C. 1963.

USDA. "World Agriculture Supply and Demand Estimates." Economic Research Service, Foreign Agriculture Service, USDA, Washington, D.C., 1974-83.

USDA. The Official United States Standards for Grain. Grain Division, Agricultural Marketing Service, USDA, Washington, D.C., 1975, p. 2.3.

USDA. Handbook of Agricultural Charts. Agricultural Handbook No. 619, USDA, Washington, D.C., 1983, p. 17.

USDA. Agricultural Outlook. AO-97, Economic Research Service, USDA, Washington, D.C., 1984, Jan/Feb, p. 28.

Van Wormer, Martin. "Corn Damage and Its Affects on Feed Manufacturing." In Corn and Soybeans Grain Damage Symposium, Department of Agricultural Engineering, The Ohio State University, Columbus, Ohio, 1972, p. 33.

Watson, S.A., F.L. Herum, and M.F. Finner. "Measuring Corn Breakage Susceptibility." Presented at the American Association of Cereal Chemists, October 30-November 3, 1983.

Williamson, J.L. "Nutritional Requirements of Livestock as Related to Corn Quality." In Corn Quality in World Markets. ed. by L.D. Hill, Interstate Printers and Publishers, Danville, Illinois, 1975, p. 17.