DESIGN OF GRAIN HANDLING AND STORAGE FACILITIES FOR TROPICAL COUNTRIES

by

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B.S., Universidad de Costa Rica, 1979

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1987

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PREFACE

The increase in the domestic crop production and/or the increase in imported grains require establishing new grain handling and storage facilities or expanding the existing ones in order to maintain grain quality and efficient grain marketing and distribution, and to reduce grain losses in a given country.

In many tropical countries, such as Central American countries, grain storage and handling systems have been adopted from developed countries, often without serious consideration on local conditions and parameters involved in designing a proper grain storage facility.

When designing a commercial grain handling and storage facility, the designer always faces the decisions of using concrete or steel bins and of selecting proper grain handling and conditioning systems. Unfortunately, a survey of current literature shows that few documents discuss how these decisions are made.

Therefore, this study is needed to develop methods for planning and designing optimal grain storage and handling facilities to be used in tropical countries.

1. To examine the advantages and disadvantages of using concrete or steel bins for storing grains under tropical conditions.

2. To study the parameters involved in the design of commercial grain storage facilities.

3. To conduct cost analysis for the processing equipment and storage structures used in commercial facilities.

4. To apply systems analysis for:
    - A. Optimum selection of storage structures.
    - B. Optimum design of commercial grain handling and storage facilities.

Chapter I of the thesis presents the results of a literature survey regarding the parameters that have been considered when choosing between concrete or steel bins.

Chapter II outlines the parameters involved in the design of commercial grain handling and storage facilities. Literature from different investigators has been gathered in order to compile in one document the data required when designing this type of facilities.

Chapter III presents a cost analysis of the different equipment used in grain handling and processing. Different figures showing the variation of costs with equipment capacity are also presented. A study of the cost of storage structures considering steel and concrete bins is included.

Chapter IV presents an application of the Technique for Order Preference by Similarity to Ideal Solution (Topsis), a multiple attribute decision making method, to select the correct type of storage structure. The Sequential Unconstraint Minimization Technique is applied to optimize the bins' size and the drying system.

Appendix I is an explanation of the structural design of concrete bins that was done to obtain data of the reinforcement steel and concrete required for different concrete silo batteries. This analysis established the basic data for the cost study of concrete bins.

CHAPTER I

USE OF CONCRETE OR STEEL BINS UNDER TROPICAL CONDITIONS

1.1 INTRODUCTION

When designing a commercial grain processing and storage facility, it is important to decide on the correct type of storage. The most common commercial storage structures are corrugated steel and concrete bins.

Corrugated steel bins are always cylindrical in shape, and available size vary from 6 m to 27 m diameter and 12 m to 23 m height. The bins are usually set on a foundation ring. The commercial sizes are usually flat with the ratio of height to diameter (H/D) lower than 2.5. The bins are arranged in batteries but are not usually interlocked. The discharge is usually through a sweep auger and unloading auger.

Concrete bins are built in different shapes, the most common being circular, rectangular and hexogonal. Diameters vary from 5 m to 12 m. and heights from 15 m. to 55 m. The wall thickness varies from 15 cm. to 20 cm. These bins are built connected to each other or independently. Because of the upright shape, the discharge is usually by gravity through a hopper.

The advantages and disadvantages of using concrete or steel bins depend on several factors related to the grain, the climate, the structure, the construction and the use that will be given to the facility.

The decision of the type of storage under tropical conditions must include parameters such as cost, availability of materials, structural aspects and grain quality preservation.

In order to describe the different aspects, a literature search was conducted through the Post Harvest Documentation Service and the After Dark Search Service at Farrell Library (KSU). The principal sources investigated were the Common Wealth Agricultural Bureau, England, the Engineering Index, Agrindex International and Agricola files from the National Agricultural Library, Washington, D.C. The most relevent aspects of this search are presented below.

1.2 GRAIN CONSERVATION DURING STORAGE

Before describing the behavior of the different types of storage bins under different circumstances, it is important to establish what is a good environment for grain conservation and the main factors that affect the stored grain. Brooker et al. (1973) described the most important source of cereal grain deterioration during storage as fungi, insects, rodents and mites. All of them affect the grain quality and quantity.

The optimum temperature for growth of most grain molds is between 25°C (77°F) and 30°C (86°F), and some molds develop best at around

$37^{o}C$ ($98^{o}F$). The minimum air relative humidity for mold germination is 65 percent. Thus, to prevent mold growth on cereal grains at any temperature, the relative humidity (RH) of the air in the grain mass must be less than 65%.

Insect development is enhanced by high moisture content (MC) conditions, (above 14%) and insect activity hardly occurs in cereal grains at moisture contents below 10%. Most insects are dormant below $10^{o}C$ ($50^{o}F$) and are killed at temperatures above $100^{o}F$.

1.3 CONDENSATION AND MOISTURE MIGRATION

1.3.1 Steel Bins

The thin outside walls of steel bins offer little thermal insulation and the temperature of the outside air can be transferred to both the grain and the air inside the bin. In this way, the outside temperature variations make the initial grain storage conditions change.

Brooker et al. (1981) described the moisture migration as follows:

When the temperature outside the bin decreases, a temperature differential is created across the walls. The air in the silo develops a continuous convection movement. The air near the walls is cooled, raising its relative humidity, and resulting in a increase of the moisture content in the bottom of the silo. This increase in moisture can create a deterioration spot. Then, the dry air rises through the central part of the bulk mass and picks up moisture from the grain. When this warm moist air contacts the cool upper grain surface, the moisture is deposited and another deterioration zone can occur.

The inverse air movement pattern may occur if the air outside the bin warms up, causing the moisture content to increase near the floor of the bin. Figure 1.1 explains this behavior.

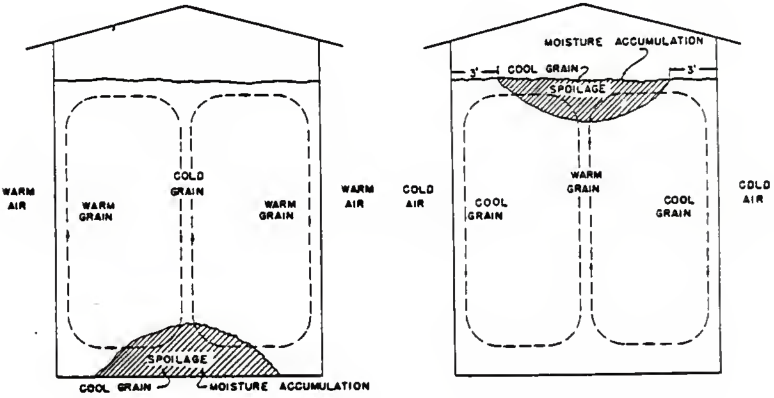

Fig. 1.1 Convection Air Currents (Brooker et al. 1981)
a) Warm grain in bin with colder surrounding air
b) Cold grain in bin with warmer surrounding air

In the tropics where seasonal temperature changes are not very large, the main problem occurs with daily temperature changes or day to night temperature variations and high humidity of air. The high daytime temperature heats the inside of the bin causing a moisture transport from the grain to the surrounding air. At night, the outside temperature drops very rapidly and the water vapor in the air spaces condenses on the internal surface of the bin, mainly on the roof. The grain can act as a condensing surface if its temperature is reduced to below the dew point temperature of the air. This condensation problem may cause deterioration areas on the top of the grain and sometimes on the walls.

Several problems with grain stored in metal silos are sited in the literature relating to condensation and grain deterioration. Shamsudin, et. al. 1984 described problems such as the occurrence of hot-spots and caking of grain in metal silos in Malaysia.

Abdalla et al. (1982) investigated the temperature and moisture changes of grain stored in sheet metal bins under the climate conditions prevailing in the North Central part of Sudan. They reported grain damaged by mold growth as a result of moisture migration within steel bins in that part of the country. The authors made management recommendations to overcome this problem and concluded that metal bins are suitable for storage of grain under the climatic conditions of North Central Sudan. In the study, they recommended the use of perforated floor as an effective method of ventilation.

Webley (1981) cites the success in use of metal silos in Austria, based on the initial low moisture content of the stored grain. He also explains that it has been not possible to keep paddy in metal bins without aeration because 10 cm of grain around the surface is completely spoiled. For a successful use of metal bins, he recommends the observation of good management standards and appropriate instrumentation for the detection of deterioration spots.

1.3.2 CONCRETE BINS

Due to concrete thermal conductivity and to the thickness of concrete bin walls, concrete bins offer better thermal insulation than steel bins.

Beaulois (1979) wrote a paper regarding the decision of using concrete or steel bins. He compared the thermal insulation of a 5 mm steel bin wall with a 140 mm concrete bin wall (average wall thickness) considering only energy transport by the mechanism of conduction, and he found that reinforced concrete walls offer a thermal insulation 1000 times greater than steel bin walls.

In a study done by Converse et al. (1973) regarding the heat transfer within wheat stored in a concrete bin, wheat temperatures showed practically no change even at 15 cm. from the wall, when the average daily external temperature was 2°C (36°F) with differences of 13.4°C (24°F) between day and night. The quality of grain used in this test was maintained reasonably well without ventilation, aeration or turning during a storage period of 2.5 years. The authors stated that the key factor in the successful storage was providing the grain a uniform low moisture content (13%) and an initial uniform grain temperature.

In another study done by Converse et al. (1977) six wheat lots out of 7, stored without aeration in concrete bins for one year, with a moisture content of 12.6%, resulted in only slight changes in fatty acid and germination. The lot that showed more deterioration had an initial moisture content of 14.2%. The literature reviewed for this project reveals no specific problems with grain conservation in concrete bins.

1.4 WEATHER EFFECTS ON THE STRUCTURE

1.4.1. Steel Bins

Tropical climates with high humidity, high temperatures and long periods of sun radiation generate an accelerated corrosive action on the steel surface structures. This problem can be worsened by condensation on the bin walls, especially underneath the roof where dew drops concentrate.

Isolated corrosion spots can occur when caking takes place on the wall surfaces. The moisture-laden cakes generate heat and acids that corrode the steel surfaces. The acids penetrate the galvanized coat, loosening part of it that is later removed during cleaning of the bins. The resulting unprotected steel surface will corrode faster.

Steel bins are not recommended under marine atmospheres in the tropics, especially on the shoreline since the most favorable environment for corrosion combines high humidity and salt (Sauter, 1984).

According to the Steel Structures Painting Council (SSPC) 1954, less severe marine atmospheres are found moving away from the coast where the structures are subject to salt-laden wind, rain and mists only a small portion of the time. Even so, thicker than normal galvanization coats are suggested.

The SSPC recommends the following galvanization thicknesses for various types of exposure.

Exposure	Thickness
Rural Atmospheres	0.076 mm, 0.45 kg of zinc/m^2
Marine Atmospheres	
Mild (light, no salt spray)	0.076 mm, 0.45 kg of zinc/m^2
Severe (heavy with spray)	0.203 mm, 2.25 kg of zinc/m^2
High Humidity Atmosphere	0.127 mm, 1.20 kg of zinc/m^2

The standard galvanized silo is usually built for specifications concerning rural atmospheres.

1.4.2 Concrete Bins

Weather effects on concrete bins are not as critical as on steel bins. Problems of water leakage may arise in concrete bins due to crack formation as a result of deficiencies in the design or bad construction techniques (Safarian, 1985). Otherwise, concrete structures are more resistant under tropical weather and require less maintenance.

1.5 UTILIZATION OF SPACE

Space is frequently a limiting parameter in choosing the type of silo. Steel bins are mainly designed to resist tensile stress and the only efficient shape is a circular bin. Otherwise, rectangular forms will introduce bending stresses that will make the steel sections not feasible to use because of the cost increase. Beaubois (1979), compared the utilization of space using concrete or steel bins obtaining the following values:

Steel bins with empty interstice = 75% of covered area.
Steel bins using interstice = 88% of covered area.
Rectangular concrete bins = 90.5% of the covered area.

It is not economical to use interstice spaces in steel bins because of the introduction of bending moments or contraction loads to the walls.

Height is also a factor. Corrugated steel bins are designed up to a height of approximately 25 m. because of structural and cost limitations (Behelen Catalog, 1986). Concrete bins are usually designed to 55 m. in height at a reasonable cost. The extra height of concrete bins gives also more storage capacity per square meter of covered area.

1.6 STRUCTURAL CONSIDERATIONS

1.6.1 Bin Structure

Given that steel bins are designed to support mainly tensile stress, the steel sections are very thin and lack rigidity to absorb compression loads or bending moments. When steel bins are connected together and two opposite interstice are filled leaving the circular bin empty, compression stresses are developed on the bin walls (Beaubois, 1979). To avoid deformation due to this stress, thicker sections and rigid girders are required which make the bins more expensive. The same considerations apply to concrete bins but due to the rigidity of the wall sections this stress is handled without increasing the existing thickness a great deal.

Steel bins should preferably be discharged through a central outlet. Eccentric discharge generates higher pressures on the opposite wall which may result in ovalization of the bin.

When the size of steel bins increases over diameters of 15 m. (49.2 ft.) and heights of 20 m. (65.6 ft.), the compression stress caused by the friction of the grain against the wall becomes very high, requiring the use of thicker plates and stiffeners to avoid buckling of the plates (Mata, 1983).

High gusts of wind may also affect the stability of steel bins, especially when they are empty.

1.6.2 SOIL CAPACITY

Bowmans (1985) considers the soil conditions one of the most important structural parameters when the bin construction material is selected. If the soil stratum has little supporting capacity or high settlements of the structure are expected, light constructions with bigger cross areas are preferred.

1.7 CONSTRUCTION ASPECTS

1.7.1 Steel Bins

The most common and economical metal bin is constructed with corrugated metal sheets. These bins are industrially constructed mostly by assembling prefabricated panels. This technique makes the initial cost, especially at the place of fabrication, very attractive. (Bowmans, 1985). The relatively easy assembly process makes this type of silo ideal for countries whose construction technology is not very advanced. The required equipment is not too complex and workers can be easily trained to erect this type of structure.

Problems related to water leakage through the wall sheets and bolts are described in Ismail et al. (1984). A skilled foreman is advisable to direct the assembly to avoid this problem.

1.7.2 Concrete Bins

The construction of concrete bins is more sophisticated and time consuming than the steel bin construction. Bowmans (1985), Reimbert (1976) and Sofarian (1985) describe the construction of concrete bins in detail. The main points are mentioned below.

This type of construction requires high technology, qualified personnel with experience in handling large quantities of concrete per hour, and extensive non-qualified personnel. The slip formed technique requires a specialized company. Additional heavy equipment such as cranes, concrete hoisters, concrete plants, concrete trucks, concrete pumps and electrical plants are also required.

Another important factor is the availability of materials such as sand, stones, steel bars and cement. They should be stored in the place of construction or very near it before starting to raise the structure. The organization and planning of the staff and the site require a specialist to be in full control of the process.

1.8 TYPE OF STORAGE FACILITY

Storage structures are usually classified according to the function they perform in the grain trading process Bouland (1966), Webley, (1981).

When the objective is to hold the commodity at a given quality level for a given period of time, they are classified as storage facilities. When these facilities hold only one or two types of grain during 1 1/2 years, the practice is to build a flat storage. Flat storages are defined as bins with diameters or widths larger than their height. For this design, corrugated steel bins are usually cheaper than concrete bins.

When the objective is to provide a link in the postharvest chain, either to accumulate grain from farms and transfer it to rail, or to accumulate from rail and transfer to ships, they are classified as working facilities. For these needs, usually upright structures are selected. They are more suitable and economical for loading and unloading the grain and are usually more economical for storing many grain varieties. One facility can have numerous bins which provides flexibility for segregating and blending grain. Under these circumstances, concrete bins are usually more economical to build and to operate than steel bins.

1.9 COST

Cost is always a very important factor when choosing among different alternatives.

Bouland (1966) showed a break-even point of about 2500 tons (100,000 bushels) of storage capacity for construction costs in the USA. The criterion was that below this capacity, steel tanks usually have a lower initial construction cost, and above this capacity, concrete tanks usually cost less.

Construction costs will vary depending on overseas freight requirements, taxes, availability of construction materials and labor costs.

No updated literature was found related to the variation of cost of storage structures with the capacity.

1.10 ASSOCIATED BENEFITS

Chung et al. (1983) during the study of the grain handling facilities in Costa Rica, considered not only the factors mentioned above, but also the associated benefits that could be brought to the country through the projects.

Social benefits like the creation of new employment sources may be of special interest for different countries. The type of structure to be built will highly influence this aspect. The requirements of foreign exchange is also considered as an associated benefit. Countries with low availability of foreign exchange will prefer the construction alternative that demands fewer imported materials.

1.11 CONCLUSIONS AND REMARKS

1. Both types of bins have been successfully used in tropical weather. When steel bins are used, they require good managment standards and good supervision during construction to avoid water leakage problems. An efficient areation system is also required.

2. Through the literature review, it can be concluded that the main

factors that provide the basis for selecting the correct type of bin are: cost, grain conservation, Longevity of the structure (including endurance and weather effects), Function of the structure, Construction aspects, Associated benefits and Operation flexibility.

3. The influence of each one of the above aspects in both types of structure is well documented in the literature. The final decision will be a compromised solution among these factors. Due to the nature of the decision parameters, the selection will differ for each specific situation.

4. No articles were found in the literature explaining a methodology to consider the different factors that influence the selection. A scientific method to form a compromise solution is missing.

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CHAPTER II

DESIGN PARAMETERS

2.1 INTRODUCTION

Even though much has been written about the factors to be considered when designing grain handling and storage facilities, currently, the information must be found in many different books and scientific papers. The lack of collected information complicates the design task.

This chapter condenses the required information for planning and designing commercial facilities. Considering that the main cereal grain crops in tropical countries are rice and corn, special interest is given to the design parameters for these two products.

Also included in this chapter is a general description of a commercial grain handling system, planning methods and guides for sizing the system, recommended layouts, grain processing and storage practices and physical characteristics of the grain.

This information has been gathered through scientific literature, the detailed study of manufacturing catalogs and personal recommendations from experts in the field.

2.2 DESCRIPTION OF THE SYSTEM.

A general commercial grain handling and storage facility usually consists of a receiving area, a processing and grain conditioning system and a storage area. In order for the grain flow within the facility to be safe, reliable and flexible, the whole process has to be considered as an integrated system.

In the receiving area, using a truck scale platform and a truck control room, the grain is weighed, sampled and loaded in. To load the grain, a grain hopper and a bucket elevator are required. Usually, a pre-cleaning device is placed in the top of the bucket elevator. For high-flow receiving rates, a truck dump platform may be used to speed up the unloading of the grain.

In the processing area, the grain is cleaned, dried and transported to storage. The grain flow will depend on the grain receiving conditions, the type of grain and the drying system. The basic equipment here are grain elevators, grain conveyor, cleaners and dryers.

The storage system is made up of a grain loading sub system, a set of storage units, usually corrugated steel or concrete bins, and an unloading subsystem.

2.3 FLOW DIAGRAM AND DESIGN CONSIDERATIONS

A general flow process can be visualized by Fig. 2.1. The functional sequence in grain handling and drying are to receive, elevate, dry, store and load out. A number of alternative equipment and system designs can carry out each of the functions. One of the

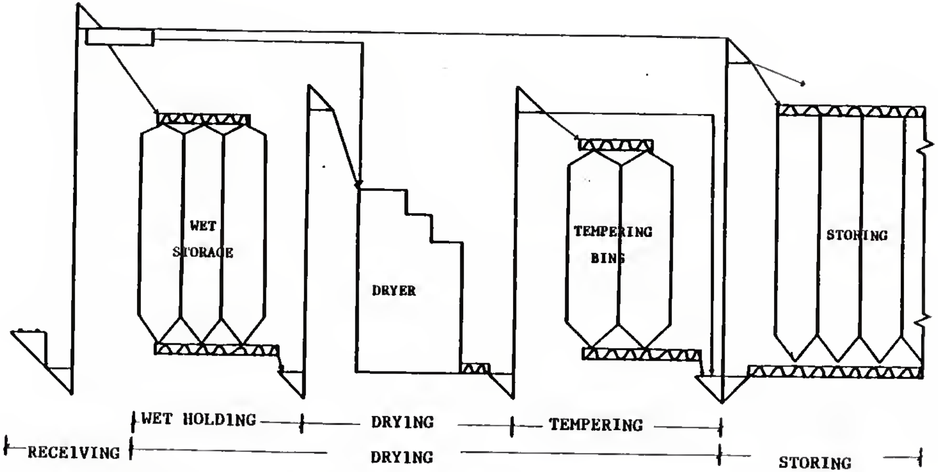

Fig. 2.1. General Flow Diagram For A Commercial Grain Handling and Storage Facility.

most important problems is that of deciding on the type of system to be used and in selecting component parts that fit and operate together. Dividing the material flow process into its functions helps to identify flow and equipment alternatives.

2.3.1 RECEIVING SYSTEM

2.3.1.1 Weighing and sampling

The first step in the process is to weigh the grain using a truck scale platform. The scale should have enough capacity to weigh medium and large size trucks. The reading and printing equipment is usually located in an administrative office, a small building next to the truck scale which also has a small grain laboratory and the manager's office. It is recommended that this area be located at the left side of the scale to allow the operator to see the truck driver at all times (Elzey, 1980). Fig 2.2 shows a typical layout of a grain storage facility.

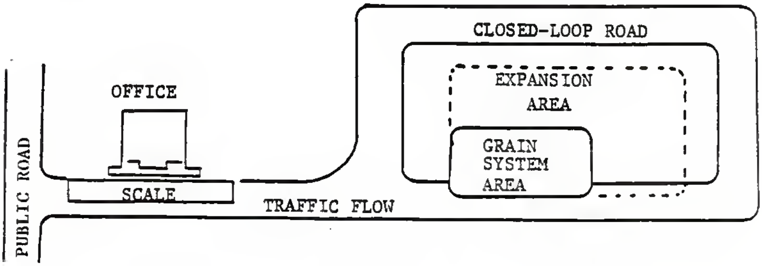

Fig 2.2 Typical Layout of Grain Storage Facility

The main duties at the administrative office are recording the weight of the grain entering and leaving the facility, testing and grading grain samples, computing and analyzing sales and costs, and compiling other figures such as filling and storing data.

2.3.1.2 Unloading

Different methods can be used to unload the grain. The best method will depend on the desired rate of handling and labor cost.

1. Hydraulic Truck Hoist. This raises the trucks unloading by gravity. It is the fastest and least labor consuming method, and can be completely automated. Lift capacities are up to 20T. (Seedburo Equipment Company).

2. Mechanical Shovels. This is an intermediate mechanical and labor consuming method. Capacities for shelled corn and rough rice are 90 T/H and 45 T/H respectively. (Seedburo Equipment Company).

3. Manual Shovels. This is the most labor and time consuming, but also the lowest initial cost.

2.3.1.3 Receiving

The alternatives for receiving the grain can be divided into a drive-over dump with gravity discharge, a combination of auger and pit and a portable hopper. The first two are considered permanent systems and are mainly used in commercial facilities. Fig. N 2.3 shows these two types.

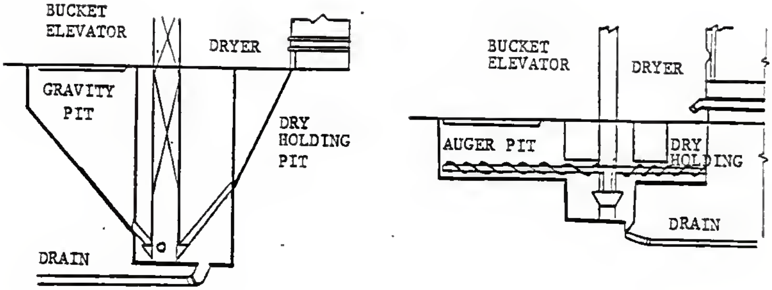

Fig 2.3. Gravity Pit and Auger Pit.
(Source: Behelen Mfg. Catalog)

2.3.1.4 Elevating

To elevate the grain, the basic alternatives are inclined auger or bucket elevator.

Advantages and disadvantages of inclined augers according to the Behelen Mfg. Catalog are that:

- Handling capacity decreases up to 60% with wet grain.
- The mechanical efficiency is about 30%, thus requiring about three times more power than bucket elevators.
- In general, augers are used for short-lift situations and low capacity.
- Initial cost is lower than bucket elevators.
- They are portable and can be used for different functions in farm facilities.

Advantages and disadvantages of bucket elevators are that:

- They carry almost as much wet grain as dry grain.
- Mechanical efficiency is about 90%.
- Low power and maintenance cost are required.
- They are suitable to elevate the grain from 3m to 60m height.
- Grain is handled more gently with less damage.
- Grain can be distributed to different points in the facility through downspouts.
- Initial cost is higher than inclined augers.
- It is a permanent system.

For handling rates above 46 T/H, an elevator leg with a downspout is more economical. The larger the volume of grain to be handled, the more the need for a permanent conveying system exists (Behelen Mfg. Catalog).

When designing the receiving system, factors that must be considered are: number of grain varieties that can be received at the same time, type of grain hauling systems (train, trucks, animals or combinations), and rate of receiving. For commercial situations, at least two receiving hoppers are recommended.

2.3.2 Processing

2.3.2.1 Flow alternatives

The flow of the processing system will depend on the grain receiving rate, conditions and varieties. The different flow alternatives will define the flexibility of the system.

When the grain is wet and dirty, it goes through cleaning, drying and storing (Fig N 2.1). When it is dry and dirty, the grain passes through the cleaner and then to the storage. If the grain is dry and clean, it goes directly to storage (Fig 2.1).

2.3.2.2 Drying subsystem

Most commercial facilities use continuous flow dryers or automated batch dryers. When either of these types of dryers are used, it may be combined with holding bins to regulate the peak receiving rates and tempering bins to increase dryer efficiency and capacity, and grain quality. For different receiving rates and varieties, the grain may go directly to the dryer or the plant operator may decide to bypass the tempering bins passing from the dryer directly to the storing bins or it may be necessary to hold the wet grain before entering the dryer (Fig 2.1).

The wet holding bins and tempering bins are recommended to be discharged by gravity, given that they will be loaded and unloaded several times a day during harvesting. Commercial size of these bins varies from 20 tons to 843 tons (Butler Mfg. Company).

More than two holding bins are recommended to allow the plant operator to segregate the receiving grain according to the variety and moisture content. This will provide more efficiency in the operation of the drying system.

A sound practice is to equip holding bins with aeration systems. Grain may remain in such bins for about two days, allowing time for maintenance or unforeseen snags in the system (Behelen Mfg. Catalog).

The capacity of continuous flow dryers varies from 9T/H to 190 T/H (Shanzer 1985). The capacity will be affected by the initial moisture content, the grain variety and amount of foreign material. A detailed explanation of drying techniques and equipment is presented in section 2.4.7.

2.3.2.3 Handling equipment.

To pass the grain from each piece of equipment to the next, the most common horizontal conveying equipment in medium size commercial facilities are U-trough screw conveyors and drag conveyors.

Advantages and disadvantages of U-trough screw conveyors, (Midwest Plan Service, Behelen Mfg. Company Catalog), are that:

- They are cheaper than drag conveyors.
- Capacities vary from 2.5 T/H to 50 T/Hr.
- Single section length vary from 3m to 45m.
- With wet grain, the conveying capacity decreases up to 50% and doubles the horsepower required.
- Mechanical efficiency is about 30%.
- They are designed for medium to heavy wear.
- They are not recommended for rice handling.

Advantages and disadvantages of drag conveyors (Tramco Metal Products, Midwest Plan Service, Behelen Mfg. Catalog) are that:

- Higher initial cost is required compared with screw conveyors.
- Capacities vary from 50 to 300 T/H
- Length varies from 3m to 125m.
- The capacity doesn't change for wet or dry grain.
- Mechanical efficiency = 90%.
- They handle the grain gently with less damage.
- They are considered noisy equipment.

For vertical conveying, bucket elevators and screw conveyors were presented in section 2.3.1.4.

2.3.3 Storage

This subsystem is formed by a loading bucket elevator, a group of storage bins and an unloading conveying system. The flow pattern should allow grain from any bin to be emptied and placed in any other bin. The sam bucket elevator used to load the battery is used to load out the grain. In this way a closed loop is obtained. When planning the loading out system, loading bulk grain to rail, trucks and bag loading systems should he considered. Depending on the situation, type of bin and storing time, this unit is equipped with aeration systems and temperature monitoring systems.

2.3.4 Guides in Designing the Flow Diagram (Behelen Mfg. Catalog)

- Handling capacity of horizontal conveyors should be about 0.25 T/H less than that of vertical elevators.

- Horizontal conveyors at top of tanks should handle about 0.25 T/H more than the vertical leg.

- Grain spreading equipment should handle 0.25 T/H more than the vertical leg.

- The central discharge conveyor should carry 0.25 T/H more than the bin unlaoding augers and 0.25 T/H less than the vertical leg.

-Use closed-loop handling through each storage and process area. Within the storage area, the grain may be conveyed from any bin to any other bin to allow blending and overturning.

- Plan the system to handle grain at a rate faster than it arrives.

- Select legs and other conveyors with sufficient capacity to allow for easier future expansion.

- In the unloading system, include overload grain holding space so that trucks can be loaded faster.

- The equipment handling rate is recommended to be at least 30 T/H.

- Matching up conveying equipment is essential to have a smooth flow of grain throughout the system. A listing of the practical capacity of each componet in the whole system can stop potential bottlenecks.

- For smooth gravity flow of all grains, use minimum downspout angles of 45° for dry grain and 60° for wet grain.

- Downspout capacity: 115 cm diameter downspout will handle up to 45 T/H. Above this rate use 200 cm diameter tube.

- Move the grain as little as possible. This will provide a less expensive and better grain quality system.

- Study the increase in cost to install higher capacity conveying equipment at initial installation. Usually it costs very little more and will allow easier future expansion.

- As part of the design, set up a plant operation manual for people who will manage the facility.

2.4 FACILITIES PLANNING

The factors to consider in planning a grain storage facility consist of selecting the site for the structure determining the storage capacity, type of storage and processing rate. The set of equipment and structures should be studied as an integrated system. The layout should be set up in a way that it allows developing over the years. As a rule, the design should retain flexibility, expansion potential and low owner and operation costs.

2.4.1 Guides For Selecting The Best Location (USDA, 1966)

1. Accessibility to producers. The storage facility must be located near grain producers in order to reduce the traveling time

from the fields to the facility. Travel time should be considered as the time to arrive at the facility, unload the grain and return to the field. Good road and bridge conditions are essential. An estimate of the average travel time is one way to measure the convenience of the site and compare it with other sites. Another way is to compare the number of tons produced within a 10 mile ratio from the potential site.

2. The system should be located outside urban areas so that further expansion is possible and so that the majority of trucks can avoid going through traffic congested areas.

3. Accessibility to markets. Good rail and truck roads are essential given that most grain is delivered to marketing areas by rail and trucks. The best method of evaluating is to compare the shipping cost per ton to principal markets.

4. Physical and topographical properties of the site. These factors will highly affect the building costs. A measure to evaluate the site preparation is that it should be less than 10 percent of the construction costs. When comparing different sites, the cost of the land and the cost of the site preparation should be considered. Additional factors to consider are size and shape of the lot and soil bearing capacity.

5. Construction costs: The variation of labor, material and freight costs among possible building sites is another factor to

consider. Initial costs will have the greatest influence in the annual facility cost.

6. Availability of utilities. The place must have access to high voltage lines, one and three phase electricity, and/or natural gas.

7. Evaluation of the factors. Usually there is not a nondominated alternative and conflicts exist among the choice when considering the different factors. In this case, finding the best location may be the use of multiple attribute decision making problem (MADM). A state-of-the-art application of these methods is presented in Hwang, and Yoon (1980). From this survey, the application of TOPSIS method is presented in Chapter 4 for deciding between concrete or steel bins. The same method is applicable for deciding the best location by changing the factors considered for the evaluation. Hwang and Yoon (1985), applied five newly-developed MADM methods for different versions of manufacturing plant site selection problems. This reference is recommended for a detailed example of the use of these methods.

2.4.2 Organizing the Systems

2.4.2.1. Facility requirements.

The facility has to be set up to allow truck and rail traffic without interferences. Recommendations on this point are given below

(Behelen Mfg. Catalog, Bouland, 1966):

1. Use complete truck road loops surrounding the facility and leave room within the loop for expansion. Common expansion necessities are storage space, drying capacity and handling rate.

2. Before setting up the facility, study the ground water level to define the underground construction level or plan in advance proper drainage. Keeping the conveying equipment above ground is important in poorly drained soils and rainy areas.

3. The weighing scale platform should be located near the entry. Usually, the trucks have to be weighed empty and full. Having only one opening gate is the most recommended. Fig. 2.2 presents a general layout.

2.4.2.2 Laboratory requirements

At the laboratory section of the office, the basic tests performed are grain moisture content, relative humidity, foreign material and test weight.

For these tests, the following equipment is recommended (Seedburo Catalog, No. 85):

- Sampling Equipment: probes, triers, mechanical diverter sampler official sample pans, falling stream sampler (Pelican or Ellis sampler)
- Moisture tester

- Test weight scale
- Standard balance scale
- Sample containers
- Official grain dockage sieves
- Black light
- Magnifier lamp
- Grain thermometer
- Standard thermometer
- Wet bulb thermometer
- Hydrometer

2.4.3 Determination of the Storage Capacity

The storage capacity for a storage facility is determined by the difference between harvesting rate and grain shipment rate. The period when the maximum amount of grain is received each year is the period to be most carefully studied.

a. Receiving pattern: At commercial facilities, little control over grain receiving patterns exists. They are the result of production time, harvesting practices, number of customers and grain varieties. To estimate the receiving pattern, the geographic area that the grain elevator will serve is considered. First estimate the amount of grain that will be produced in the area, the percentage that will be moved to the elevator under consideration and the amount of grain from outside the area that may be moved to the elevator. The pattern of grain receipts should be developed for an average crop year considering the different grain varieties separately. For the peak month, the study should consider the daily receiving pattern and for the peak day, the breakdown of the hourly receiving will define the peak receiving rate (Bouland, 1966).

Shipping Patterns: Some control can be established over the shipping of grain. It will be affected by the demand of grain. Major shipments usually occur during harvesting time when storage space must be available and also during the time when the prices are high. Fig. 2.4 shows typical patterns of receipts and shipments of grain during harvest time. From this data, we obtain curves of cumulative receipts and shipments (Fig. 2.5). The maximum difference between the cumulative receiving and shipments represent the storage space required.

2.4.4 Determination of the Truck Receiving Capacity

The truck receiving area consists of two main components, a truck scale and a pit. These two elements can be together or the pit can be located about 30m from the scale. In this way, one scale can serve up to three pit driveways.

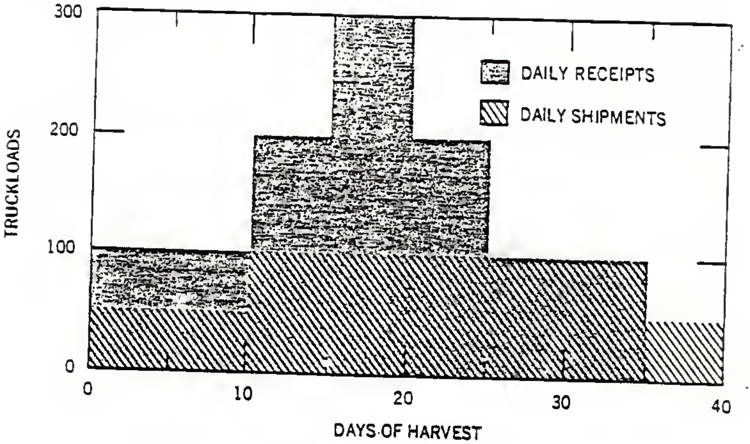

Fig. 2.4. Grain Receiving and Shipment Pattern. (Bouland 1966)

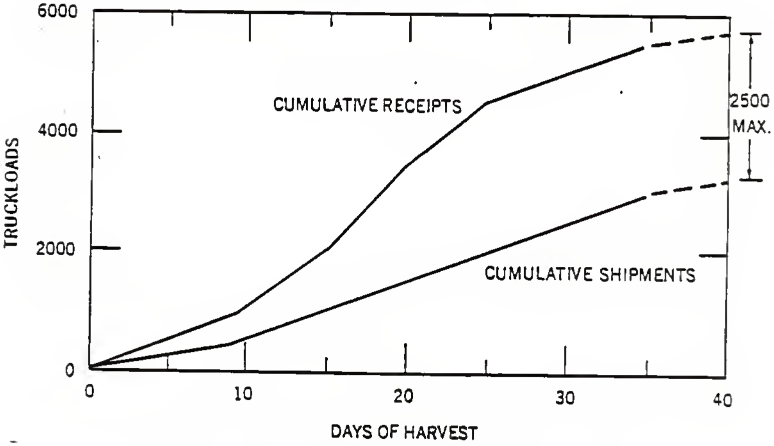

Fig. 2.5. Cumulative Receipts and Shipments. (Bouland 1966)

To determine the truck receiving capacity it is necessary to determine the pattern of truck arrivals. An estimation must be made of the total number of trucks that can be expected during the harvest, the maximum number of trucks per day and then the maximum number of trucks per hour.

To keep the truck waiting costs at a reasonable rate, Bouland (1966) considers that the receiving capacity should be such that the maximum waiting time be one hour.

An example of the receiving pattern from the Hard Winter Wheat area and Corn belt area given by Bouland (1966) illustrates the different patterns.

In the case of Hard Red Winter wheat, large quantities of grain must be received during the harvesting time that lasts only 10 to 15 days, and there is a peak day when about 22% of the trucks arrive. On the peak day more than 10% of the trucks arrive in one hour.

To establish a balance between ownership, operating costs and trucks waiting cost, the design of the receiving capacity for the Hard Red Winter area is recommended to be 60 to 70% of the peak hourly arrival rate.

On the other hand, in the corn belt area, harvest usually lasts four to six weeks. About ten percent of the total number of trucks arrive on the peak day, and during this day, about fifteen percent of the total trucks arrivals during one hour. The recommendation is to design the receiving capacity to absorb the peak hourly arrival rate.

2.4.5 Determination of the Type of Storage

Bulk storage facilities are of two main types, flat or upright storages.

Flat storages are buildings with diameters or widths larger than their height. They are often built if only one or two grain segregation types are stored. The practice in the grain trade is to build flat storages when only one type of grain is received and is kept in storage at least 1 1/2 years.

Flat storages are comparatively inexpensive to build but grain is difficult to load out.

Upright storages are bins with diameter or width smaller than their height. Grain is easier to handle in these storage bins. They are usually economical for storing many varieties of grain and for loading and unloading grain repeatedly throughout the year.

2.4.6 Number and Size of Bins

In addition to determining the type of storage, the number of bins needed must be decided. The facility should be flexible enough to segregate grain on the basis of variety, moisture content and protein content, requiring several containers.

Bouland (1966) recommends having at least two bins for each type of storage grain. Experienced people in the design of handling facilities, recommend three bins per variety of grain to provide good flexibility. In this way, grain can be more readily segregated and blended. There are also economic and structural considerations in determining the number and size of bins.

As the size of the storage bin is increased and the number of bins is decreased, the area of walls decrease and so do the materials required. The cost does not decrease proportionally because of the need to increase wall strength due to the increased load against the walls. Chapter 4 of the study presents a technique to optimize the combination of number of bins, diameter and height that result in the minimum annual cost.

2.4.7 Drying System and Rates

The most common drying systems are natural air drying, batch in bin drying, layer drying, portable batch drying, continuous flow drying and dryeration system. Chang, (1978), studied several drying systems for shelled corn and obtained ranges where each system is economically suitable. He found natural air drying economical at annual volumes below 69.6T; batch-in bin drying from 500T to 1800T; portable batch drying from 1500T to 3600T and continuous flow drying above 1800T. Fig. 2.6 shows his results.

Chang, (1981), studied six drying systems for rough rice and found layer drying to be the most economical system for volume ranging from

130T to 380T per year, and batch-in-bin drying with stirrers the best system for harvesting volumes from 380T per year to 3800T per year.

Similar results have been reported for other investigators as Carpenter and Brooker (1972) Bridges et al. (1979) and Holmes et al. (1985). Loewer et al. (1976), studied layer drying, batch in bin and

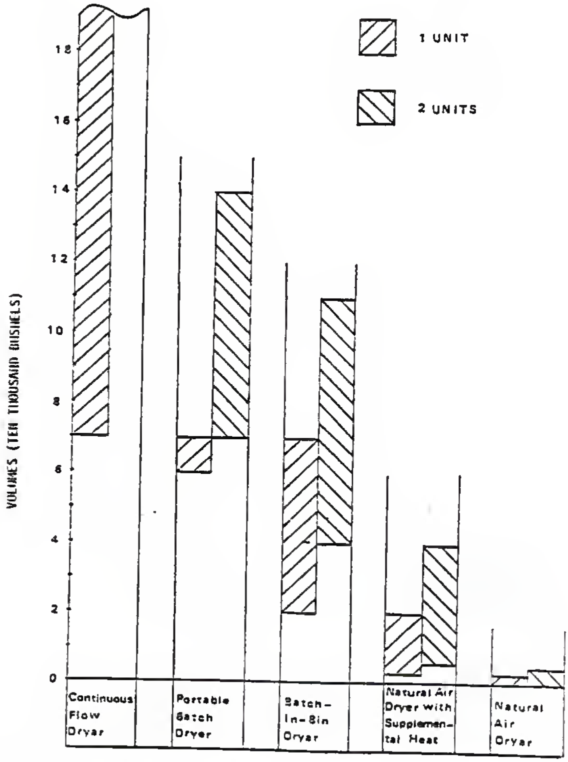

Fig 2.6. Economical Ranges for Different Drying Methods (Chang, 1978)

portable batch dryer. They found the first type to be economical for small capacities below 250T and the other two systems to be competitive for farm capacities above 250 T/year.

The above studies agree that for commercial facilities with high drying rates, continuous flow drying systems are the most suitable.

The grain dryer is one of the most important and expensive pieces of the conditioning equipment. Good management is necessary for the successful use of a dryer. This part of the system is where bottle necks are more frequently formed.

The drying capacity may be complemented with wet storage capacity. There should be many satisfactory dryer-wet holding combinations; thus the designer should search for the lowest cost one.

As a starting point, some plant designers (Bouland, 1966) recommend that the drying capacity should be able to dry in 24 hours of continuous operation the grain handled by the elevator in an average of ten hours operating day. Some manufacturers recommend selecting a unit that will dry in 15 hours of continuous operation the grain received in 8 to 10 hours. This will provide extra drying capacity if the system is operated up to 24 hours per day (Behelen Mfg. Catalog).

Bouland (1966) presents a method to evaluate the dryer size and wet storage capacity. The same method can be used to evaluate the capacity of other conditioning equipment. The method analyzes the elevator operations on a peak harvest day based on an assumed truck arrival pattern on this day, and an estimated percentage of arriving grain that will need drying and a trial dryer capacity. The accumulation of the hourly wet storage will give the wet holding capacity required for the peak day. Another criterion is that holding capacity should be enough to feed the dryer for at least 10 hours of continuous operation.

2.4.7.1 Dryeration

The dryeration system is usually combined with batch or continuous flow dryers. Some advantages of the system are given below (McKenzie and Fost, 1967)

- Capacity increases of 60% for 10 points moisture removal and up to 100% with less moisture removal are attainable.

- Better quality corn is obtained. The breakage is lowered in some cases to 80% less than corn dried with conventional methods.

In this process, the corn is dried to 16% or 18% moisture, then the hot grain is transferred immediately into an aeration bin where it is allowed to rest without movement for 4 to 10 hours. In this period, additional moisture moves out to the surface of the kernel where it is evaporated using heat remaining in the grain and an air flow of 0.5 to 1 CFM per bushel. Letting the grain rest and then cooling it slowly will remove two to three additional points of moisture and decrease stress damage to the kernel.

The dryer capacity increases because of eliminating the cooling cycle in the dryer and avoid the need to remove the last percentage points of moisture from the center of the kernel. Fig. 2.7 illustrates this method.

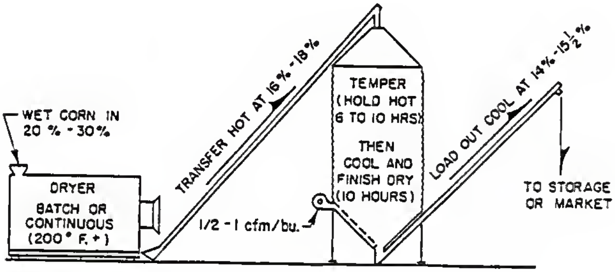

Fig. 2.7 Dryeration Process.
(Mckenzie and Foster 1967).

2.5 GRAIN PARAMETERS FOR GRAIN CONDITIONING AND STORAGE

2.5.1 Grain Preservation

Table 2.1 shows grain moisture contents recommended for safe storage of grain.

Table 2.1 Moisture Content During Harvest and For Safe Storage, Percent (Brooker et al. 1981)

Cereal	Maximum during Harvest	Optimum at Harvest for Minimum Loss	Required for Safe Storage 1Yr.	5 Yrs.
Corn	35	28-32	13	10-11
Rice	30	25-27	12-14	10-12
Sorghum	35	30-35	12-13	10-11
Wheat	38	18-20	13-14	11-12

Table N 2.2 presents the effects of moisture content and temperature on the growth of storage fungi in stored corn. The growth rates of storage fungi decrease and safe storage periods increase as grain temperatures and moisture contents are lowered.

Table 2.2. Safe Storage Period for Corn (Dry Matter Loss Less than 1.0%) (USDA 1968).

Storage Air	Moisture Content (%,w.b.)			
	15	20	25	30
Temperature °F	Days			
75	116	12	4	2
70	115	16	5	3
65	207	21	7	4
60	259	27	9	5
55	337	35	12	7
50	466	48	17	10
45	726	75	27	16
40	906	94	34	20
35	1140	118	42	25

2.5.2 Air Flow Rates

Table 2.3 presents airflow rates commonly used for aeration and drying systems.

Table 2.3 Airflow Rates (Brooker et al. 1981).

Drying System	$m^3/sec/m^3 \times 10^{-3}$
Aeration	0.27 - 13.4
Dryeration	6.7 - 13.4
Natural Air	26.8 - 67.0
Layer Drying	26.8 - 134.0
Heated Air (130°F to 500°F)	402 - 1340.0

2.5.2.1 Static pressure drop

Equation 2.1 from Hukill and Ives, (1955) can be used to compute the resistance of grains and seeds to airflow. It can be used over an airflow range of .01 to 0.20 $m^3/s\ m^2$.

$$\frac{P}{L} = \frac{a\ Q^2}{\ln (1 + bQ)} \qquad \text{Eq. 2.1}$$

Where:

P = pressure drop, Pa

L = bed depth, m

a = constant for particular grain

Q = airflow rate $m^3/s.m^2$ of grain

b = constant for particular grain

Table 2.4 Values of Constants Used in Airflow Resistance Equation 2.1

Grain	Value of a (SI Units)	Value of b (SI Units)
Oats	2.53×10^4	14.6
Shelled Corn	2.06×10^4	30.7
Soybeans	1.14×10^4	18.1
Wheat	2.91×10^4	9.84

Haque et al. 1978 expressed the pressure drop as a function of the airflow rate, and the percentage of fines present. Equation 2.2 can be used to correct for fines.

$$\frac{P}{L}\text{ corrected} = \frac{P}{L}\text{ clean } (1+(14.5566-26.418Q)\ (fm))$$

Where:

P = pressure, Pa

L = bed depth, m

Q = airflow rate m^3/sec

fm = fraction of fines by weight, decimal.

Knowing the resistance to the airflow, the fan KW required for aerating the grain can be computed from the Equation 2.3.

$$KW = \frac{Q \times P}{1000 \times Mef} \qquad \text{Eq. 2.3 (Mech. Eng. Handbook)}$$

Where:

KW = fan kilowatt

Q = airflow, m^3/min

P = pressure drop, Pa

2.5.3 GRAIN DRYING RECOMMENDATIONS

Table 2.5 (Hall, 1980), summarizes a number of recommendations for grain drying. Table 2.6 represents equations to compute the equilibrium moisture content.

Table 2.5. Grain Drying Reoommendations (Hall, 1980)

Recommendations		Ear Corn	Shelled Corn	Wheat	Oats	Barley	Grain Sorghum	Soybeans	Rice	Peanuts
1. *Maximum* Moisture Content of Crop at Harvesting for	with Natural Air	30%	25%	20%	20%	20%	20%	20%	25%	45–50%
	with Heated Air	35%	35%	25%	25%	25%	25%	25%	25%	45–50%
2. Maximum Moisture Content of Crop for Safe Storage in a Tight Structure		13%	13%	(13% (12% for (seed wheat	(13% (12% for (seed oats	13%	12%	11%	12%	13%
(If the above products are to be stored for long periods, the moistore content should be 1 to 2% lower than shown in this tabulation.)										
3. Pounds of Water per Bushel Which Must Be Removed for Safe Storage When Grain Is Harvested at Moisture Content of	30%	22.0	13.1							
	25%	14.7	8.7		5.0		9.2	11.0	6.5	
	20%	6.1	4.7	5.2	2.7	4.2	5.3	6.8	3.2	
	18%	5.5	3.3	3.7	1.8	2.9	3.9	5.1	2.0	
	16%	3.0	1.9	3.1	1.1	1.8	2.5	3.5	1.0	
4. *Maximum* Relative Humidity of Air Entering Crop Which Will Dry Crop Down to Safe Storage Level When Natural Air Is Used for Drying		60%	60%	60%	60%	80%	60%	65%	60%	75%
5. *Maximum* Safe Temperature of Heated Air Entering Crop for Drying When Crop Is to Be Used for	1. Seed	110°F	110°F	110°F	110°F	105°F	110°F	110°F	110°F	80°F
	2. Sold for Commercial Use[1]	130°F	130°F	140°F	140°F	105°F	140°F	120°F	110°F	90°F
	3. Animal Feed[2]	160°F	180°F	180°F	180°F	180°F	180°F	—	—	—
6. Preferred Depth of Crop for Batch Drying with Heated Air		5–20 ft (not critical)	18–24 in.	16–24 in.	18–24 in.	18–24 in.	10–24 in.	18–24 in.	8–18 in.	4–8 ft
7. *Maximum* Depth of Crop at Different Moisture Levels for Drying in Tight Structure with Fans Capable of Delivering the Required C.F.M. as Listed in 8. Below.	Moisture, %	30 25 20	30 25 20 18	20 18 18	25 20 18	20 18 18	25 20 18 18	25 20 18 16	25 20 18 18	40–50%
	Depth, ft	15 20 20	4 5 8 8	4 9 6	4 8 8	4 6 8	4 4 8 6	4 8 8 10	4 8 8 10	6
The above depths can be increased somewhat—especially at the lower moisture levels—provided fan capacity will meet the airflow requirements in 8. at relatively high static pressures.										
8. Minimum Airflow to Dry Crop at Moisture Level and Depth as Listed Above in 7.	*CFM per Bushel* Natural Air[3]	5 5 3	* 5 3 3	3 2 1	4 2 1.5	3 2 1	* 4 3 2	* 4 3 2	4 3 2 1	3
	Heated Air with Not over 15°F Rise in Temperature	5 5 3	6 5 3 2	3 2 1	4 2 1.5	3 3 1	5 4 3 2	5 4 3 2	4 3 2 1	3

Source: CDMC (1956).

*Not recommended.

[1] Higher temperatures than those listed may be used when the corn is dried under carefully controlled conditions so that the maximum temperature of the kernels does not exceed 130°F at any time.

[2] If there is any possibility that the crop may be sold, use the lower temperatores as listed above for commercial use.

[3] For fall crops or in humid areas, natural air drying depends on weather conditions and may take days or months to complete. Heated air drying under same weather conditions can be completed in hours or a few days depending upon volume to be dried.

Note: See Appendix Table A.6 for metric conversions.

Table 2.6. Equilibrium Moisture Content Equations and Constants Approved by the American Society of Agricultural Engineers (Chung and Lee, 1985).

Equation[3]	Constants	Grain	
		Rough Rice	Yellow dent corn
Modified Henderson equation			
$M = \frac{1}{100}\left[\frac{\ln(1-RH)}{-K(T+C)}\right]^{1/N}$	K	1.9187	8.6541
$RH = 1 - \mathrm{Exp}[-K(T+C)(100M)]^{N}$	N	2.4451	1.8634
	C	51.161	49.810
	SEM	0.0097	0.0127
Chung-Pfost equation			
$M = E - F \ln[-(T+C)\ln(RH)]$	A	594.61	312.40
$RH = \mathrm{Exp}\left[\frac{-A}{(T+C)}\mathrm{Exp}(-BM)\right]$	B	21.732	16.958
	C	35.703	30.205
	E	0.29394	0.33872
	F	0.0046015	0.058970
	SEM	0.0096	0.0121

M = grain moisture (decimal, dry basis)
RH = relative humidity (decimal)
T = temperature (C)

SEM = Standard error moisture

2.5.5 Physical and Thermal Properties of Grain.

Tables below represent rice and corn characteristics such as equilibrium moisture content, angle of repose and coefficient of friction, bulk density, porosity values, physical dimensions specific heat and thermal conductivity. These grain properties are usually required in analysis and design of grain handling and storage systems.

Table 2.7. Angle of Repose and Coefficient of Friction at 12 to 16% Moisture Content, w.b. (Brooker et al., 1981).

	Angle of Repose	Static Coefficient of Friction Steel	 Concrete	 Plywood
Barley	30	0.22-0.44	0.47-0.58	0.30-0.36
Rice	36	0.40-0.50	0.45-0.60	0.40-0.45
Shelled Corn	27	0.25-9.50	0.30-0.50	0.28-0.42
Soybeans	30	0.35-0.40	0.27-0.30	
Wheat	31	0.22-0.44	0.45-0.55	0.30-0.45

Table 2.8. Bulk Density of Corn. (Chung and Lee, 1985).

Variety	Moisture Content (%,wet basis)	Bulk Density (kg/m^3)	Models
Pfister	6.7	744.5 (8.6)	
Shelled	7-25	752.9 - 656.8	
Shelled	-	717.6	
Flint	6-28	789.1 - 644.8	828.5-6.56M
Dent	6-28	779.0 - 635.5	818.1-6.52M
Yellow Dent	10-35	742.2 - 638.5	$682.9+14.22M-9.9843M^2+0.0158M^3$
Yellow Dent	12-23	784.3 - 698.4	
Seed	16-44	734.1 - 710.3	$1086.3-2.97M+4.81M^2$
Ear Husked	---	448.5	
Green Sweet	---	448.5	

M = moisture content (%, wet basis)
Number in parentheses represents standard deviation.

Table 2.9 Bulk Density of Rice and Rough Rice (Chung and Lee, 1985).

Variety	Moisture Content (%, wet basis)	Bulk density (kg/m^3)	Models
Rice			
Caloro	8.6	571.1 (1.7)	
Calrose	9.2	570.7 (6.2)	
Hy Mix Early	8.8	591.2 (9.3)	
Rough Rice			
Short	14-22		537.6 + 1.22M
Short	11-20	632.0 - 664.0	583.6 + 4.27M
Medium	12-18	598.3 - 648.3	499.7 + 8.33M
Medium	6-28		567.2 + 4.13M
Medium	13.2	590.0	
Long	12-18	585.6 - 615.1	519.4 + 5.29M
Long	9-11	561.0 - 598.0	
Long	13.5	710.0 - 780.0	
Long	14-22		$592.2-1.105M+0.00995M^2$
--	--	576.7	

M = moisture content (%, wet basis)
Number in parentheses represents standard deviation.

Table 2.10. Porosity Values of Rice and Rough Rice (Chung and Lee, 1985).

Grain	Moisture Content (%, wet basis)	Porosity (%)	Models
Rice			
Honduras	11.9	50.4	
Wateribune	12.3	46.5	
Rough Rice			
Durar	11.4	51.0	
Taichung	9.3	52.0	
Kalinpong	9.7	54.5	
Short	14-22	46.4-47.6	$49.7 - 0.227M$
Medium	12-18	58.5-53.1	$65.6 - 0.457M$
Medium	13.2	52.5	
Long	12-18	59.6-56.9	$69.5 - 0.885M$
Long	14-22	48.4-50.8	$49.4+0.064M-0.0099M^2$
Corn			
No. 1	9.0	40.0	
Yellow	25.0	44.0	
Yellow	9-14	38.5-47.6	
Yellow	9-27		$101.0 - 0.078D_b$
Shelled	9-31	38.5-47.6	
Yellow Shelled	9-27		$81.4-0.056W_1$
Yellow Dent	12-23.4	37-42	
Yellow Dent (Shelled)	15.0	40.0	

M = Moisture content (%, wet basis),
D_b = bulk density (kg/m^3),
W_1 = test weight (kg/m^3)

Table 2.11 Physical Dimensions of Rough Rice and Corn (Chung and Lee, 1985).

Grain	Variety	Moisture content (%, wet basis)	Length (10^{-3})	Width (10^{-3})	Thickness (10^{-3})
Rough Rice	Short Grain Caloro	10.4 - 2.26	$7.318+1.22x10^{-2}M$	$3.358+8.90x10^{-3}M$	$2.187+8.9x10^{-3}M$
	Medium grain Saturn	12 - 18	$7.747+1.27x10^{-2}M$	$2.842+7.62x10^{-3}M$	$1.842+8.9x10^{-3}M$
	Long Grain Bluebonnet	12 - 18	$8.941+5.84x10^{-2}M$	$2.388+1.65x10^{-2}M$	$1.765+1.43x10^{-2}$
Corn	Pfister	6.7	16.26(0.91)	20.27 (1.07)	12.80 (0.71)
	Beck	13.96 - 21.26	13.30 (0.99)	8.7 (0.76)	4.70 (0.68)

M = moisture content (%, wet basis)
Numbers in parentheses indicate the standard deviation.

Table 2.12 Specific Heat and Thermal Conductivity Values for Rice and Corn Approved by the American Society of Agricultural Engineers (Chung and Lee, 1985)

Grain	Moisture content (%, wet basis)	Mean temperature (^{o}K)	Specific Heat (KJ/kg.K)	Thermal conductivity (W/m.K)
Rice, rough	10.2 - 17.0		1.1095 + 0.0448M	
Rice, shelled	9.8 - 17.6		1.2016 + 0.0381M	
Rice, finished	10.8 - 17.4		1.1807 + 0.0377M	
Rice, rough, medium	10.2 - 20.0		0.9214 + 0.545M	0.866 + 0.001327M
Corn, yellow, dent	0.0	293.7	1.5324	0.14055
	5.1	293.7	1.6915	0.14661
	9.8		1.8338	0.15198
	13.2			0.17656
	14.7	293.7	2.0264	0.15908
	20.1	293.7	2.2232	0.16358
	24.7		2.3739	0.16998
	30.2	293.7	2.4618	0.17240
	0.68 - 20.3	308.4	1.4654+0.0356M	0.1409+0.00118M

^{a}M = moisture content (%, wet basis)

2.6 CONCLUSIONS AND REMARKS

Through this chapter, the different parameters and factors that affect the design of grain handling and storage facilities were presented. The first part provided a detailed explanation of the flow sequence and tips useful in its design. The second part presented most of the factors that have to be considered for planning the system and existing methods to compute flow rate, drying and storage capacity. The third part summarized most of the physical and thermal properties of grains required when designing elevator facilities.

The gathering of all this information provides a useful aid for designers.

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CHAPTER III

COST ANALYSIS ON EQUIPMENT FOR GRAIN PROCESSING SYSTEMS AND STORAGE STRUCTURES

3.1. INTRODUCTION

Since there are many alternative systems for handling, drying and storage of rough rice and shelled corn, it is not easy to select an economical system which is best suited for all sets of conditions.

To be able to specify the type of equipment, the capacity or the size of the storage structures, it is necessary to know how costs change when varying different design parameters. With a quantitative method of comparison, better designs can be obtained. Mathematical models and cost estimates of the different parts of the system make it possible to apply optimization techniques to minimize the cost of the compleete system and to detect the parameters that most influence the final cost.

Through this chapter, cost analysis is applied to the main equipment required for receiving, drying and handling in commercial size facilities. Storage structures including steel and concrete bins are also considered. Mathematical equations have been developed for each piece of equipment so that optimization techniques can be applied when designing. A description of the equipment with available capacities and size, and recommendations for its use are also included.

3.2 REVIEW OF LITERATURE

In order to establish a methodology for the cost study and applications of system analysis to design problems, a literature survey was done of scientific articles and catalogs of grain conditioning and storage equipment. Facility planning manuals were also collected from manufacturers and carefully studied. Some of the most recent studies are cited here.

Park (1982) developed mathematical models and applied optimization techniques to feed mill design. He demonstrated the applicability of optimum systems to select a feed mill by single objective nonlinear programming and multiple decision making methods.

Chang (1981) developed mathematical models and model systems for rough rice handling, drying and storage. He also developed an approach for designing optimum systems by multiple objective decision making methods applied to farm facilities.

Chang (1978) applied mathematical modeling for dryer selection applicable to on-farm grain drying. To formulate the model, he studied dryer specifications from numerous manufacturers and dealers in the U.S.A. He concluded that the final choice depends upon the annual volume, the marketing pattern, the type of farm, the cost and the kind and capacity of existing facilities.

Bridges (1979) developed a computer program for designing, harvesting, handling, drying and storage systems. The program ranks the cost of the feasible systems considered and presents the equipment and labor required by each feasible system. The study was done for on-farm size facilities using corrugated steel bins for storage. The equipment comparisons in the program were based on lowest annual cost. Labor costs were not considered with each individual selection of equipment, but were assigned to the total system for the ranking.

Brook and Bakker-Arkema (1980) applied dynamic programming to find the optimum operational parameters and dimensions of a multistage concurrent flow dryer. They set up an objective function based on energy and capital costs. The energy cost was calculated using cost equations developed by Farmer(1972) and capital cost was obtained from a dryer manufacturing company for different dryer types.

Loewer et al. (1976a) developed a computer program for designing new on-farm facilities using a centralized layout. With this program, the designer can obtain detailed cost analysis of several alternatives, allowing comparison of each design and economic factors related to the system. Loewer et al. (1976b) used the same program to make cost analysis of different farm facilities varying the handling rate, drying system and storage capacity. They used purchase costs through equations and cost arrays from the manufacturers' suggested list price. For annual cost, they used straight line depreciation based on an estimated life of the equipment, a constant rate for repairing, interests, taxes, insurance and expenditures for electricity and LP-gas.

Carpenter and Brooker (1972) developed simulation models for determining minimum cost machinery systems for harvesting, drying and storing shelled corn. They obtained optimum harvest starting moisture and minimum cost drying systems for different annual volumes. Other factors such as date of maturity, level of field losses and relative risks were also evaluated with their models.

Most of the cost studies for grain handling facilities have been done for on-farm facilities, considering harvesting handling rates, and small size equipment such as portable augers. In the storing system, steel bins have been considered exclusively. Compared to on-farm facilities, commercial facilities require higher handling and processing rates greater grain flow flexibility and several storage containers to allow grain segregation and blending. Reinforced concrete steel silos have to be considered as a feasible storage alternative in these larger facilities. Through this study, costs of equipment for medium handling rates and costs of concrete bins are considered.

3.3 PROCEDURE

For the cost analysis, the first step was to collect information on the initial cost of equipment and construction materials. To accomplish this task, price quotations were requested from a number of manufacturers. Table 3.1 presents a list of the companies contacted. Even though one of the objectives of this study is to develop design methodologies and criteria applicable to tropical countries, the cost information was obtained from US manufacturers, mainly because of the difficulty in gathering and classifying prices from different countries. The methodology of the study and behavior of costs for different equipment are applicable to all countries. Countries that import machinery from the USA can add freight cost to purchasing costs to obtain the local values. The information from US companies was classified by type of equipment, and specifications were carefully studied to define the range of applicability for each piece of equipment.

The SAS computer program was used to perform multiple regression analysis for obtaining mathematical models of the cost of the different equipment. It was also used with the continuous flow dryers to obtain energy consumption models as a function of the drying rate and to obtain mathematical equations to compute the quantities of concrete and reinforced steel required for building concrete bins.

In this analysis, only initial purchasing costs and models for energy consumption were considered. Economic information for maintenance, interest, taxes and expected life was obtained from Loewer et al (1976b).

Table 3.1. Companies Contacted for Price Quotations.

Company & Address	Item
Industry General Corporation Contractors/Engineers 5384 Poplar Avenue Suite 500, Box 17221 Memphis, Tennessee 38187-0221	Slip Form
Borton, Inc. 200 East First Street Box 2108 Hutchinson, Kansas 67504	Slip Form
McPherson Concrete Storage Systems, Inc. Box 369 McPherson, Kansas 67460	Concrete Silos and materials
Modern Concrete Farm, Inc. Route 4 Myerstown, PA 17067	Jump-Form for Concrete Silos
Seedburo Equipment Company 1022 West Jackson Bld. Chicago, IL 60607	Bucket Elevators, Grain Conveyors, Truck Scales Lab Equipment
Universal Industries 1326 Waterloo Road Cedar Falls, IA 50613	Bucket Elevators Belt Conveyors
Buhler Manufacturing Box 9497, 1100 Xenium Lane Minneapolis, MN 66550	Drag Conveyors Bucket Elevators
C-E Raymond Combustion Engineering, Inc. 200 West Monroe Street Chicago, IL 60606	Continuous Flow dryers

Berico Industries Box 12285 Overland Park, KS 66212	Continuous Flow Dryers Automated Batch Drying
Mathews Company 500-T Industrial Avenue Crystal Lake, IL 60014	Grain Dryers
Chicago Eastern Company 200 North Prospect Morengo, IL 60152	Continuous Flow Dryers
Combustion Engineering Inc. Dept. TR-3 300 North Cedar Street Abilene, KS 67410	Bucket Elevators Drag and Belt Conveyors
Tramco Metal Products, Inc. 1011 East 19th Street Wichita, KS 67214	Drag Conveyors Bucket Elevators
Stormor Fremont, NE 68025	Corrugated Steel Bins Batch-in-bin Drying Systems
Farm Fans, Inc. 5900-T Elwood Avenue Indianapolis, IN 46203	Grain Dryers, Fans and Heaters
Behlen Manufacturing Co. Box 569 Columbus, NE 68601	Continuous Flow Dryers Automatic Batch Dryers Batch-in-bin Dryers Corrugated Steel Bins U-Trough and Chain Conveyors
Portable Elevator Division 920T Grove Street Boomington, IL 61701	Bucket Elevators Screw and Drag Conveyors
Nebraska Eng. Co. 9364 N 45 St. Omaha, NE 68112	Grain Unloading Equipment Grain Drying Accessories Sweep Augers, Batch in bin

	Drying Parts, Stirs, Grain Spreaders, Augers, Dump Pit Hoppers, Grain Cleaners
Cardwell Mfg. Company Kearney Industrial Tract, Box 338 Kearney, NE 68847	Centrifugal and Axial Fans, Gas Heaters, Bin Accessories
Hutchinson Division Inc. West Crawford Clay Center, KS	Grain Augers, Pit Augers Unloading Equipment, Grain Cleaners, Bucket Elevators
Gilmore and Talge Co. Clay Center, KS	Transport Augers Bin Unloading Equipment Grain Cleaners
Butler Manufacturing Co. Agricultural Equipment Div. BMA Tower Penn Valley Park Box 917 Kansas City, MO 64141	Corrugated Steel Bins and parts, Fans and Heaters Hopper Grain Bins, Scale Systems, Bucket Elevators Grain Cleaners, U-Trough and Drag Conveyors, Continuous Flow Dryers.
Shanzer Grain Dryers Dept. Box 834 Ellis, SD	Automated Batch and Continuous Flow Dryers
QED Dryers, Inc. 4993 27th Avenue Rockford, IL 61109	Continuous Flow Dryers

3.4 MODEL RECEIVING SYSTEM

a. Gravity hopper

The typical gravity hopper is shown in Fig. 3.1. The required pit size is computed by Equation 3.1 (Loewer et al., 1976a).

$$PTSIZE = TU\ (TC/TU - PCAP/60) \qquad \text{Eq. 3.1}$$

Where:

PTSize = Pit size (m^3)

TU = Truck unloading time (minutes)

TC = Truck loading capacity (m^3)

PCAP = Pit unloading capacity. (T/H).

The cost of the gravity pit is computed by Equation 3.2.

$$PGRAPIT = 761.35 + 47.89 \times PSIZE \qquad \text{Eq. 3.2}$$

Where:

PTSIZE = m^3

PGRAPIT = price of gravity pit ($).

The R^2 of Equation 3.2 is 0.93. The price includes the concrete structure and the grate system. It is applicable for pit sizes between $3m^3$ and $12m^3$.

b. Auger pit

This type of pit is shown in Figure 3.1. Its cost depends on the auger pit capacity and the auger length. The auger pit capacity depends on the truck receiving rate and the auger length depends on the facility layout.

The cost can be computed by the Equation 3.3.

$$PAPIT = 1216.91 + 3.12PCAP + 1.14 \times ACAP \times ALN \qquad \text{Eq. 3.3}$$

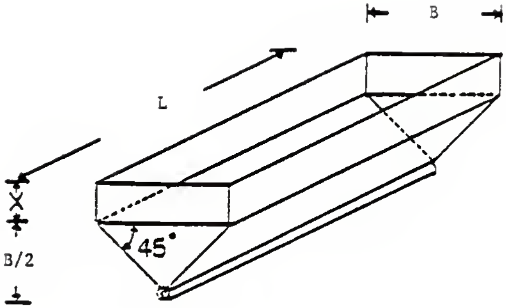
Where:

PAPIT = price of auger pit (\$)
ACAP = auger unloading capacity (T/H)
ALN = auger length (m).

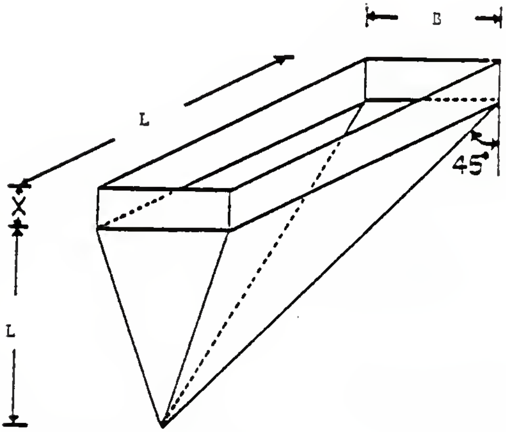
The R^2 value of this equation is 0.97 and the cost includes U-trough, cover, motor mount, drive kit, dump pit hopper, oil enclosed speed reducer, motor pully and belt shield. The equation is suitable for auger capacities from 20T/H to 250T/H.

c. Bucket elevators

Bucket elevators are commercially available for heights varying from 3 m to 60 m and capacities from 2T/H to 400 T/H. The elevator capacity is given at 75% cap fill. The cost of this equipment is a



Auger Pit Type



Gravity Flow Type Pit

Fig. 3.1. Auger and Gravity Flow Pits.

function of the height, conveying capacity and motor size. For certain ranges of capacities, the price per meter height is constant because using the same bucket size, the belt speed and/or the bucket spacing can be changed to vary the capacity. Sometimes, a small increase in initial cost can allow for easy expansion of the handling capacity. This aspect is shown in Fig. 3.2.

The elevator cost is given by Equation 3.4 and the R^2 value of this equation is 0.95.

$$PBUEL = 1139.13 + 161.58HT + 2.52ECAP - 1.7ECAP \times HT + 656.2HP \qquad \text{Eq. 3.4}$$

Where:

PBUEL = Price of bucket elevator ($/unit)

HT = elevator height (m)

ECAP = elevator capacity (T/H)

HP = elevator horsepower.

Bucket elevators are usually combined with metal downspouts for gravitational grain unloading. Research on grain damage as a function of velocity indicates that grain velocities over 8.9 m/sec should be avoided (Butler Mfg. Catalog). Grain retarders are suggested to reduce these velocities. The spout lengths at which these velocities take place are in function of the spout angle and are shown in Table 3.2.

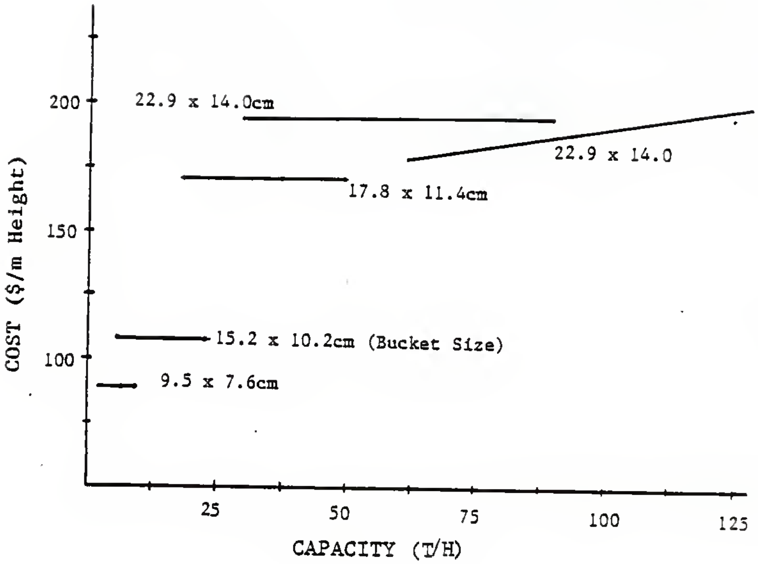


Fig. 3.2. Bucket Elevator: Cost/m heigt ($/m) vs. Capacity (T/H).

Table 3.2. Spout Length at Which Grain Velocity Exceeds 8.9 m/sec (Butler Mfg. Catalog).

Spout Length (m)	Spout Angle					
	35°	40°	45°	50°	55°	60°
27.4	8.7					
15.2		8.3				
12.2			8.9			
9.1				8.7		
7.6					8.8	
6.1						8.5

3.5 MODEL PROCESSING SYSTEM

a. Grain Cleaners

The primary function of the grain cleaner is to remove the foreign material in order to maintain grain quality during storage for longer periods of time.

Chung (1986) reviewed the state of the art in grain cleaning equipment. They gathered literature from about 1600 manufacturers worldwide and classified it into 37 different types of cleaners according to the separation procedures and capabilities of the equipment.

Separation using the scalping procedure segregates rough materials like straw, broken kernels, stones, seeds, hulls, etc. The scalping procedure is accomplished by rotating perforated cylinders (rotating drums), flat sieves (rotating, gyrating or vibrating) or cylindrical sieves. Separation by aspiration blows air through the grain to separate fine materials. Equipment combining both systems, usually called "scalpirator" are also available. Most grain cleaners can be used with various kinds of grains by changing the screens for the specific grain. Some screen cleaners can be adapted to the bucket elevator distributor. This type of unit removes approximately 66% to 75% of foreign matter at optimum flow rates. It is recommended that these units be used to clean dry grain only (Butler Mfg. Catalog).

Important factors when choosing a grain cleaner are capacity, cost, power, information related to the scalping unit, number of aspirators and number of flat sieves.

Choosing the type of cleaner will depend on the grain storage period and ambient conditions. In general, the cost of air cleaners is higher than the cost of screen cleaners. Figure 3.3 shows the variation of cost with capacity for different cleaners.

In order to provide a better idea of the different types of grain cleaners, Tables A2.1, A2.2, A2.3 and A2.4 in Appendix II show basic information on four different types.

Due to the variation of cost with the cleaner type, two equations were developed. Equation 3.5 represents the cost of gravity or screen cleaners and Equation 3.6 can be used for scalpirators.

$$PGCLE = 228.83 + 55.46CAP. \qquad \text{Eq. 3.5}$$

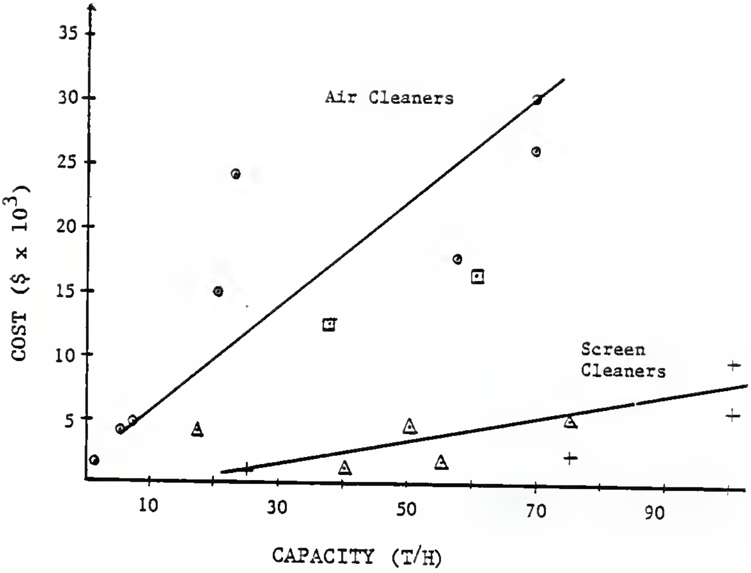


Fig. 3.3. Grain Cleaners Cost: Cost: ($ x 10^3) vs. Capacity (T/H)

$$PSCLE = -528.42 + 12.43CAp - 12.36CCAP^2 \qquad \text{Eq. 3.6}$$

Where:

PGCLE = price of gravity cleaner (\$)

PSCLE = price of scalpirator (\$)

CCAP = cleaning capacity (T/H).

The R^2 values of these equations are 0.97 and 0.91 respectively.

3.5.1 Drying Sub System

a. Holding bins

These bins are used to store wet grain temporarily in order to regulate the drying rate capacity. They are also used for tempering purposes. Because of the bins' hopper bottoms they are suitable in cases when they are loaded and unloaded several times a day. They are usually built with corrugated steel and capacities vary from 17 tons to 830 tons. The cost is represented by Equation 3.7, whose R^2 value is 0.97.

$$PHOLBIN = 1444.02 \times 27.53\ D^2 \times H \qquad \text{Eq. 3.7}$$

Where:

PHOLBIN = Price of holding bins (\$/unit)

D = bin diameter (m)

H = bin height (m).

b. Grain dryers

For commercial facilities, continuous flow dryers are considered in this study. The regular continuous flow dryer have a heating or drying section, a cooling section and a discharge. The drying capacity varies from 5 T/H to 100 T/H for 10 points moisture removal with drying temperature varying from 82°C to 104°C. The heat required varies from 2.1 million KJ/H to 11.6 million KJ/H, the electric load from 11 KWH to 260 KWH including power for drying, cooling and discharge, and the air flow rate from $62m^3/min \times m^3$ to $125m^3/min \times m^3$.

The cost of continuous flow grain dryers can be represented by Equation 3.8 with R^2 value of 0.91.

$$PCFDRYR = 4704.66DCAP - 2602.15 \qquad \text{Eq. 3.8}$$

Where:

PCFDRYR = price of continuous flow dryer ($)

DCAP = drying capacity (T/H).

This equation is suitable for capacities between 4 T/H and 60 T/H for 10 points moisture removal and air plenum at 104°C. Manufacturers suggest a 3% decrease in drying rate per each 5°C temperature drop.

The dryer price includes the drying tower completely assembled, fan tower with centrifugal fans factory mounted and balanced, burners installed in each drying fan, electrical control panel complete with all necessary safety controls, factory assembled gas manifold, garner hin for spout connection, metering pan and drive, 30.5cm diameter dry grain discharge auger, exhaust air temperature sensor, automatic grain moisture control, fan platforms, column catwalks and rear access platform. All drives and fans come complete with TEFC motor for use with three phase 230V or 460V. c. Centrifugal and axial fans

Fans are used to move air through the grain mass. The axial-flow fan usually delivers more air at less than 3.5 in of H_20 of static pressure. A centrifugal fan performs hetter at static pressures greater than 4.5 in. of H_20). For static pressures between 3.5 and 4.3 in of H_20 the engineer can consider both types. (Brooker et al. 1981).

The power ranges from 0.6 KW to 76 KW. The cost of axial and centrifugal fans can be predicted with Equations 3.9 and 3.10; the R^2 values of these equations are .93 and .97, respectively.

$$PAXIALF = 270.59 + 120.75HP - 3.92HP^2 \qquad \text{Eq. 3.9}$$

$$PCENTF = 57.46HP + 1388.26 \qquad \text{Eq. 3.10}$$

Where:

PAXIALF = price of axial fan. ($)

PCENTF = price of centrifugal fan ($)

HP = Horsepower.

3.5.2 Handling Equipment

a. U-trough augers

U-trough augers or screw conveyors are available in capacities from 10 T/H to 200 T/H, the flight diameter varies from 15.2 cm to 46 cm and length of one unit from 3 m to 45 m.

A wide range of capacities can be covered with the same auger diameter and the cost is also constant for those capacities. Figure 3.4 shows the variation of cost with capacity. Even though increasing the speed can increase the handling capacity, manufacturers recommend that a higher capacity operating at slower speed provides longer life, less maintenance and decrease grain damage. Equation 3.11 can be used to predict the cost of this equipment; the R^2 value is 0.90.

$$\begin{aligned} PUTROUH = {} & 385.78 + 40.68 \times LN - 0.51 \times CAP \times LN \\ & + 300.9 \times HP \end{aligned} \qquad \text{Eq. 3.11}$$

Where:

PUTROUH = auger price ($)

LN = auger length (m)

CAP = auger capacity (T/h)

HP = Horsepower.

The price includes intake section, discharge, cover, bolts, nuts and washers for cover, motor mount, speed reducer, motor pulley, driven pulley and belts. The motor is not included. The equation can be used for length from 3m to 45m and capacities from 10 T/H to 150 T/H.

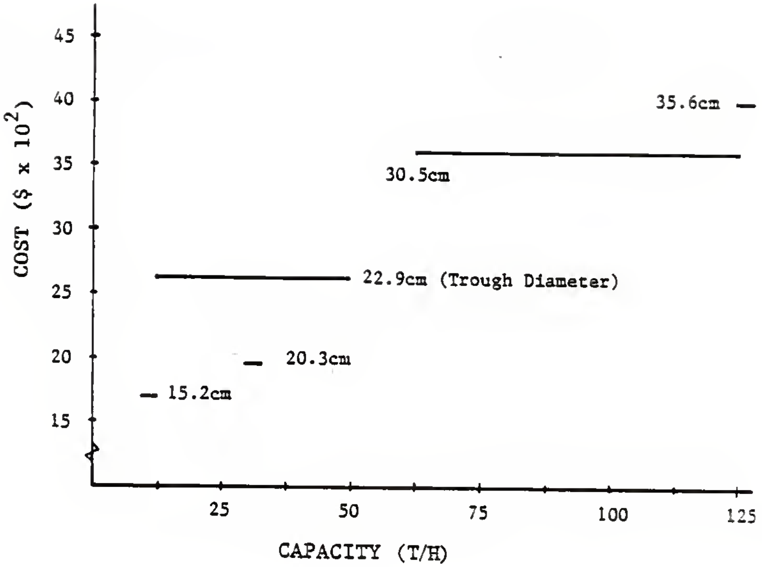


Fig. 3.4. U-Trough Srew Conveyor (constant length of 18.3 m): Cost ($) vs. Capacity (T/H).

b. Drag conveyors

This type of equipment is ideal for large conveying capacities. Using the same rectangular trough and pallet size, the capacity can be increased by speeding up the conveyors.

For most companies, the conveyor length ranges from 3.05 m to 140 m for capacities lower than 200 T/H.

Medium capacities from 10 T/H to 60 T/H can usually be covered by the smallest available size and the equipment is over designed. The minimum power recommended by some companies is 1.15 KWH. Capacities lower than 60 T/H require a bigger gear reducer, increasing the drive price for a given length. Fig. 3.5 illustrates this aspect.

The longer the conveyer length, the larger the bearings, shafts, chain and power required, increasing the cost linearly.

The variation in cost for different capacities for a constant length is presented in Fig. 3.6.

The variation of capacities and the size of the conveyors is presented in Table 3.3

Table 3.3 Drag Conveyer Size and Capacities (Tramco Mfg. Co.)

Conveyor Size (cm)	22.9	27.9	38.1	48.3	63.5
Capacity T/H	30-100	90-200	162-375	262-625	387-1000
Maximum length (m)	450	183	128	90	69

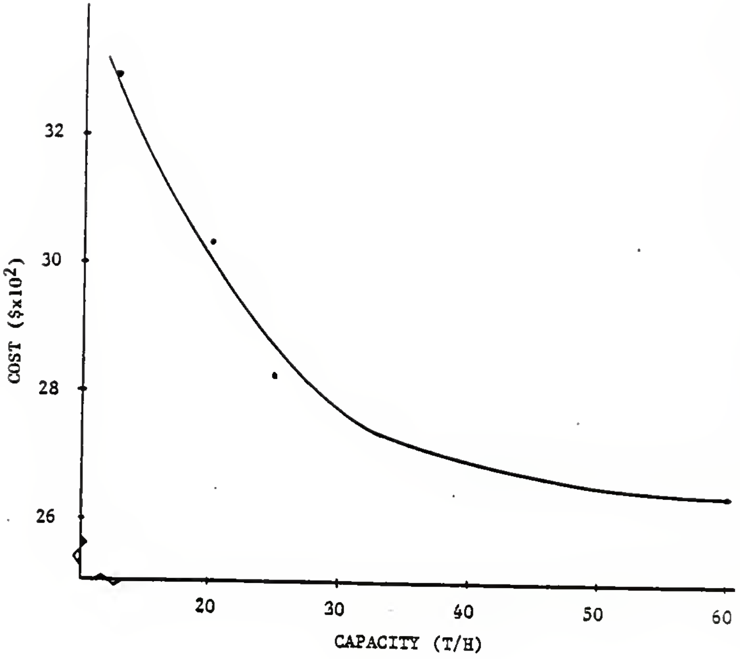


Fig. 3.5. Drag Conveyors (Constant Length = 3.05 m): Cost for Capacities Lower Than 60 T/H.

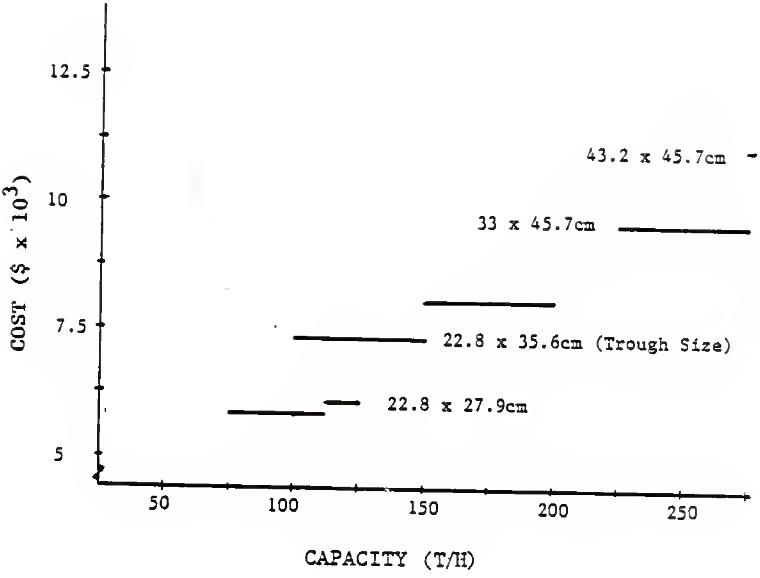


Fig. 3.6. Drag Conveyor (length of 16.5 m): Cost ($) vs. Capacity (T/H).

The price of drag conveyors can be estimated by the Equation 3.12. with an R^2 value of 0.98. This equation is suitable for capacities between 50 T/H and 320 T/H and length from 3.05 m to 450 m.

$$PDRAGCO = 2045.7 + 192.52 \times LN + 4.77 \times CAP + 0.86 \times CAP \times LN \qquad \text{Eq. 3.12}$$

Where:

PDRAGCO = price of drag conveyer ($)

LN = length (m)

CAP = conveying capacity (T/H).

The price includes galvanized head and take up, head and tail bearings, galvanized trough and covering, steel chains, flights and attachments.

3.6 MODEL STORING SYSTEM

For this system, steel bins and concrete bins are considered as storing alternatives. The cost of both alternatives are also compared.

3.6.1 Steel Bins

Corrugated steel bins are industrially prefabricated and built through an assembling process, making their cost very competitive, especially for countries with a highly developed steel industry.

When pricing steel bins, it must be remembered that they are formed from several parts that are usually sold separately. The most important parts to consider are the bin body with the corrugated sheets, stiffeners, bolts, walls and roofs, perforated floor and substructure for aerating the grain, foundations, unloading equipment and assembling of the components.

A wide range of commercial sizes are available, with diameters varying from 5 m to 32 m and heights from 7 m to 25 m. Due to structural and economic limitations, these sizes are combined between a height to diameter ratio (H/D) greater than .6 and smaller than 2.7, and storage capacity per bin varies from 200 T to 11,800 T.

With this set of existing sizes, the designer always has a problem of deciding the appropriate size and number of bins. Chapter II, Section 2.4.6, explains some considerations related to plant flexibility. Figure 3.7 shows the cost/m^3 varying with the ratio H/D for different diameters. The unit cost decreases when decreasing the H/D relation and increasing the bin diameter. In general, H/D ratios, lower than 1.25 provide lower unit costs. This figure can aid in choosing the bin size and number of bins that will provide an economical storing system. The unit cost in this figure considers only the cost of the bin body.

Figure 3.8 shows the variation of cost when changing the storage capacity. The cost in this graphic includes all parts components. The upper line is for H/D ratio $2.2 < H/D < 2.5$, the lower line is for $0.4 < H/D < 1.7$. This figure demonstrates the degree of importance that

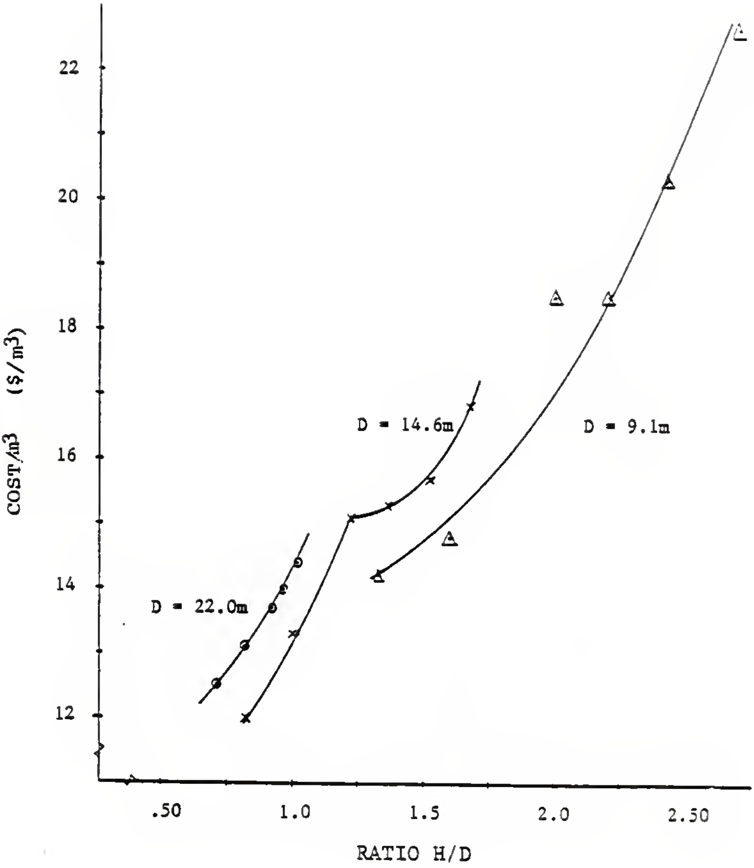


Fig. 3.7. Influence of Size in Steel Bins Cost.

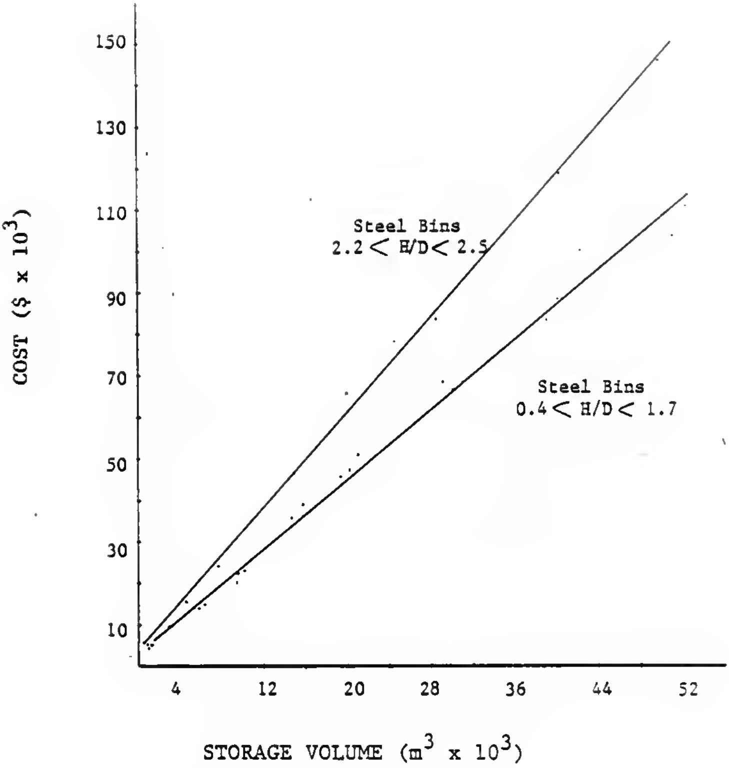


Fig. 3.8. Storage Volume vs. Steel Bins Cost: Influence of H/D Ratio in Cost.

has to be given to the size and number of bins when planning a storage facility. As an example, for 28000 m^3 storage capacity, the cost can be 35% more expensive with H/D ratio larger than 2.2.

For modeling the cost of steel bins, the following equations have been developed through multiple regression analysis.

Equations 3.13 through 3.18 are suitable for bin diameters between 5.5 m to 22 m, heights between 7 m to 23 m and H/D relations from .6 to 2.7. The variables in the equations represent:

PSBIN = price of corrugated steel bin ($/unit)

PFLOR = price of perforated floor ($/unit)

PASBIN = cost of assembling steel bins ($/unit)

PFOUNSB = price of assembling steel bins ($/unit)

PUNLEQ = price of unloading equipment ($/unit)

D = bin diameter (m)

EH = bin eave height (m)

UCC = unit concrete cost including labor ($/$m^3$)

USC = unit reinforcement steel including labor ($/T)

AUD = auger unloading diameter (cm)

UCAP = auger unloading capacity (T/H).

Cost of corrugated steel bin body is given in Equation 3.13, where the $R^2 = 0.98$

$$PSBIN = 12.34D^2 \times EH + 3127.17 \qquad \text{Eq. 3.13}$$

This equation includes the cost of the corrugated sheets, stiffeners, bolts, seals and roof.

Cost of perforated floor and substructure is represented by Equation 3.14, whose R^2 value is 0.99.

$$PPFLOR = -1411.42 + 134EH + 138.76D^2 \qquad \text{Eq. 3.14}$$

The equation considers a 12% perforated floor with a 20 gauge plank and steel columns.

Cost of assembling steel bins can be determined from Equation 3.15, whose $R^2 = 0.98$

$$PASBIN = 1489.37 + 1.54D^2 \times EH \qquad \text{Eq. 3.15}$$

This equation considers labor and equipment necessary for assembling the bin. The data was provided by Dr. T. O. Hodges, Kansas State University.

Cost of foundation can be estimated by Equation 3.16, whose R^2 is 0.99

$$PFOUNSB = (15.18 + 0.013D^2 \times H)\ UCC +$$
$$(-1070.3 + 0.54D^2 \times EH + 558.5\frac{EH}{D})USC \qquad \text{Eq. 3.16}$$

The first part of the equation in parenthesis represents the volume of concrete (m^3) required for the foundation ring. The second part in parenthesis represents the reinforcement steel required (T). The terms UCC and USC represent the unit cost of concrete ($\$/m^3$) and steel

($/t) respectively including labor cost. The materials are based on a regular soil condition. Data was provided by Dr. T.O. Hodges.

For countries needing to import the bins, the freight cost is an important component to add. The cost will vary with the transport length and weight of the material. Equation 3.17 represents the weight of the bin. Multiplying this equation by the freight rate (cost/weight) for the required distance will obtain the freight costs. The R^2 value of this equation is .95.

$$BWEIGHT = -10448.21 \times 147.79D \times EH$$

Where:

BWEIGHT = weight of steel bins (kg).

Bins have to be unloaded with mechanical equipment. For these purposes, horizontal augers combined with sweep augers are used. The cost of this equipment is represented by Equation 3.18 with the R^2 value of 0.98.

$$PUNLEQ = -4709.4 + 3.44.49AUD - 46.6UCAP + 118.59D \qquad \text{Eq. 3.18}$$

This equation considers the price of the sweep auger, a central bin well with slide gate, intermediate wells, unloading auger, unloading tube, transmission and speed reducers. Motors are not included. The equation represents unloading auger diameters from 15 cm to 30.5 cm and unloading capacities from 15 T/H to 65 T/H.

3.6.2 Concrete Bins

Concrete bins are built at the plant site, according to the size and layout that have been pre-determined. They can be designed independently and built one at a time using jumping forms or can also be designed interlocked. In such cases, they are built in groups using a slipping form technique. In this study, the second case is considered.

In the literature reviewed for Chapter 1, no recent documents were found regarding the cost of concrete bins for several storage capacities.

Mata (1983) determined the quantities of concrete and horizontal steel required to build a battery of 18000 m^3 capacity. He considered different layouts, number and size of bins, and computed the quantities of concrete and horizontal reinforcement steel required to build the bin walls.

Due to the lack of information on concrete bins cost for different storage capacities, a study was done to provide values for quantities of reinforcement steel and concrete required for several bin batteries. it is possible to obtain a fast estimate of the cost to compare with other storage alternatives.

The study considered storage capacities from 3800 m^3 to 51500 m^3, a ratio of height to diameter of $3 < H/D < 5$, layouts of two and four bins wide by the number of bins required to obtain a given capacity.

Bin sizes considered are shown in Table 3.4.

Table 3.4 Bin Sizes Considered for the Study.

Diameter (m)	Heights			
5	15	20	25	
7	25	30	35	
8	25	30	35	40
9	30	35	40	
10	30	35	40	

Through the study, all main parts of the silo battery were considered: silo walls, hopper and support, roof and foundations. Appendix I offers a detailed explanation of the analysis that was performed, including variables and assumptions.

a. Factors that influence the cost: Even though the data in the design analysis mentioned above was obtained considering most of the factors that influence the final cost, some variables were fixed and will introduce variations for specific applications. The designer or person evaluating the alternatives should take into consideration the factors affecting the final cost and the way the study was done and make adjustments when applying the conclusions of this study.

b. Design theories: Many theories regarding the design of concrete bins have been formulated to predict the stresses in the walls and hoppers (Ravenet J. 1977). The American Concrete Institute, ACI

Committee 313-77, adopted the theories developed by the authors M. Reinbert and H.A. Janssen to design concrete bins. Both theories can be used to compute the static horizontal, vertical and frictional stresses in the walls and hopper. The ACI - 313 - 77 suggests the use of an everpressure factor to consider the dynamic pressures generated when unloading the bins. This factor has different values for each theory, making the final pressures using Reinbert or Janssen methodologies very similar. If other design theories are considered,there will be variations in the loads against the silo wall and so in the silo cost. The details of these theories are explained in Fintel (1985), Safarian and Harris (1985) and Reimbert and Reimbert (1973).

c. Physical Characteristics of the grain: The design parameters used to compute the static pressures are bulk density, angle of repose and the coefficient of friction between the grain and the bin wall material.

Mata (1983) made the recommendation that the horizontal pressure should be computed for the grain with lower values of friction coefficient because the horizontal pressure decreases as the friction coefficient increases (see Fig. 3.9 Horizontal Pressure vs. Friction Coefficient). On the other hand, the vertical pressure should be computed for the grain with bigger angles of repose because the

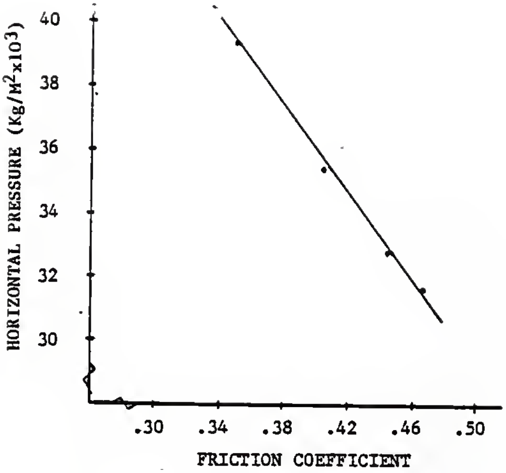


Fig. 3.9 Horizontal Pressure vs. Friction Coefficient (Mata 1983)

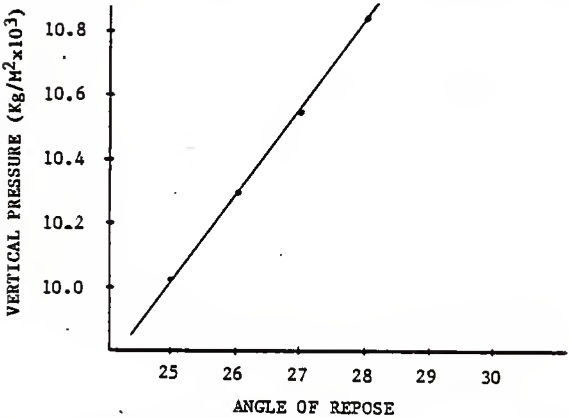


Fig. 3.10 Vertical Pressure vs. Angle of Repose (Mata, 1983).

vertical pressure increases with the angle of repose of the grain. (see Fig. 3.10. Vertical Pressure vs. Angle of Repose).

d. External forces: The wind force should be considered in the design, especially when the bins are empty. This force usually varies with the geographical location of the project and proper building codes have to be applied for an accurate estimation of the forces.

The seismicity of the zone greatly influences the final cost of the battery. As the bin's height rises and the stored volume increases, overturning of the structure is more critical, increasing the foundation's size changing the optimum size of the bin. For this study a seismic coefficient of .15 was considered.

e. Soil conditions: The allowed load on the soil may restrict the building dimensions and the ground water level can influence the depth of elevator pits. In some areas, especially near the cast, the allowed load and the possible settlement of the structure are so critical that it requires the use of piles. In this case, the cost of the foundation may increase more than 15% (Bouland, 1966).

In general, the solution for the foundation is a continuous mat slab with a minimum area of the cross-section of the battery. Depending on the battery volume, concrete depth of 1.0 m is not uncommon for the mat foundation.

The combination of seismic load and soil conditions is one of the structural considerations that most affects the final costs. Thus it is recommended to perform a soil study in the feasibility stage of the project. This will allow a better estimate of the costs and analysis of alternatives. For the study, a soil capacity of 30 T/m^2 was considered.

f. Availability of raw materials, labor and technology: The main cost components for this sort of silo are concrete, reinforcement steel, forms and labor. For countries where these elements are available in required quantities, concrete bins are a feasible solution even for small storage capacities.

The construction of concrete bins, especially when building several silos at a time, is high labor consuming, making of special interest labor availability and wages.

Concrete bins require high construction technology, especially when using slipping or stepping forms. The planning and managing of the construction are crucial.

g. Influence of size and number of bins: Fig. 3.11 is a relation of the concrete index (concrete volume/storage capacity) versus bin height for different bin diameters. From this graph, it can be seen that the optimum H/D ratio decreases as the bin diameter (D) increases. For D = 5 m, H/D ratio of 5 requires the minimum concrete volume, for D = 10 m, H/D was less than 3. A minimum value is presented for 8 m diameter and H/D = 4.

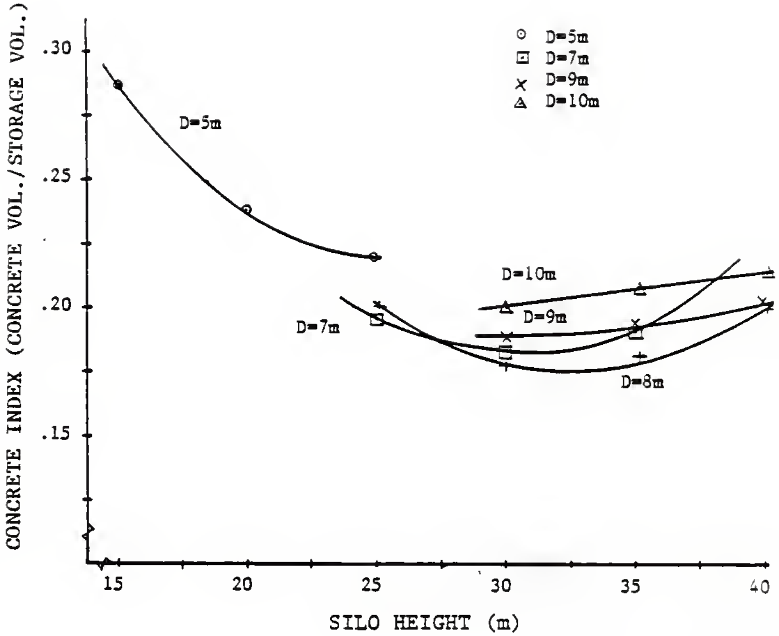


Fig. 3.11. Optimum Concrete Silo Size: Concrete Index (Concrete Vol./Storage Vol.) vs. Silo Height (m).

Fig. 3.12, concrete index vs. storage capacity, shows the variation in concrete volume when using a layout of two or four bins wide. From the graph it can be concluded that the more compact the bin battery, the less concrete required.

3.6.2.1. Cost of concrete bins

From the study mentioned above, Fig. 3.13 shows the cost of different storage capacities using concrete bins. The lower line was obtained using the H/D ratios from Fig. 3.9 that gives the minimum concrete volume. The upper line was obtained using other bin sizes. This graph demonstrates the importance of searching for an optimum battery size and configuration when using concrete bins. For a storage capacity of 28000 m^3, a cost variation larger than 22% can be obtained depending on the battery size. This graph takes into consideration all silo parts such as walls, hoppers, roof and foundations, as well as labor, materials and overhead costs.

Equations 3.19 through 3.22 can be used to model the cost of concrete bins. These equations were developed using the data in Tables A1.10 through A1.15 in Appendix I. It is important to clarify that equations 3.20 and 3.21 are only recommended for obtaining a rough estimation of the cost of the concrete bins alternative. By any circumstance can be applied for designing a bin battery. From this set of equations, the variables represent:

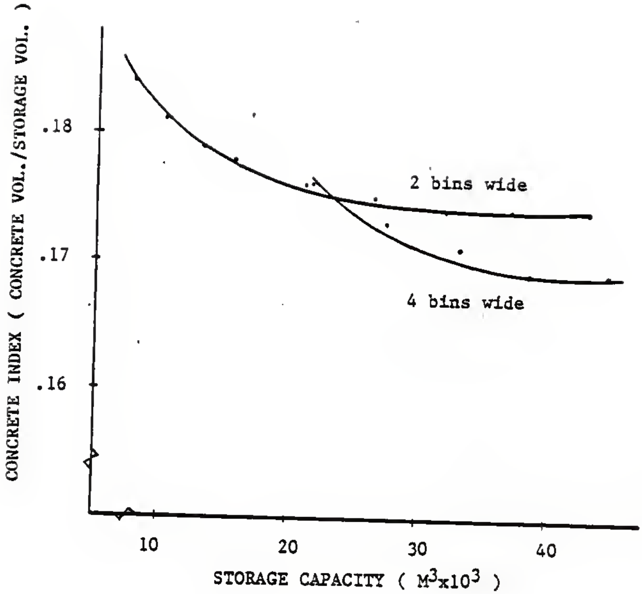


Fig. 3.12. Concrete Index (Concrete Vol./Storage Vol) vs. Storage Capacity.

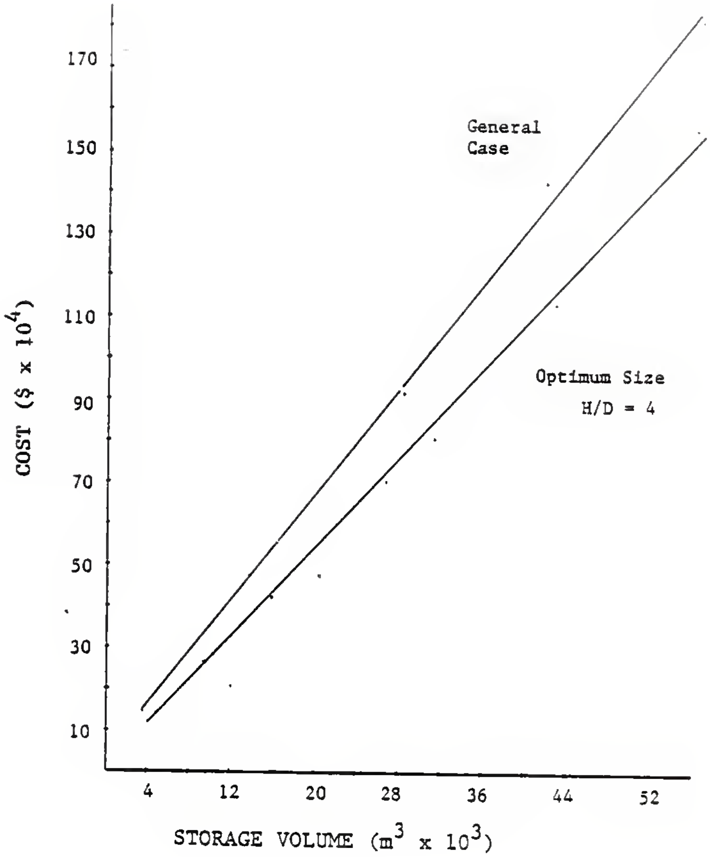


Fig. 3.13. Cost of Concrete Bins vs. Storage Volume.

CAP = battery storage capacity (m^3)

D = silo internal diameter (m)

H = total silo height

NB = number of bins

NIB = number of inter-bins

VC = volume of concrete (m^3)

WS = weight of reinforcement steel (T)

LC = labor cost ($/battery)

COCSI = cost of concrete silo ($/battery)

CUC = concrete unit cost ($/$m^3$)

SUC = steel unit cost ($/T)

OVC = overhead cost (percentage of materials + labor cost).

Equation 3.19 gives the storage capacity (m^3) as a function of the bin diameter, height, number of bins and number of inter-bins, and the R^2 value is 0.99.

$$CAP = 0.652D^2 \times H \times NB + 0.127 \times D^2 \times H \times NIB - 127.69 \qquad \text{Eq. 3.19}$$

Equation 3.20 can be used to compute the volume of concrete (m^3) required for building the bin battery; the R^2 value is 0.97.

$$VC = 0.186 \times CAP - 35.27\frac{H}{D} - 21.13NB + 423.37 \qquad \text{Eq. 3.20}$$

Equation 3.21 can be used to compute the quantity of reinforcement steel required for the bin battery with the R^2 value of 0.98.

$$WS = 0.0156 \times CAP - 53.91\frac{H}{D} - 2.08 \times NB + 227.26 \qquad \text{Eq. 3.21}$$

Equation 3.22 represents the labor cost, where the R^2 value is 0.99. Data for this equation was supplied by construction companies specializing in building concrete silos. The value of this component may vary depending on the labor efficiency, wages, and equipment availability.

$$LC = (28.4 + 0.49D + 0.18D^2) \times H \times NB. \qquad \text{Eq. 3.22}$$

The other important cost component is overhead cost. This item is as a percentage of the materials plus labor costs, and considers the cost of slipping forms, administration, technical direction, taxes, profits and unforseens. Some planners consider this item to be around 40% for the State of Kansas.

Combining Equations 3.20, 3.21, 3.22 and the overhead costs the final cost for different batteries can be obtained. Equation 3.23 summarizes the whole analysis.

$$COCSI = (VC \times CUG + WS \times SUC + LC)\ (1 + OVC) \qquad \text{Eq. 3.23}$$

3.6.2.2 Cost Comparison of Concrete and Steel Bins:

Having studied the parameters that define the cost of corrugated steel and concrete bins, it is possible to compare their initial building cost for different storage capacities. Figure 3.14 compares the cost of flat steel with concrete upright structures. The lower

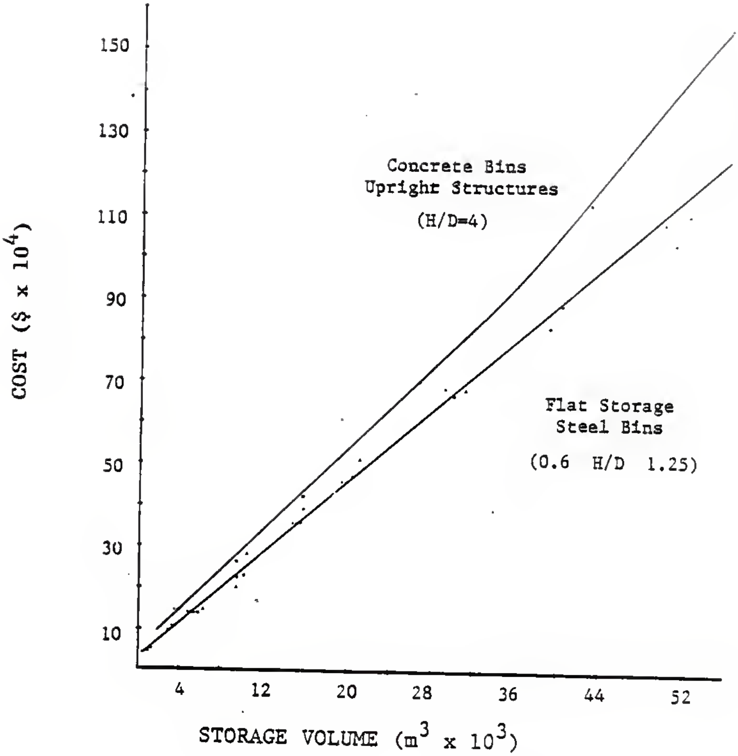


Fig. 3.14. Storage Volume vs. Cost: Flat Storage Structures (Steel Bins) vs. Concrete Upright.

line represents the cost of steel bins for different storage capacities using bins with H/D ratio from .6 to 1.25. Upright structures are represented by the upper line using an H/D ratio of 4. The graph shows no breakeven point for the capacities studied and the initial cost of flat structures is lower than upright structures.

Figure 3.15 compares the cost of upright concrete structures with steel bins using a H/D ratio between 2.2 and 2.5. In this case, the initial cost of steel bins is larger than concrete bins.

Figure 3.16 compares the unit cost ($\$/m^3$) of steel bins and concrete bins using different H/D ratio. The following conclusions can be obtained from this figure.

1. The unit cost of steel bins increases as the H/D ratio increases.

2. The unit cost of concrete bins present a minimum value for an H/D ratio equal to 4. An 8 m bin diameter was considered since it presented a minimum value in Fig. 3.11.

3. For H/D ratio lower than 1.5, steel bins present a lower unit cost than concrete bins.

4. For H/D ratio higher than 1.5, lower unit storage cost can be obtained using concrete bins with H/D equal to 4.

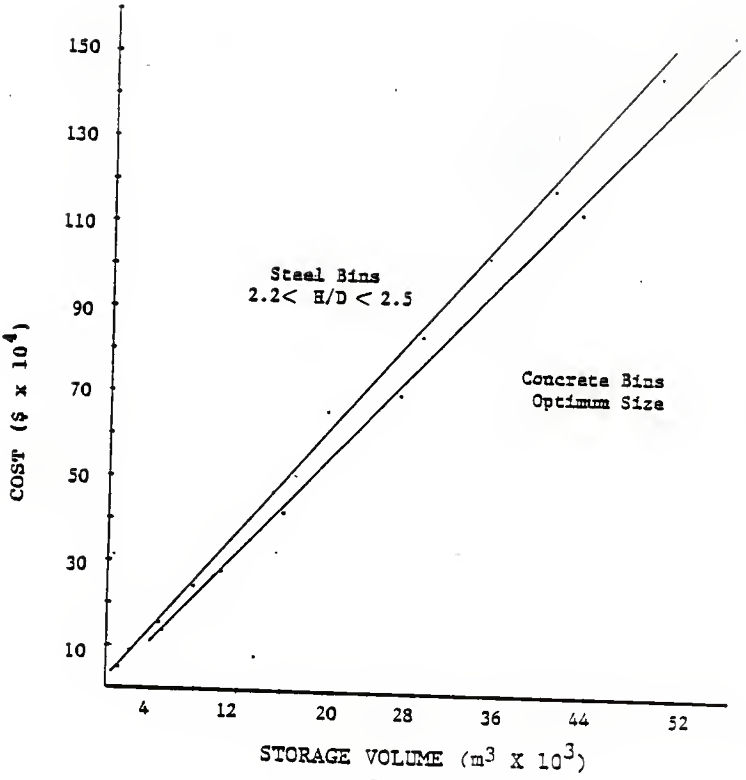


Fig. 3.15. Storage Volume vs. Cost: Upright Concrete Bins and Upright Stell Bins.

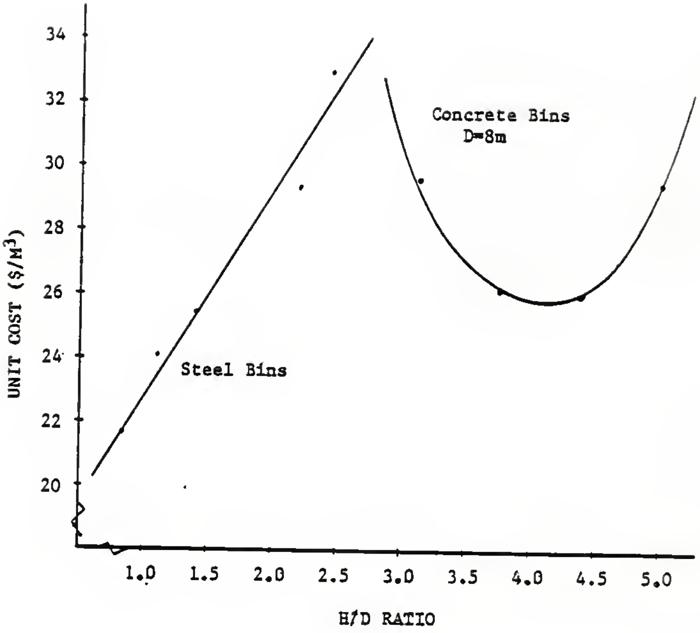


Fig. 3.16. Concrete and Steel Bins: Unit Cost vs. H/D ratio.

When studying storage alternatives for a given project, costs other than initial construction costs have to be considered. Of special importance is operational cost. This will vary with the number of times the bin is loaded and unloaded. Maintenance cost will vary depending on the climate and use of the structure, and freight costs become very important for countries that have to import steel bins. Associated benefits such as foreign exchange requirements and the job resources that the project may create can be considered as extra economical benefits for a given alternative. The importance of this aspect will depend on how critical the money exchange is for the country. For countries short of dollars, this criterion may be crucial.

3.7 MODELING FOR ENERGY REQUIREMENTS.

This section includes the equations necessary for computing power for handling equipment and heat required for drying.

a. Drying: Heat required for drying as a function of drying rate is represented by Equation 3.24 with the R^2 value of 0.91.

$$\text{Heat} = 1794049 + 277475\,\text{DCAP} + 2952.85\,\text{DCAP}^2 \qquad \text{Eq. 3.24}$$

Where:

Heat = heat in KJ/H

DCAP = drying capacity T/H.

The power required for the dryer as a function of drying capacity is computed by Equation 3.25, whose R^2 value is 0.98.

$$DKW = 5.26 + 1.73 \times DCAP + .04DCAP^2 \qquad \text{Eq. 3.25}$$

Where:

DKW = power required for drying (KW)

DCAP = Drying Capacity (T/H).

b. Aeration

Recommended aeration rates were presented in Chapter II, the following equations are used to compute the fan power required to blow air through the grain mass and the pressure drops were presented in Chapter II and are summarized in Table 3.8.

c. Conveying equipment: Equation 3.28 can be used for computing the power required for horizontal drag conveyors, horizontal screw conveyors and bucket elevators. The efficiency factor will vary for each case.

$$CKW \quad \frac{2.725 \times 106^{6} \times CAP \times Dist.}{Mef} \qquad \text{Eq. 3.28}$$

(Handbook for Mech. Eng.)

Where:

CKW = power required for conveying equipment

CAP = handling capacity (K/H)

Dist = conveying distance (m)

Mef = mechanical efficiency. Varies for each equipment.

Recommended mechanical efficiencies were obtained by Chang (1981) from different manufacturers. Table 3.5 summarizes the information.

Table 3.5 Mechanical Efficiency (Chang, 1981)

Equipment	Meff.
Bucket Elevator	90%
Transport Auger	30%
Sweep Auger	20%
Auger Pit	45%
Drag Conveyer	90%

d. Economic information: An important consideration when analyzing annual operational cost is the economic information. Table 3.6 from Loewer et al. (1976b), summarizes expected life, interest and repair for different equipment. The sum of percentage includes depreciation using straight line method without salvage value.

Table 3.6 Economic Information of Grain Handling, Drying and Storage Systems (Loewer et al., 1976b)

Subsystem	Expected Life (year)	Interest (%)	Taxes, Insurance (% of initial cost)	Repair (% of initial cost)	Sum of Percentages (%)
1. Steel Structure	20	8.0	1.25	0.05	14.30
2. Concrete Bins	30	8.0	1.25	0.01	12.59
3. Perforated floor and structure	20	8.0	1.25	0.05	14.30

4. Concrete Bins	30	8.0	1.25	0.01	12.59
5. Fan and motor	10	8.0	1.25	0.01	20.25
6. Gas Heater	10	8.0	1.25	1.00	20.25
7. Continuous Dryer	10	8.0	1.25	2.00	21.25
8. Stirrer and motor	7	8.0	1.25	2.00	25.54
9. Perforated bin-wall liner	20	8.0	1.25	0.05	14.30
10. Steel hopper	10	8.0	1.25	0.05	19.30
11. Auger pit	10	8.0	1.25	1.00	20.25
12. Gravity pit	20	8.0	1.25	0.05	14.30
13. Transport auger	7	8.0	1.25	4.00	27.54
14. Electric motor	10	8.0	1.25	1.00	20.25
15. Overhead distributing auger	7	8.0	1.25	2.00	25.54
16. Bucket elevator	20	8.0	1.25	0.05	14.30
17. Distributor	20	8.0	1.25	0.10	14.35
18. Cleaner	20	8.0	1.25	0.50	14.75
19. Downspouting	20	8.0	1.25	0.02	14.27
20. Grain spreader	10	8.0	1.25	1.00	20.25
21. Sweep auger	7	8.0	1.25	2.00	25.54
22. Tube and sump	20	8.0	1.25	0.05	14.30
23. Horizontal unloading auger	7	8.0	1.25	2.00	25.54
24. 25° Bin unloader	7	8.0	1.25	2.00	25.54
25. Return unloading auger	7	8.0	1.25	2.00	25.54

Conclusions:

1. Tables 3.7 and 3.8 summarize the mathematical equations developed through this chapter to provide models that allow the application of systems engineering techniques for designing commercial grain handling and storages facilities.

2. Recommendations for the use of different processing equipment and suggestions for choosing the appropriate capacity are given all through the chapter.

3. Figures 3.2, 3.4 and 3.6 supply evidence of the advantage of reconsidering the handling capacity that is obtained directly from the design. The design size may be at the maximum of the equipment handling capacity and in such case, choosing the next size and varying the conveying speed will increase the handling rate without changing the equipment.

4. Figures 3.7, 3.8, 3.11 and 3.13, demonstrate the economical impact of optimizing the size and number of bins when planning the storage system. When the size of concrete bins is not optimized, the initial construction cost can increase as much as 32%. When the size of steel bins is not optimized, the initial construction cost can increase as much as 22%.

5. Through Figures 3.14, 3.15 and 3.16 it is concluded that the storage capacity is not the factor that will dictate when each storage

system is economically the best. Rather, the size of the bins related to the use of the facility will influence the best economical decision.

6. Corrugated steel bins can be built at lower costs then concrete structures when using H/D ratios lower than 1.25.

7. The most economic size of concrete bins varies with their diameter. As the diameter increases, the H/D relation decrease. Considering only the quantity of concrete required to build the bin, 8 m diameter with H/D ratio equals to 4 was the optimum size.

8. For facilities not perfectly defined as flat or upright cost cannot be considered as the only factor in choosing the best storage system. Under these circumstances, the use of multiple attribute decision making methods, considering the factors listed in Chapter I, are strongly recommended for making the correct decision.

Table 3.7 Summary Table of Mathematical Models for Equipment and Grain Storage Systems

SUB SYSTEM	ITEM	COST FUNCTION $/UNIT =	R^2
Receiving	Auger Pit	1216.91 + 3.12 APCAP + 1.14 x APCAP x LN	.97
	Gravity Pit	761.35 + 47.89 P Size	
Processing	Bucket Elevators	1139.13 + 161.58 HT + 2.52 CAP - 1.7 CAP x HT _ 655.53 HP	.95
	Aspiration Cleaner	-528.42 + 1243 CAP - 12.36 CAP^2	.91
	Gravity Cleaner	228.83 + 55.46 CAP	.97
	Holding Bins	1444.02 + 27.53 D^2 x H	.99
	Continuous Flow Dryers	Price = 4704.66 CAP - 2602.15	.91
	Screw Conveyors	385.78 + 40.68 LN - 0.51 CAP * LN + 300.90 HP	.90
	Drag Conveyors	2045.7 + 192.52 LN + 4.77 CAP	.98
	Axial Fans	270.59 + 120.75 HP - 3.92 HP^2	.93
	Centrifugal Fans	57.46 HP + 1388.26	.97
	Electric Motors	43.88 HP + 91.45	.99

SUB-SYSTEM	ITEM	COST FUNCTION $/UNIT =	R^2
Storing Steel Bins	Steel Bins/bin	$12.34\ D^2 * EH + 3127.17$	.98
	Perforated Floor/Bin	$-1411.42 + 38.76\ BD^2 + 134\ H$	.99
	Assembling/ Bin	$1489.37 + 1.54\ D^2 * H$	.98
	Foundations/ Bin	$(15.18 + 0.013\ D^2 * H) \times 111.9 + (558.5 \frac{H}{D} + 0.54\ D^2 * H - 1070.3) * 0.545$	.90
	Concrete Cost	$(0.19\ CAP + 35.27 \frac{H}{D} - 21.13\ NB + 423.37)\ 66.7$	.97
	Reinforcement Steel Cost	$(0.016\ CAP - 53.91 \frac{H}{D} - 2.08\ NB + 227.26)\ 418.9$	.98
	Labor Cost	$(28.4 + 0.49D + 0.18D^2)\ H*NB$	.99
	Overhead Costs	% (Concrete Cost + Reinf. Steel Cost + Labor Cost) % = 0.40 (Kansas)	

Table 3.8 Energy Function

Sub-System	Item	Energy Function	R^2
Drying	Dryers	Heat = 1794049 $+_2$ 277475DCAP 2952.85DCAP^2	.91
		DKW = 5.26 + 1.73DCAP + .04DCAP^2	.98
Aeration and Dryeration	FanKW	Q x P/1000 x Mef (Marks Handbook for Mechincal Eng.) $P = aQ^2 / Ln (1 + bQ)$ (Hukill and Ives, 1955)	
Conveying Systems	CKWH	2.725×10^6 x CAP x Dist./Mef (Marks' Handbook for Mech. Eng.)	

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CHAPTER IV

SYSTEM ANALYSIS FOR THE DESIGN OF GRAIN HANDLING AND STORAGE FACILITIES

4.1 INTRODUCTION

In the previous chapters, 9 large number of factors and considerations for designing grain handling and storage facilities has been reviewed. Decisions made by experience or trial and error require a lot of time, effort and uncertainty of the final solution. Comparing the several different systems in order to make the best choice is impractical without the use of system analysis methods.

This chapter demonstrates the application of system analysis, including multiple attribute decision making methods (MADM) for making decisions among a finite number of alternatives, and minimization techniques for designing facilities.

The problem of choosing the proper type of silo is solved using a MADM method call Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The Sequential Unconstraint Minimization Technique (SUMT) is applied to obtain the optimum number of bins, diameter and height that give the minimum cost for a given storage capacity. The same minimization technique is applied to select the optimum size of holding and tempering bins to study the cost of different drying techniques.

4.2 REVIEW OF LITERATURE

Some literature sited in Chapter III is also applicable in this chapter.

Chang (1978) determined the annual drying costs and optimum drying costs of five different corn drying systems. He modeled the drying annual cost using regression analysis and wrote an objective function in terms of a single independent variable. Differential calculus was used to determine the optimum dryer capacity for different systems and then to obtain the optimum drying costs.

Chang (1981) developed a mathematical model for rough rice handling, drying and storage for farm sizes, including price model, energy model and grain damage model. A general multiple objective problem was formulated to design the optimum system with multiple conflicting objectives and systems constraints. Nonlinear goal programming was introduced to obtain the optimum design from six drying methods and two handling systems. By sensitivity analysis he obtained the best drying system for different harvest volumes.

Park (1982) developed a computer program and mathematical model for the feed mill industry. The models included capital investment, energy uses, labor and profit models. He optimized the feed mill design by applying a single objective nonlinear programming and multiple objective decision making using the iterative nonlinear goal programming method.

Loewer et al. (1976) developed a computer program for farm facilities design. The program ranks the cost of the feasible systems considered and presents the equipment and labor required for each system. Through the program, the best design is found searching the cost of several alternatives of comparative storage system.

Plato and Gordon (1983) applied Dynamic Programming to determine the quantity of grain that should be carried into the next marketing gear to dampen the grain prices fluctuation. This method determines the carry-over from one harvest to the next by maximizing a specific objective function such as the value of grain consumption subject to a random variable such as production. In this way the optimal grain storage is found.

Brook and Bakker-Arkena (1980) developed a dynamic programming algorithm to obtain the optimal operational parameters and size for a multistage concurrent flow dryer for drying corn. The objective function was based on energy and capital costs. Moisture content and different grain quality factors were used as constraints to the operational parameters.

Carpenter and Brooker (1972) developed simulation models to determine minimum cost machinery system for harvesting, drying and storing shelled corn. They obtained optimum harvest starting moisture and minimum cost drying systems for different annual volumes. Using a digital computer, they simulated the operation of alternative machine systems over a 20 year period of weather conditions. In this way, the evaluated field drying, field losses, days suitable for harvesting, optimum cost harvesting and drying system, minimum cost harvesting drying and storage, maturity date costs and relative risks.

Hwang and Yoon (1981) compiled and systematically classified the literature on methods and applications of multiple attribute decision making (MADM). The study provides a concise look into the existing methods, their characteristics and applicability to analysis of MADM problems. The study also introduces models for MADM, transformation of attributes, fuzzy decision rules and methods for assessing weight.

4.3 CHOOSING BETWEEN CONCRETE OR CORRUGATED STEEL BINS

From the conclusions of chapter I, regarding the factors to consider when choosing the best storage system, and the results of the cost analysis of storage structures in chapter III, it is concluded that the decision has to be independently analyzed in each situation.

The problem can be divided into three general categories. A set of circumstances for which corrugated steel bins are the best solution, the case when the decision factors clearly define the use of concrete bins; and the third category where the different factors have to be weighted in order to define the best choice.

4.3.1. Favorable Conditions for Using Corrugated Steel Bins:

When the following set of conditions are present, the use of corrugated steel bins is usually the best solution.

- Need to store only 1 or 2 types of grain for a period of time of 1.5 years or more (Bouland, 1966). In this case, flat storages can be used with a low storing cost/yr.

- Need for less than three turnover per year. This will make the project not require gravity flow discharge.

- Possibility of disassembling the bins and moving them to another location.

- Low soil capacities that make shorter bins with bigger diameters behave better structurally.

- Unfavorable environment for corrosion. This is, when combination of high temperatures with high relative humidities during long periods of time or marine atmospheres are not present.

- Existence of bin steel industry in areas near the project.

- Climate conditions favorable for grain storage.

4.3.2 Favorable Conditions for Using Concrete Bins:

Under the following set of conditions, concrete bins usually represent the best solution.

- Grain turnover more than three times a year, making gravity flow necessary. Tall bins with small diameters are then more efficient. In this case, the facility is classified as a working facility and emphasis is given to minimizing the operational costs.

- Need for a number of bins to store different grain varieties and blending.

- Aggressive corrosion environments. Presence of high temperatures and high relative humidities for long periods of time or presence of marine atmospheres.

- Good soil stratum, capable of handling high concentrated forces.

- Small space available for the facility.

- Expected useful life for the facility greater than 20 years.

- For large commercial elevators, the upright type of structure usually fits better. In this case, concrete bins are preferred.

4.3.3 Undefined Conditions for the USe of Concrete or Steel Bins

In situations where the last two sets of conditions are combined or not clearly defined, the following aspects from Chapter I should be considered in making the decision.

- Initial cost, total cost of the facility, considering materials, labor, freight and foreign exchange.

- Grain preservation in relation to the storage time, moisture migration, insect and mold infestation.

- Longevity of the structure: considering the structure endurance and stability against winds, natural phenomena, and the maintenance requirements.

- Construction aspects: degree of construction difficulty, construction time and technology requirements.

- Associated benefits: generation of employment, foreign exchange requirements and use of local resources.

- Operation Flexibility, measured in relation to the number of bins and discharge methodology.

Some of the aspects cited can be measured in a certain unit like cost in dollars or longevity of the structures in years, but in other cases such as grain preservation, the attribute has no unit of measure to quantify the alternative. Even more problematic is to compare among alternatives having conflicting attributes with no uniform units of measure.

In such a case, the use of multiple attribute decision making methods (MADM) is suggested as a scientific way to obtain the best solution.

4.4 USE OF MULTIPLE ATTRIBUTE DECISION MAKING METHODS

Hwang and Yoon (1981) provide a concise explanation of existing MADM methods, their characteristics and applicability for analyzing certain types of problems. They also introduce methods for transformation of attributes, fuzzy decision rules, and methods for assessing weights. Among the MADM methods, the TOPSIS method is selected to analyze the problem of using concrete or steel bins mainly because of the degree of information that the method utilizes and the information that the method provides with the solution of the problem.

Hwang and Yoon (1981) developed the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) based on the concept that the best alternative should have the shortest distance from the ideal solution and the farthest from the negative-ideal solution. To obtain the rank of the alternative under these criteria, the method considers the relative closeness to the ideal solution simultaneously.

The ideal solution is a hypothetical solution which is composed of all best attribute values attainable from the set of alternatives; and the negative-ideal solution is composed of all worst attribute values attainable. Figure 4.1 illustrates the concept of the Euclidean distance from each alternative (A_i) to the ideal and negative-ideal solution.

The TOPSIS method evaluates the following decision matrix which contains an alternative associated with n attributes or criteria (Hwang and Yoon, 1981).

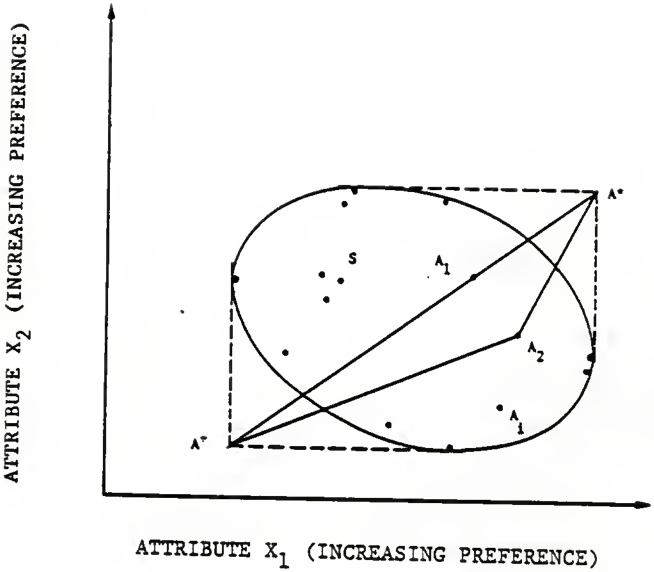


Fig. 4.1. Euclidean Distance to the Ideal and Negative Ideal Solutions in Two Dimensional Space.

$$D = \begin{array}{c|cccccc|}
 & X_1 & X_2 & \cdots & X_j & \cdots & X_n \\
A_1 & X_{11} & X_{12} & \cdots & X_{1j} & \cdots & X_{1n} \\
A_2 & X_{21} & x_{22} & \cdots & X_{2j} & \cdots & X_{2n} \\
\vdots & \vdots & \vdots & & \vdots & & \vdots \\
A_i & X_{i1} & X_{i2} & & X_{ij} & \cdots & X_{in} \\
\vdots & \vdots & \vdots & & \vdots & & \vdots \\
A_m & X_{m1} & X_{m2} & & X_{mj} & \cdots & X_{mn}
\end{array}$$

Where:

A_i = the i^{th} alternative considered,

x_{ij} = the numerical outcome of the i^{th} alternative with respect to the j^{th} criterion.

TOPSIS assumes that the larger the attribute outcomes, the greater the preference for the "benefit" criterion and the less the preference for the "cost" criterion. Any outcome which is expressed in a nonnumerical way should be quantified through an appropriate scaling technique. Since all criteria cannot be assumed to be of equal importance, the attributes receive a set of weights from the decision maker.

Detailed information on the computational procedure of TOPSIS, methods for assessing weights, and scales for fuzzy attributes can be found in Hwang and Yoon, (1981).

In the present study, the method was applied using TOPSIS software for micro-computers developed by Dr. C.L. Hwang at the Industrial Engineering Department, Kansas State University.

To show the applicability of the method, two example problems are presented.

4.4.1 Example I

- Definition of the problem: Commercial type of storage.
- Storage capacity: 20,000 m^3
- Country: Costa Rica
- Type of facility: more than three turnovers a year expected.
- Number of grain varieties: 4
- Climate: Tropical weather (warm temperatures and high relative humidity).
- Construction aspects: Advanced concrete technology available and not steel bin industry.
- Possible associated benefits: Using concrete structures can generate employment and decrease the requirements of foreign exchange by about 25%.

a. Storing alternatives and Initial cost:

	Alternatives	Initial Cost
1.	Build 100% of the capacity with steel bins	$455,000
2.	Build 100% of the capacity with concrete bins	$535,000
3.	Build 50% of the capacity with steel bins and 50% with concrete bins	$504,000
4.	Build 70% with concrete bins and 30% with steel bins	$523,600

The cost of alternatives 1 and 2 was obtained from Fig. 3.8 and

Fig. 3.13. The cost of alternatives 3 and 4 were obtained combining the cost of the first two alternatives in the percentage of the type of bin used to store the grain. b. Attributes for evaluating the alternative

Cost

Grain preservation

Longevity of the structure

Construction aspects

Associated benefits

Operation flexibility

To evaluate each attribute under each alternative, the interval scale for evaluating fuzzy attribute was used as shown in Fig. 4.2 (MacCrimmon, 1968).

For Cost Attributes			For Benefit Attributes
	0	0	
Very High	1.0	1.0	Very Low
High	3.0	3.0	Low
Average	5.0	5.0	Average
Low	7.0	7.0	High
Very Low	9.0	9.0	Very High
	10.0	10.0	

Fig. 4.2 Assignment of Values for an Interval Scale

Table 4.1 presents the decision matrix after the quantification of nonumerical attributes. Considering the factors mentioned in Chapter I, grain preservation in steel bins was considered to be between average and high. From the Interval Scale, a value of 6 is assigned. The concrete bins alternative present more advantages to preserve the grain and a very high value was assigned, which corresponds to a 9 in the Interval Scale. For the alternatives combining steel and concrete bins, a proportional value to the use of each alternative was assigned.

Table 4.1. Decision Matrix after the Quantification of Nonnumerical Attributes

Alternative	COST cost x 10^3 (\$)	BENEFIT G. Conser. Preser.	BENEFIT Longevity	COST Cons. Asp.	BENEFIT Ass. Ben.	BENEFIT Op. Flex
Steel	455.0	6.0	7.0	1.0	5.0	5.0
Concrete	553.0	9.0	10.0	6.0	9.0	9.0
St.50%/C50%	504.0	7.5	8.5	3.5	7.0	7.0
C70%/St30%	523.6	8.1	9.1	4.5	7.8	7.8

c. Attribute weights

One method of assessing weights is through the eigenvector method. To apply this method, the decision maker is required to judge the relative importance of two criteria and form what is called the pairwise comparison matrix. Saaty (1977) gives an intensity scale of importance for activities and has broken down the importance ranks as shown in Table 4.2.

Table 4.2 Intensity Scale for Pairwise Comparison (Saaty, 1977)

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two criteria contribute equally to the objective.
3	Weak importance of one over another	Experience and judgment slightly favor one criterion over another.
5	Essential or strong importance	Experience and judgment strongly favor one criterion over another
7	Demonstrated Importance	A criterion is strongly favored and its dominance is demonstrated in practice.
9	Absolute Importance	Evidence favoring one criterion over another is of the highest possible order of affirmation.
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed.

The pairwise comparison matrix for the problem is established using Saaty's scale. The results are shown in Table 4.3.

Table 4.3 Pairwise Comparison Matrix

	Cost	G. Preser.	Longevity	Cons. Asp
Cost	1.00	3.0	1.00	7.00
G. preser.	.33	1.0	0.25	5.00
Longevity	1.00	4.0	1.00	4.00
Cons-asp.	.14	0.2	0.25	1.00
Ass-ben.	.33	0.33	0.25	5.00
Op. flex.	.33	4.00	1.00	6.00

(cont.)

	Ass. Ben.	Op. Flex.
Cost	3.00	3.00
G. Conser.	3.00	0.25
Longevity	4.00	1.00
Cons-asp.	0.20	0.17
Ass-ben.	1.00	0.20
Op. Flex.	5.00	1.00

In this matrix, comparing cost with longevity of the structure, equal importance is given to both attributes and a value of one is assigned. Between weak and essential importance is given to longevity of the structure over grain conservation and a value of 4 is assigned from the intensity scale.

The procedure details for obtaining the weights using the eigenvector method are explained in Hwang and Yoon, 1981.

The decision maker weights are:

Cost	G. Preser.	Longevity	Cons. Asp	Ass. Ben.	Op. Flex.
0.30	0.11	0.25	0.03	.08	0.23

With this set of weights, 30% of the decision is given to the cost factor, 11% to grain preservation and so forth.

d. Solution and rank

Positive ideal solution. The PIS is obtained combining the best attributes in the decision matrix.

Cost x 10^3	G. Preser.	Longevity	Cons. Asp.	Ass. Ben.	Op. Flex.
455.0	9.0	10	1.0	9.0	9.0

Negative ideal solution. The NIS is obtained combining the worst attributes in the decision matrix.

Cost x 10^3	G. Preser.	Longevity	Cons. Asp.	Ass. Ben.	Op. Flex.
553.0	6.0	7.0	6.0	5.0	5.0

The relative closeness to the ideal solution is:

Rank		
4	Steel	0.30
1	Concrete	0.70
3	St50-C50	0.50
2	C70-St30	0.63

One of the most inportant advantages of this method is to obtain a cardinal rank of the alternatives. In this way, the degree of preference is established. In this example, concrete bins are .70 closer to the ideal solution and steel bins are .30, so the first alternative is prefered more than two times the second one. The combination of storing 70% in concrete bins and 30% in steel bins is .63 close to the ideal solution. In case the first alternative is not attainable, the second one can be choosen without loosing to much.

The rank order is:

Rank	Relative closeness to Ideal Solution
1 Concrete	0.70
2 C70-St30	0.63
3 St50-C50	0.50
4 Steel	0.30

4.4.2 Example II

- Definition of the problem: Long term storage
- Storage capacity : 20,000 m^3
- Country: USA
- Type of facility: Long term storage
- Number of grain varieties: 2
- Climate: Four seasons
- Construction aspects: Advanced concrete technology and advanced steel industry.
- Possible associated benefits: Not considered of interest in this example.

a. Facility alternative and initial costs:

b. Decision matrix:

The decision matrix in Table 4.4 presents the facility alternatives and attributes considered for the study and the quantification of fuzzy attributes.

Table 4.4 Decision Matrix for Example II

Alternative	COST cost x 10^3	BENEFIT G. Preser	BENEFIT Longevity	COST Cons. Asp	BENEFIT Op. Flex
Steel	455	7.00	7.00	1.00	5.00
Concrete	553	9.00	10.00	5.00	9.00
St50-c50	504	8.00	8.50	3.00	7.00
C70-st30	523.6	8.40	9.10	3.80	7.80

Table 4.5 The Eigenvector Pairwise comparisons

	Cost	G. Conser	Longevity	Cons. Asp	Op. Flex
Cost	1.00	3.00	1.00	6.00	5.00
G-conser	0.33	1.00	1.00	7.00	6.00
Longevit	1.00	1.00	1.00	5.00	4.00
Cons-asp	0.17	0.14	0.20	1.00	0.33
Op-flex	0.20	0.17	0.25	3.00	1.00

The decision maker subjective weights are:

Cost	G. preser.	Longevity	Cons. asp	Op. Flex
0.36	0.26	0.26	0.04	0.08

Positive ideal solution

Cost	G. preser	Longevity	Cons. Asp	Op. Flex
455000.00	9.00	10.00	1.00	9.00

Negative ideal solution

Cost	G. preser.	Longevity	Cons. Asp	Op. Flex
553000.00	7.00	7.00	5.00	5.00

Relative closeness to the ideal solution

Rank		
4	steel	0.42
1	concrete	0.58
3	st50-c50	0.50
2	c70-st30	0.56

Rank Order: Relative closeness to the ideal solution

Rank		
1	concrete	0.58
2	c-70-st30	0.56
3	st50-c50	0.50
4	steel	0.42

In this example, the numerical values assigned to the attributes, the relative importance of attributes in the pairwise comparison matrix, and the weights vary from Example I according to the new situation. The rank order of the alternatives happened to be the same as in Example I, but the cardinal order of the alternatives changed.

In order to show the sensitivity of the method and how the best solution varies with the weight factor, cost attribute, storage capacity and type of facility, a sensitivity analysis was conducted using the software previously mentioned.

In the long term storage example for 20000 m^3 storage capacity, the cost of the concrete alternative is 20% higher than the steel bins alternative. Table 4.6 presents the relative closeness to the ideal solution increasing the cost of concrete bins with respect to steel bins from 20% to 50% using two different weights for the attributes. The second set of weights is given directly to the program based on the decision maker's experience.

TABLE 4.6
Long Term Storage Facility Weights Through Pairwise Comparison And Direct Weights

Capacity M^3	Cost Variation	Rank (weights 1)		Rank (weights 2)	
20000	20%	1. Concrete	.58	1. Steel	.55
		2. C70-St30	.56	2. St50-C50	.50
		3. St50-C50	.50	3. C70-St30	.47
		4. Steel	.42	4. Concrete	.45
20000	30%	1. Concrete	.53	1. Steel	.61
		2. C70-St30	.52	2. St50-C50	.50
		3. ST50-C50	.50	3. C70-St30	.43
		4. Steel	.47	4. Concrete	.39
20000	40%	1. Steel	.52	1. Steel	.66
		2. St50-C50	.50	2. St50-C50	.50
		3. C70-St30	.49	3. C70-St30	.40
		4. Concrete	.48	4. Concrete	.34
20000	50%	1. Steel	.56	1. Steel	.70
		2. St50-C50	.50	2. St50-C50	.50
		3. C70-St30	.46	3. C70-St30	.38
		4. Concrete	.44	4. Concrete	.30

1. Weights: Pairwise Comparison Weights (From Example 2)

Cost	G. Pres.	Longevity	Cons. Asp.	Op. Flex.
.36	.26	.26	.04	.08

2. Weights - Direct Weights

Cost	G. Pres.	Longevity	Cons. Asp.	Op. Flex.
.60	.20	.10	.05	.05

Table 4.7 compares the solutions for long term types of storage and commercial storage for a capacity of 20000 m^3. In this table, the cost gap between concrete and steel bins was increased, making concrete bins more expensive than steel bins by 20% to 50%.

Figure 4.3 shows that concrete bins are the preferred solution for commercial type of storage, even if this cost is up to 34% more expensive than steel bins. After this cost difference, the steel bins are preferred.

Table 4.7 Influence of Cost Variation

	Commercial Type of Storage[1]		Long Term Storage[2]	
Cost Variation	Rank[3]		Rank[3]	
21%	1. Concrete	.59	1. Steel	.55
	2. C70-St30	.55	2. St50-C50	.50
	3. St50-C50	.47	3. C70-St30	.47
	4. Steel	.41	4. Concrete	.45
30%	1. Concrete	.53	1. Steel	.61
	2. C70-St30	.51	2. St50-C50	.50
	3. ST50-C50	.48	3. C70-St30	.43
	4. Steel	.47	4. Concrete	.39
40%	1. Steel	.53	1. Steel	.66
	2. St50-C50	.48	2. St50-C50	.50
	3. C70-St30	.47	3. C70-St30	.40
	4. Concrete	.47	4. Concrete	.34
50%	1. Steel	.57	1. Steel	.70
	2. St50-C50	.48	2. St50-C50	.50
	3. C70-St30	.45	3. C70-St30	.38
	4. Concrete	.43	4. Concrete	.30

Fixed Storage Capacity = 20,000 m^3

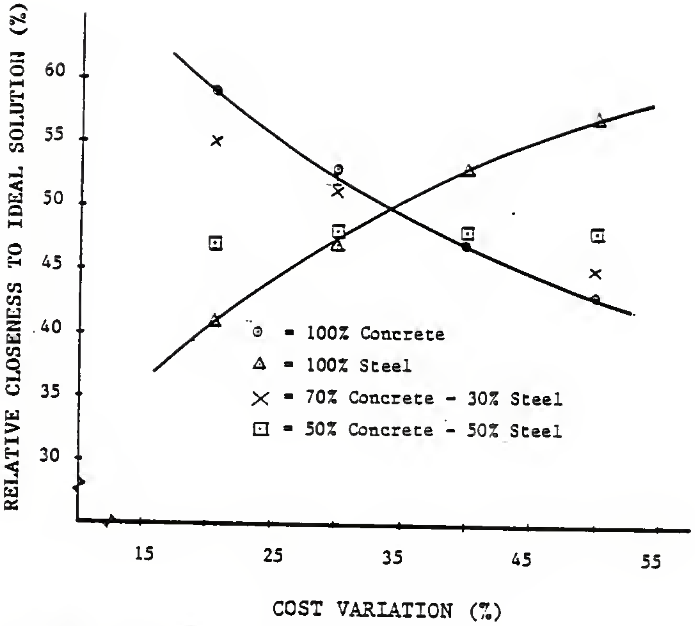
1. Direct Weights for Commercial Type

Cost	G. pres.	Longevity	Cons. Asp.	Ass. Ben.	Op. Flex.
0.50	0.10	0.15	0.03	0.07	0.15

2. Direct Weight for Long Term Storage

Cost	G. pres.	Longevity	Cons. Asp.	Op. Flex.
.60	.30	.10	.05	.05

3. Rank = Relative closeness to the ideal solution.



a) Weights

Cost	G. Pres.	Long.	Cons. Asp.	Assoc. Ben.	Op. Flex.
.50	.10	.15	.03	.07	.15

b) Storage capacity of 20000 m^3

Fig. 4.3. Choice of Concrete or Steel Bins for Commercial Type od Storage.

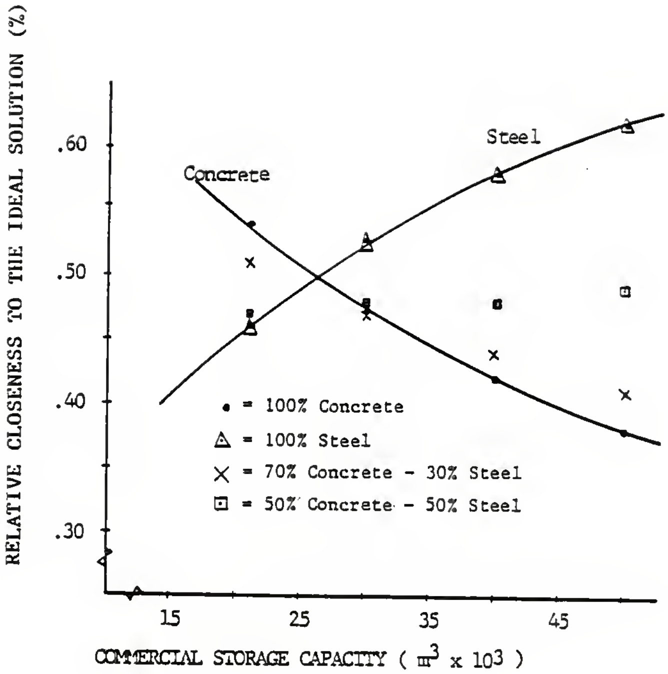
Figures 4.4 and 4.5 show the variation in the breakeven value for commercial type of storage if 55% and 60% of the decision is assigned to the cost factor. Table 4.3 summarizes the sensitivity of the cost factor.

Table 4.8 Breakeven Values Between Concrete and Steel Bins For Commercial Type of Storage Assigning Different Weights to the Cost Factor.

	Cost Variation
Weight To Cost Factor	Breakeven Value %
.45	42.5
.50	34.5
.55	26.0
.60	19.0

From Table 4.8 and Figs. 4.3, 4.4 and 4.5, if a 60% value is assigned to the cost factor, the use of concrete bins is preferred even if their cost is up to 19% more expensive than the steel bins alternative. If less weight is assigned to the cost factor, say 50%, the concrete bins solution is preferred even if its cost is 34.5% more than the steel alternative.

Fig. 4.6 shows the effect of the cost variation on the ideal solution for a long term type of storage. In this case, assigning 60% to the cost factor, concrete bins are preferred even if they were up to 21% more expensive than steel bins. Usually in the U.S., concrete

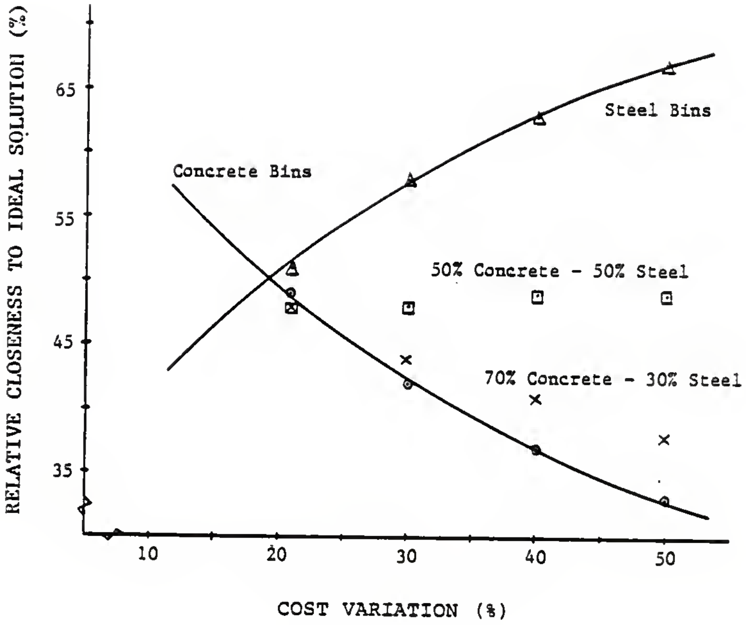


a) Weights :

Cost	G. Pres.	Long.	Cons. Asp.	Ass. Ben.	Op. Flex.
.55	.09	.12	.03	.07	.14

b) Fixed cost variation . Concrete bins 20% more expensive than steel bins.

Fig. 4.4. Influence of the Weight Factor in the Choice of Concrete or Steel Bins For Commercial Type of Storage With a Fixed Cost Variation.

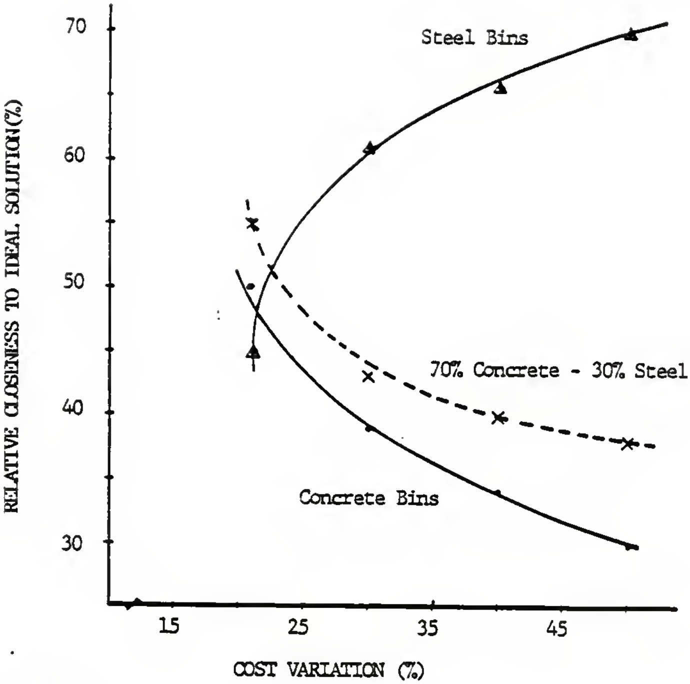


a) Weights

Cost	G. Pres.	Long.	Cons. Asp.	Assoc. Ben.	Op.Flex.
.60	.08	.11	.03	.06	.12

b) Fixed storage capacity of 20000 m^3

Fig. 4.5. Infuence of the Weight Factor in the Choice of Concrete or Steel Bins For Commercial Type of Storage With a Fixed Storage Capacity.



a) Weights

Cost	G.Pres.	Long.	Cons.Asp.	Op.Flex.
.60	.20	.10	.05	.05

b) Fixed storage capacity of 20000 m^3

Fig. 4.6. Choice of Concrete or Steel Bins for Long Term Type of Storage.

bins are more than 20% more expensive than flat steel bins. Similar results are shown in Fig. 4.7 for assigning 65% to the cost factor.

Table 4.9 shows the variation in relative closeness to the ideal solution with respect to the storage capacity for both commercial and long term storage. Figures 4.8 and 4.9 represent the graphical results of this table. Figure 4.8 shows that for commercial type of storage with concrete bins being 20% more expensive than steel bins, the concrete bins are the preferred solution for all ranges of capacities studied. For long term storage situations, Fig. 4.9 shows that there is a trend of steel bins being a preferred solution for capacities lower than 30000 m^3, whereas for bigger capacities there is no difference between the two principal alternatives.

TABLE 4.9. Influence of Storage Capacity

Capacity m^3	Commercial Type of Storage[1] Rank[3]		Long Term Storage[2] Rank[3]	
8000	1. Concrete	.60	1. Steel	.54
	2. C70-St30	.56	2. St50-C50	.50
	3. St50-C50	.47	3. C70-St30	.48
	4. Steel	.40	4. Concrete	.46
16000	1. Concrete	.63	1. Steel	.52
	2. C70-St30	.57	2. C70-St30	.50
	3. ST50-C50	.47	3. St50-C50	.50
	4. Steel	.37	4. Concrete	.48
32000	1. Concrete	.64	1. C70-St30	.51
	2. C70-St30	.58	2. Concrete	.50
	3. St50-C50	.47	3. St50-C50	.50
	4. Steel	.36	4. Steel	.50
40000	1. Concrete	.63	1. C70-St30	.51
	2. C70-St30	.58	2. Concrete	.50
	3. St50-C50	.47	3. St50-C50	.50
	4. Steel	.37	4. Steel	.50

Fixed Cost Variation: Concrete 20% more expensive than steel.

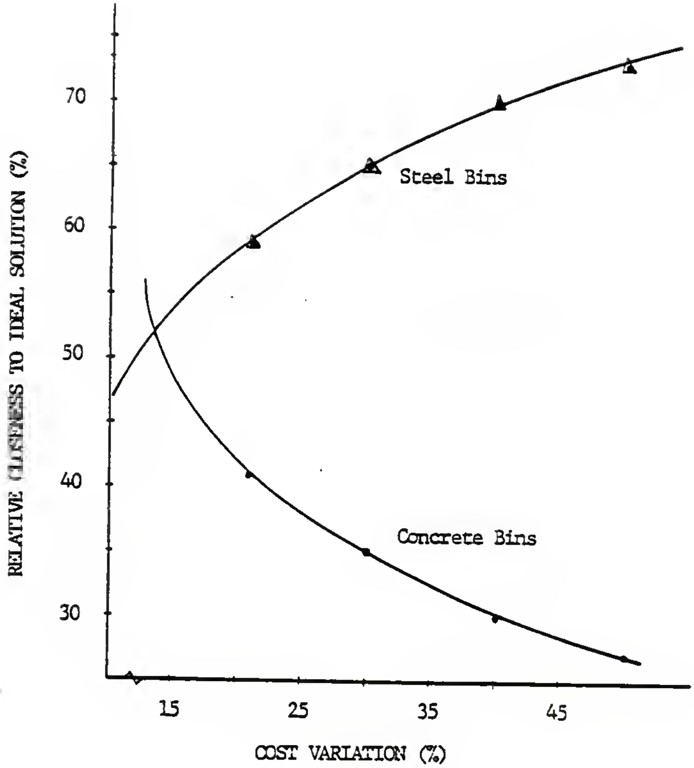
1. Direct Weights for Commercial Type

Cost	G. Pres .	Longevity	Cons. Asp.	Ass. Ben.	Op. Flex
0.50	0.10	0.15	0.03	0.07	0.15

2. Direct Weight for Long Term Storage

Cost	G. Pres.	Longevity	Cons. Asp.	Op. Flex.
.60	.20	.10	.05	.05

3. Rank = Relative closeness to the ideal solution.

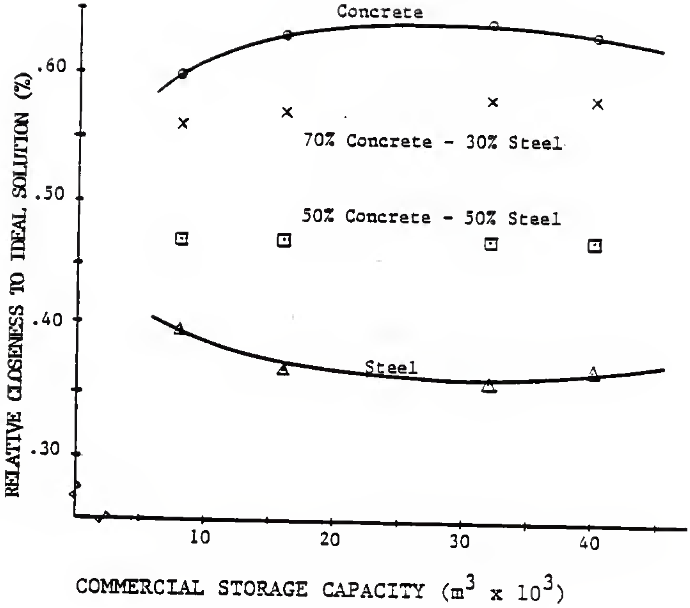


a) Weights

Cost	G.Pres.	Long.	Cons.Asp.	Op.Flex.
.65	.17	.09	.04	.05

b) Fixed Storage Capacity of 20000 m^3.

Fig. 4.7. Choice of Concrete or Steel Bins for Long Term Type of Storage.

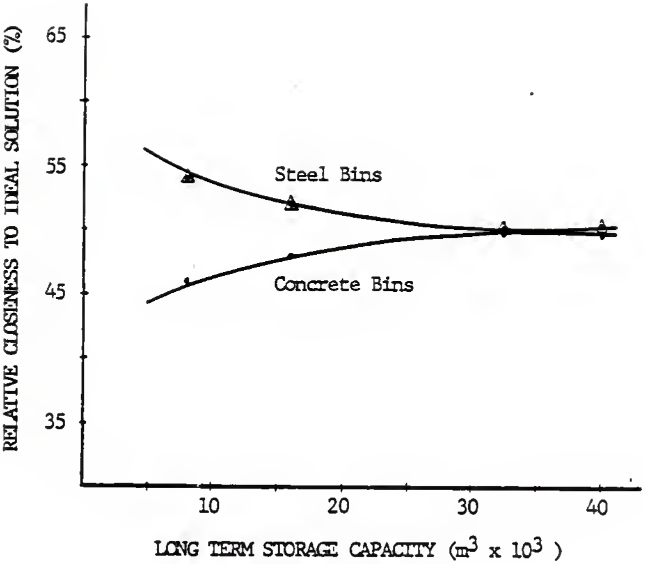


a) Weights

Cost	G.Pres.	Long.	Cons.Asp.	Op.Flex.
.60	.20	.10	.05	.05

b) Fixed Cost Variation: Steel bins 20% lower than concrete bins.

Fig. 4.8. Influence of the Storage Capacity in Choosing the Proper Type of Bin for Commercial Storage Facility.



a) Weights

Cost	G.Pres.	Long.	Cons.Asp.	Op.Flex.
.60	.20	.10	.05	.05

b) Fixed cost variation. Steel bins 20% lower than concrete bins

Fig. 4.9. Influence of the Storage Capacity in Choosing the Proper Type of Bin for a Long Term Storage Facility.

4.5 APPLICATION OF MINIMIZATION TECHNIQUES TO THE DESIGN OF GRAIN STORAGE FACILITIES.

To illustrate the use of minimization techniques and mathematical modeling, a design example was set up to choose the bin diameter, height and number of bins that will result in a minimum fixed annual cost for both concrete and steel bins.

The sequential unconstraint minimization technique (SUMT) modified with the pattern search by Hooke and Jeeves (1961) was used for obtaining optimum bin sizes.

The SUMT technique solves the problem:

Minimize $F(X)$

$$\text{Subject to} \quad gi(X) > 0 \quad i = 1,2,\ldots,m \qquad \text{Eq. 4.1}$$

$$\text{and } h_j(X) = 0 \quad J = 1, 2, \ldots l$$

Where:

X is a n-dimensional vector $(X_1, X_2, \ldots X_n)$

$F(X)$ = objective function to be minimized

$g_i(X)$ = inequality constraints

$h_j(X)$ = equality constraints.

The SUMT technique is considered one of the simplest and most efficient methods for solving the problem given by the Equation 4.1

(Lai, 1970). The basic scheme of this technique is that a constraint minimization problem is transformed into a sequence of unconstrained minimization problems which can be optimized by any available technique for solving unconstrained minimization.

For this study, the technique was applied using the computer program KSU-SUMT, developed by Lai (1970). The unconstrained minimization technique employed in the KSU-SUMT program is the Hooke and Jeeves pattern search technique including some modifications to increase the efficiency of the method. Among these modifications, a heuristic program technique is used to handle the inequality constraints of the problem given by equation 4.1. The method and its computational procedure is illustrated in detail in Lai (1970). The reader interested in this technique is referred to Fiacco and McCormick (1964); Hooke, and Jeeves, (1961), Hwang et al. (1969).

Design Example:

It is desired to choose the bin diameter, height and number of bins that minimize the facility's fixed annual cost for a 20,000 m^3 storage capacity.

4.5.1 Design with Concrete Bins

From the economic information in Table 3.7, the concrete bins' fixed cost/year as a percentage of the initial cost is:

Depreciation	3.33%/year
Interest	8.00%/year
Taxes and Insurance	1.25%/year
Total Fixed Cost %/year(FC%)	12.59%/year

The mathematical model is set up in the following manner.

a. Objective function:

From the cost study in Chapter III, Equation 3.23 represented the cost of concrete bins as a function of the diameter, height and number of bins. Multiplying the equation by the FC%, the fixed cost/year is obtained.

For the study, the following unit costs are used:

$CUC = \$66.7/m^3$

$SUC = \$418.9/Ton$

Overhead Costs = 40% of labor + materials cost

Where:

CUC = concrete unit cost ($\$/m^3$)

SUC = steel unit cost ($\$/T$)

Substituting these values into Equation 3.23 and simplifying, the following objective function is obtained.

$$\text{Cost/year} = 3.42\text{CAP} - 3665.8\ H/D - 401.99\text{NB}$$
$$+ 5.01H \times \text{NB} + 0.09D \times H \times \text{NB} + 0.03D^2 \times H \times \text{NB} + 21757.18$$

Where:

CAP = storage capacity (m^3)

H = bin height (m)

D = bin diameter (m)

NB = number of bins

b. Constraints:

Equation 3.19 for the storage capacity has to be satisfied as an equality constraint.

$$\text{CAP} = .625D^2 \times H \times \text{NB} + 0.1266D^2 \times H \times \text{NIB} - 127.69$$

NIB was replaced with the formula: $\text{NIB} = \text{NB}/2 - 1$

c. Inequatity constraints:

Equation 3.23 was developed for bin heights between 15 m and 40 m, bin diameters between 5 m and 10 m and H/D ratio between 3 and 5. The number of bins have to be at least 2 per grain variety. These aspects are mathematically represented by:

Bin Height: $15 < H < 40$

Bin Diameter: $5 < D < 10$

Number of bins: $\text{NB} > 4$

H/D ratio: $3 < H/D < 5$

Substituting the variables names in terms of X_i to fit the problem into the Equation 4.1, and letting SCAP = $20000m^3$, the minimization problem is defined. (X_1 = D, X_2 = H, X_3 = NB)

Minimize

$$Y = -3565.8\ X_2/X_1 - 401.99X_3 + 5.01X_2 \times X_3 + .09X_1 \times X_2 \times X_3 + 0.03X_1^2 \times X_2 \times X_3 + 9.0097.18$$

Subject to:

$$-.625X_1^2 \times X_2 \times X_3 - 0.1266\ X_1^2 \times X_2\ (.5X_3 - 1) + 20127.69 = 0$$

$5 < X_1 < 10$

$15 < X_2 < 30$

$X_3 > 4$

$3 < X_2/X_1 < 5$

The KSU-SUMT program has the characteristic that the designer has to search through the equation, using different initial values,to get a feeling of the equation behavior. In this case, two possible alternatives with different bin sizes and number of bins but similar annual cost were obtained.

Alternative I

D = 7.76m

H = 32.9m

NB = 14.2

Cost/year = $72,777/year

Alternative II

D = 5.89m

H = 23.2m

NB = 34.7

Cost/year = $67,440/year

The designer can choose between the alternatives. If the cost of the land is significant, it should be noted that the first alternative requires only about 60% of the area of the second one. The initial cost difference between the alternatives in handling equipment can be easily computed from Equations 3.4 and 3.12, in Chapter III.

Extra length in bucket elevator in Alternative I (60 T/H) = $1,857.

Extra length in loading and unloading equipment of Alternative II, using drag conveyors (60T/H) = $22,458.

The handling equipment in Alternative II is $20,601 more expensive than the Alternative I. Considering the cost of the land and handling equipment, Alternative I is preferred.

4.5.2 Design with Corrugated Steel Bins.

The same procedure as with concrete bins was followed. From the economic information, Table 3.7, the steel bins and unloading equipment fixed cost/year as a percentage of the initial cost is:

Steel bins $FC_1\% = 14.3\%$

Unloading Equipment $FC_2\% = 25.5\%$

The mathematical model is set up in the following manner:

a. Objective Function:

Adding Equations 3.13, 3.14, 3.15, 3.16, and 3.18, the objective functions are set up. The unit oosts used for the study are:

CUC = \$111.9/m^3 including labor

SUC = \$.545/kg including labor.

Steel bin alternative cost:

Steel bins = $12.34D^2 \times H + 312717$

Perforated floor = $38.76D^2 + 134H - 1411.42$

Assembling = $1.54D^2 \times H + 1489.37$

Foundations = $(15.18 + 0.013D^2 \times H)\ 111.9 +$

$(558.5\ H/D + 0.54D^2 \times H - 1070.3).545$

Unloading Equipment = $334.49UD - 46.6UCAP + 118.59D - 4709.4$

Adding these equations and multiplying by the number of bins (NB) and the FC\$ and simplifying, the final objective functions is obtained. To fit the problem in equation 4.1, the follwoing variable names were changed:

$X_1 = D$

$X_2 = H$

$X_3 = NB$

Simplified objective function:

$$\text{Cost/year} = 2.23X_1^2 \times X_2 \times X_3 + 5.54X_1^2 \times X_3 + 19.16X_2 \times X_3$$
$$+ 43.53\ (X_2 \times X_3)/X_1 + 514.51X_3 + f30.24X_1 \times X_3$$

b. Constraints:

The storage capacity is an equality constraint:

$$SCAP = .785X_1^2 \times X_2 \times X_3$$

c. Inequality constraints:

Bin Diameter	$6 < X_1 < 27$
Bin Height	$12 < X_2 < 23$
H/D ratio	$.5 < X_2/X_1 < 2.5$
Number of bins	$X_3 > 4$

For a CAP = 20,000 m^3, the minimization problem is defined:

Minimize :

$$Y = 2.23X_1^2 \times X_2 \times X_3 + 5.54X_1^2 \times X_3 + 19.16X_2 \times X_3$$
$$+ 43.53\ (X_2 \times X_3)/X_1 + 514.51X_3 + 30.24X_1 \times X_3$$

Subject to:

$$20{,}000 - 785X_1^2 \times X_2 \times X_3 = 0$$

$6 < X_1 < 27$

$12 < X_2 < 23$

$.5 < X_2/X_1 < 2.5$

$X_3 > 4$

Using the KSU-SUMT program and searching with different initial values, the following alternatives were obtained.

Alternative I

D = 11.7

H = 22.3

NB = 8.3

Cost/year = $74,593.6/year

Alternative II

D = 18.9

H = 14.8

NB = 4.8

Cost/year = $73,120/year

In this case, the second alternative using five storage bins is preferred.

Using the same objective function and constraints, the design was performed for three different storage capacities. Table 4.5 summarizes the results.

Table 4.10 Fixed Cost Per Year for Different Storage Capacities.

	Storage Capacity m^3	Diameter (mm)	Height (mm)	Number of bins	Cost per year $
Steel Bins	20,000	18.9	14.8	5	73,120
Concrete Bins	20,000	7.8	33	14	72,777
Steel Bins	10,000	12.6	16	5	39,070
Concrete Bins	10,000	6.7	33	10	36,638
Steel Bins	5,000	9.8	13.7	5	22,224
Concrete Bins	5,000	5.4	27.5	9	18,594

From the above table, very small differences were found between the annual cost of storage facilities built in concrete or corrugated steel bins for capacities from 5000 m^3 to 20000 m^3. Even though steel bins require less initial cost, the alternative with concrete bins averages a lower annual cost. When searching with the KSU-SUMT method for the different storage capacities, a trend was found that diminishing the number of bins obtains the minimum annual costs.

When all factors were considered in the design, the best H/D ratio for concrete bins was $4 < H/D < 5$ and for steel bins $.75 < H/D < 1.4$. The number of bins is a factor that has to be considered when optimizing the battery size.

4.6 OPTIMIZATION OF THE DRYING SYSTEM

To optimize the minimum cost/year drying system for commercial facilities, the following drying systems were studied in combination with continuous dryers.

A. Using only continuous flow dryers. (D)

B. Using continuous flow dryer with tempering bins. (DT)

C. Using continuous flow dryers with holding bins. (HD)

D. Using holding bins, continuous flow dryer and tempering bins. (HDT)

The study was conducted for annual storage capacities of 20,000 m^3 and 5000 m^3.

a. Procedure and assumptions:

- The grain receiving period was established in 60 days
- The corn is dried from 25% MC to 15% MC.
- Receiving hours = 10 H/day
- Average receiving rate/hr = annual storage capacity/60 days/10 H/day.
- When the dryer was the only equipment involved, the dryer capacity was obtained considering a drying peak of 50% above the average receiving rate.
- When tempering bins were combined with continuous flow dryers, to

use the dryeration system, a 40% increase in the system dryer capacity was considered. Even though Mckenzie et al. 1967 obtained dryer capacities increase up to 60%, for the present study a more conservative value is preferred. Hence, the dryer capacity was chosen 40% lower than the drying peak.

- When holding bins were combined with the dryer, the dryer capacity was the average receiving rate and the peak was regulated through the holding bins.

- When considering holding bins, dryer and tempering bins, the dryer size was considered 40% less than the receiving rate and the difference of the dryer plus tempering with the receiving peak was regulated through the holding bins.

- The size and number of holding and tempering bins were obtained through the KSU-SUMT program. The objective function is Equation 3.7 from Chapter III, to minimize the annual cost of the holding bins.

$$\text{PHOLBIN} = (1695.0 + 42.78D^2 \times H).\ 143 \times NB$$

Constraints: steel bins are available for diameters between 2.7m and 9.1 m, heights from 3.35 m to 14.5 m and H/D ratios between 0.b and 2.7. The minimum number of bins is considered to be two. The following equations represent these constraints.

Number of bins: $NB > 2$

Bin Diameter: $2.7 < D < 9.1\text{m}$

Bin Height: $3.35 < H < 14.5$

H/D ratio: $0.6 < H/D < 2.7$

Holding Capacity: $HCAP = (.785D^2 \times h + .562D^3)NB$

Where:

h = bin height from hopper ring to top

H = bin height from ground to top

The rest of the variables were defined in Chapter III. The cost of the dryer and handling equipment was obtained through the respective equations developed in Chapter III.

The equipment considered in each case is listed below, and its location is represented in Fig. 4.10.

CASE	Equipment Considered in the Drying System
A.	grain dryer only
B.	grain dryer, tempering bins, BE4 and 2TA5.
C.	grain dryer, holding bins, 2TA2 and BE2.
D.	grain dryer, holding bins, tempering bins, 2TA2, BE2, BE4 and 2TA5.

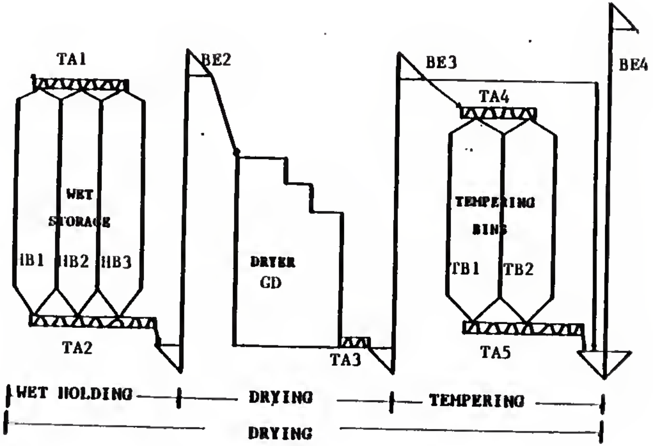


Fig. 4.10. Commercial Drying Systems.

The codes are:

BE = bucket elevator
RH = receiving hopper
HB = holding bins
GD = grain dryer
TA = transport auger

Depending on the plant layout, sometimes it is possible to avoid the use of BE2 using the receiving bucket elevator to feed the dryer. In this study, to solve a general case, BE2 was considered.

b. Annual Cost:

The annual cost in each case was computed considering fixed costs and operating costs. The fixed cost for drying and handling equipment was obtained through the respective equations developed in Chapter III and the economic information in Table 3.7. Operating costs included electricity for the dryer and handling equipment, fuel for the dryer, electricity to aerate the grain in the holding bins and for dryeration. The following data was used to compute the operating costs:

Electricity cost = \$0.024/KWH
Propane gas = \$0.106/l
Aeration rate in holding bins = .007m^3/sec x m^3
Dryeration rate = .007m^3/sec x m^3

c. Results of the analysis:

The results from the study are summarized below:

1. Annual Storage Capacity = 20000 m^3

A. Using dryer only

Dryer size = 36T/H

Fixed costs = $33,770
Operating costs = $38,000
Total Cost/year $74,156

B. Using dryer and tempering

Dryer size = 26T/H

Tempering: 3 bins, D = 5.5m, H = 3.4m

1 bucket elevator

2 U-trough augers

Fixed Costs = $28,259.40
Operating Cost = $28,348.70
Total Cost/year $56,608.10

C. Using dryer and holding bins

Dryer size = 24 T/H

Holding bins: 3 bins D = 4.6, H = 3.4

1 bucket elevator

2 U-trough augers

Fixed costs = $25,558.00
Operating costs = $26,198.40
Total Cost/year $51,756.40

D. Using holding bins, adjusted dryer capacity and tempering bins

Dryer size = 17 T/H

Holding bins: 2 bins, D = 4.6m, H = 3.4m

Tempering bins: 3 bins, D = 4.6m, H = 3.4m

2 bucket elevators

4 U-trough augers

Fixed costs = $21,418.00
Operating costs = $18,963.00
Total cost/year $40,381.00

2. Annual Storage Capacity = 10,000m^3

A. Using dryer only

Dryer size = 18 T/H

Fixed Costs = $16,621.50
Operating costs = $19,909.20
Total cost/year $36,531.70

B. Using dryer and tempering

Dryer size = 13 T/H

Tempering bin: 2 bins, D = 4.6, H = 4.47

1 bucket elevator

2 U-trough augers

Fixed costs = $14,743.00
Operating costs = $15,152.00
Total cost/year $29,895.00

C. Using average receiving rate for the dryer and holding bins

Dryer size = 12 T/H

Holding bins: 2 bins, D = 4.6m, H = 3.4m

1 bucket elevator

2 U-trough augers

Fixed costs = $13,406.30
Operating costs = $14,239.00
Total cost/year $27,645.30

D. Using holding bins, adjusted dryer capacity and tempering bins

Dryer size = 8.6 T/H

Holding bins: 2 bins, D = 3.7, H = 4.3m

Tempering bins: 2 bins, D = 4.6m, H = 3.4m

2 bucket elevators

4 U-trough augers

Fixed costs = $12,189.10
Operating cost = $11,287.00
Total cost/year $23,476.10

3. Annual Storage Capacity = 5000m^3.

A. Using dryer only

Dryer size = 9 T/H

Fixed costs = $8,047.00
Operating costs = $11,580.00
Total costs $19,627.00

B. Using dryer and tempering

Dryer size = 6.5 T/H

Tempering bins: 2 bins, D = 3.7, H = 3.4

1 bucket elevator

2 U-trough augers

Fixed costs = $7,239.30
Operating costs = $9,510.30
Total Costs $16,749.60

C. Using average receiving rates for the dryer and holding bins

Dryer size = 6 T/H

Holding bins: 2 bins, D = 2.7m, H = 5.59

1 bucket elevator

2 U-trough augers

Fixed costs = $7,041.60
Operating costs = $8,869.60
Total costs $15,911.20

D. Holding bins, adjusted dryer capacity and tempering bins.

Dryer size = 4 T/H

Holding bins: 2 bins, D = 2.7, H = 4.47

Tempering bins: 2 bins, D = 4.6, H = 3.4

2 bucket elevators

4 U-trough augers

Fixed costs = $7,397.20
Operating costs = $7,539.70
Total costs $14,936.90

The results from the analysis of drying systems can be visualized in Figure 4.11. For the capacities studied, the drying system combining the use of holding bins, grain dryer and dryeration, resulted in the lowest cost per year. For annual storage capacity of 5000 m^3, the use of holding bins and dryeration process resulted in 31% lower cost than the use of the dryer only. For annual storage capacity of 20,000 m^3 the use of holding bins and dryeration process

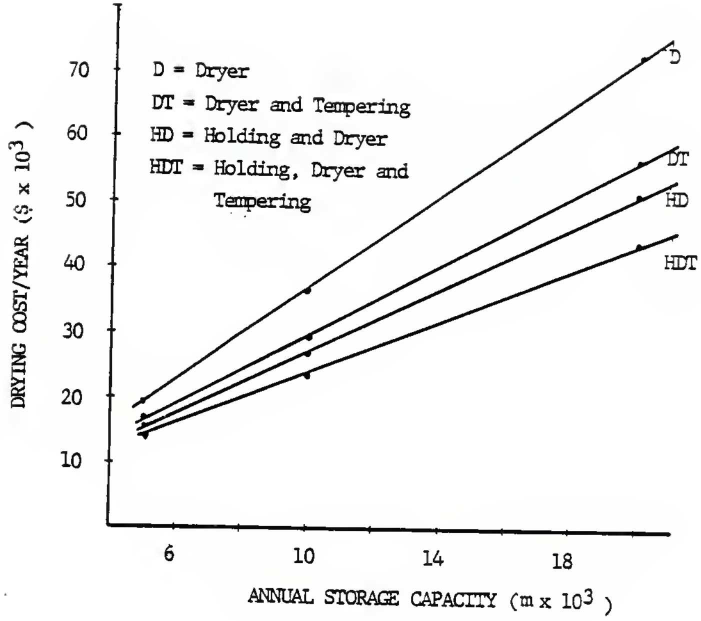


Fig. 4.11. Commercial Drying Cost.

resulted in 84% lower cost than the use of the dryer only.

In addition to the lower cost of using the dryeration technique, other advantages exist such as the increase in the drying rate and the reduction in the stress rack formation and kernel breakage. In one dryeration test, the percentage of cracked corn kernel was 7.6% compared to 43.6% with conventional drying and cooling (McKenzie et al. 1967). The reduction in grain breakage is attributed to the relative low kernel temperature of the grain as it leaves the dryer, the tempering process that relieves stresses in the outer layers of the kernel, and the slow cooling process.

The managing of the dryeration process is more involved in the traditional drying process. Some of the factors to be considered are (Brooker et al. 1981):

1. The temperature and moisture content of the corn coming from the dryer must be continuously monitored.

2. Precautions should be taken to prevent excessive condensation in spouting and other grain-handling equipment.

3. The temperature of the air coming from the grain in the tempering bin should be checked to insure that the grain is cooled before the bin is unloaded.

4. The corn should be thoroughly mixed as it is taken from the tempering bin.

When rice is to be dried the use of the conventional drying system is not recommended because of the possibility of excessive grain breakage. Dryeration process is highly recommended in such cases.

4.7 Conclusions:

1. The TOPSIS method is a very straight forward method for analyzing the selecting of concrete or storage bins. This method considers not only the cost of the alternative but also other important parameters. The decision maker has a way to define the degree of importance that is given to each attribute and obtain an indisputable preference order of solution. Traditionally, this type of decision left the decision maker feeling a high degree of uncertainty.

2. Breakeven values between the use of concrete and steel bins were obtained considering the percentage of cost variation between concrete and steel bins, with the cost of concrete bins higher than the steel bins. For commercial facilities, concrete bins were the best solution even if they cost up to 19% more than steel bins, considering a weight factor of .6 to the cost and .4 to the rest of the attributes. For long term storage, steel bins were the best solution when their cost is at lease 21% less than the concrete bins, considering a weight factor of .6 to the cost and .4 to the rest of the attributes.

3. The SUMT Minimization technique was also applied to the design of concrete and steel bins to obtain the ratio, diameter, height and

number of bins that minimize the cost per year. For concrete bins, H/D ratios between 4 and 5 were found to be optimum ratios for storage capacities from 5000 m^3 to 20000 m^3. For steel bins, H/D ratios from .75 to 1.40 gave the minimum storage cost per year. In both cases, a trend was observed that using the minimum number of bins possible to obtain better cost values.

4. Special attention has to be given to the annual cost when comparing concrete and steel bins. For capacities from 5000 m^3 to 20,000 m^3, concrete bins presented a lower annual cost.

5. Different drying systems for commercial facilities were studied by the SUMT Minimization Technique. The use of dryeration process with holding bins to cover the receiving peak was the lowest cost drying system for annual capacities from 5000 m^3 to 20,000 m^3. The higher the annual storage capacity, the more economical the use of dryeration becomes.

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APPENDIX 1

DESIGN OF THE CONCRETE SILO BATTERIES FOR THE COST STUDY

In order to provide design suggestions for the size and practical elements for the cost of concrete bins, a rough reinforced concrete silo design of a set of batteries was conducted. Through this design, the quantities of concrete and reinforced steel required to build different silo complexes were computed. Special interest was given to complement data from existing studies.

1.1 Design Variables

The storage capacities, bin sizes, layouts and general design variables covered by the study are explained in this section.

1.1.1 CAPACITY AND SIZE

Battery Capacities: From 3800 m^3 to 51500 m^3

Bin Diameters: 5 m, 7 m, 8 m, 9 m, 10 m

Bin Heights: 15 m, 20 m, 25 m, 30 m, 35 m and 40 m

Ratio H/D: The study covered bin sizes within an H/D relation of $3 \leq H/D \leq 5$

Bin sizes considered in the design (Table A1.1).

Table A1.1. Bin Sizes Considered For the Design

Diameter (m)	Heights			
5	15	20	25	
7	25	30	35	
8	25	30	35	40
9	30	35	40	
10	30	35	40	

Layout: Two basic layouts were studied using 2 and 4 bins wide.

Number of bins: The number of bins varied from 6 to 32, increasing in even numbers.

For further explanation of the dimensions, Figs. A1.1, A1.2 and A1.3, present a general layout of the batteries studied.

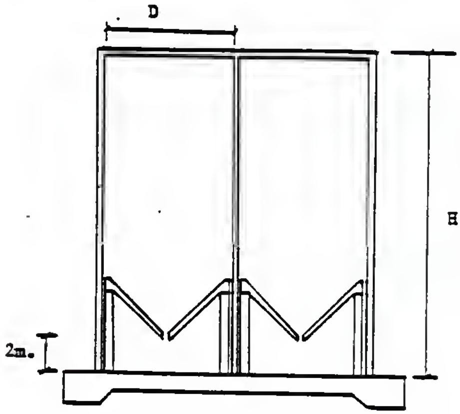

Fig. A1.1. Typical Section of Concrete Bins.

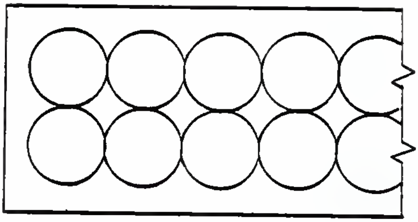

Fig. A1.2. Layout of Two Bins Wide Concrete Battery

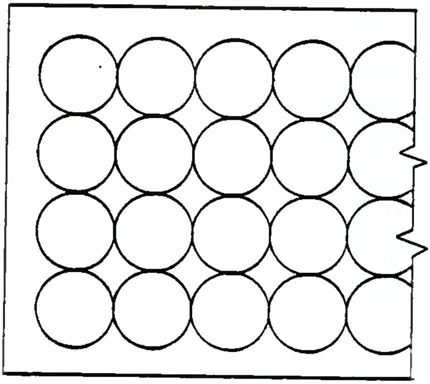

Fig. A1.3. Layout of 4 Bins Wide Concrete Battery.

1.1.2 Grain Characteristics (Fintel, 1985)

Bulk Density = 780 kg/m^3 (Wheat Density)

U = Friction coefficient between stored material and wall = 0.444

P = Angle of internal Friction = 25^o

1.1.3 Concrete and Steel Characteristics (Fintel, 1985):

f'c = 280 kg/cm^2

fy = 2800 kg/cm^2

fs = 1200 kg/cm^2

c = 2400 kg/m^3

Ec = 15200 fc = 254345 kg/cm^2

G = E/2(1-r) = 1589656 kg/cm^2

r = Poisson Ratio = 0.2

Js = 7746 Kg/m^3

Where:

f'c = ultimate compressive strength of concrete

f_y = yield stress of steel

Ec = modulus of elasticity of concrete

G = modulus of elasticity of concrete in shear

f_s = steel stress, tension

c = reinforcement concrete density

J_s = steel density

r = poisson ratio

1.2 DESIGN PROCEDURE

1.2.1 Silo Walls:

1.2.1.1 Concrete and horizontal reinforcement steel:

Mata (1983), worked the design of concrete silo walls and obtained the wall thickness (e) and the volumes of concrete and horizontal steel for different diameters (D) and heights (H). His results are shown in table A1.2 and A1.3. In this design the interrelation of adjacent bins was not considered but is accurate enough for the purpose of this study.

1.2.1.2 Vertical steel:

The main function of the vertical steel is to absorb the tension stress in the silo walls due to seismic forces.

The ACI-313-77 specifies that the vertical steel area should not be lower than 0.0015 times the concrete section for the external reinforcement and 0.0010 for the internal reinforcement. Likewise, the percentage of minimum vertical reinforcement with respect to the concrete area should not be lower than 0.0020 per unit of wall thickness. The distance between bars should not exceed four times the wall thickness nor 45 cm. It is not recommended to use reinforced bars less than $N_o 4$.

For this study, a 0.0015% of the cross concrete area, minimum bars N_o 4 and maximum separation of 45 cm was considered. The results for vertical steel requirements are shown in table A1.4.

Table A1.2. Concrete Volume m^3 Per Bin for Different Diameter and Height (Mata, 1983).

		Height, m						
D (m)	e (cm)	10	15	20	25	30	35	40
5	15	24.3	36.4	48.5	60.7	72.8	84.9	97.1
7	15	33.7	50.5	67.4	84.2	101.1	117.9	-
	17.5	-	-	-	-	-	-	157.8
8	15	38.4	57.6	76.8	96.0	115.2	134.4	-
	20	-	-	-	-	-	-	206.1
9	15	43.1	64.7	86.2	107.8	129.4	150.9	-
	20	-	-	-	-	-	-	231.2
10	15	47.8	71.7	95.7	119.6	143.5	-	-
	17.5	-	-	-	-	-	195.8	-
	20	-	-	-	-	-	-	256.4
12.5	15	59.6	89.4	119.2	149.0	178.8	-	-
	17.5	-	-	-	-	-	243.9	-
	22.5	-	-	-	-	-	-	359.8
15	15	71.4	107.1	142.8	178.5	-	-	-
	17.5	-	-	-	-	250.3	-	-
	20	-	-	-	-	-	334.3	-
	25	-	-	-	-	-	-	479.1

D = Silo Diameter
H = Silo Height
E = Wall Thickness

Table A1.3 Horizontal Reinforcement Steel (m^3) Per Bin For Different Diameter and Height (Mata, 1983)

	Height (m)					
D (m)	15	20	25	30	35	40
5	0.06	0.12	0.18	0.23	0.28	0.35
7	0.10	0.21	0.35	0.52	0.67	0.83
8	0.13	0.27	0.45	0.67	0.93	1.16
9	0.16	0.34	0.56	0.88	1.18	1.50
10	0.18	0.41	0.71	1.03	1.49	1.89
12.5	--	0.59	1.05	1.62	2.27	3.14
15	-	-	1.44	2.28	3.26	4.35

Table A1.4 Wall Vertical Steel Per Silo

Diameter (m)	Height (m)	Vertical Steel m^3/bin
5	15	.066
	20	.088
	25	0.111
7	25	.155
	30	.186
	35	.217
8	25	.177
	30	.213
	35	.248
	40	.319
10	30	.266
	35	.310
	40	.398

1.2.2 Hopper Design

The bin hoppers were designed supported on a ring bin and this one on a number of columns depending on the bin diameter. The whole hopper system was designed independently from the bin walls. See Fig. A1.4 The hopper angle was 45 degrees based on recommendations from Bomands, (1985), to allow a smooth gravity flow and avoid clogging the hopper.

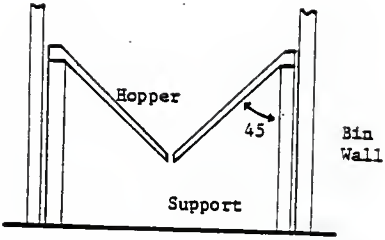

Fig. A1.4 Design of Hopper Support.

To design the hopper shell, Equations 1 and 2 from Fintel (1985) were used. Through these formulas, the meridional and tangential forces are calculated.

$$\text{Fmu} = 1.7\ \frac{\text{q des D}}{\text{4 sin}} + \frac{\text{WL}}{\text{D sin}} + 1.4\ \frac{\text{Wg}}{\text{D sin}} \qquad \text{Eq. 1}$$

$$\text{Ftu} = 1.7\ \frac{\text{q des D}}{\text{2 sin}} \qquad \text{Eq. 2}$$

Where:

Fmu = meridional force

qdes = design static vertical pressure due to stored material

D = bin diameter

= angle of inclination of hopper wall

W_l = total portion of weight due to material stored in the hopper

W_g = total portion of weight due to hopper weight.

These forces were obtained for different bin diameters and heights, at different hopper levels. The results showed that the variation of Fm and Ftu when varying the bin height was not significant. Thereafter, only one hopper and support was designed for each bin diameter. Table A1.5 shows the results from this analysis.

Bin Diameter (m)	Concrete m^3/bin	Steel m^3/bin
5	4.7	.072
7	9.3	.213
8	14.5	.473
9	24.3	.748
10	37.3	1.127

Table A1.5 Concrete and Reinforcement Steel For Bin Hoppers

To design the ring bin and supporting columns, the shearing stress, compressive force, torque, vertical and horizontal bending moments were computed for every bin diameter. The method to obtain these forces was taken from Safarian Sargis (1985) and Fintel (1985). The method is not detailed here because of the extensive explanation.

Tables A1.6, A1.7 and A1.8 show a summary of the results from this analysis.

Table A1.6 Concrete and Reinforcement Steel For the Hopper Supporting Columns.

Bin Diameter (m)	Concrete m^3/bin	Steel m^3/bin
5	3.2	0.027
7	6.8	0.069
8	13.1	0.173
9	16.3	0.215
10	31.0	0.399

Table A1.7 Concrete and Reinforced Steel for Ring Bin

Bin Diameter (m)	Concrete m^3/bin	Steel m^3/bin
5	3.82	0.067
7	9.93	0.225
8	14.76	0.276
9	20.5	0.507
10	27.8	0.401

Table A1.8 Summary of Concrete and Steel Required for Hopper, Ring-Bin and Column Supports.

Bin Diameter	Concrete m^3/bin	Steel m^3/bin
5	11.72	0.166
7	26.03	0.507
8	42.36	0.922
9	61.10	1.470
10	96.10	1.927

1.2.3 Roof Design

The analysis was simplified designing one bin roof per each bin diameter and intercell. The quantities of concrete and steel for one bin diameter and intercell were multiplied by the number of silos and intercells in each battery. The analysis was done assuming the roof borders attached to the bin walls. Then, the tangential and radial bending moments were computed according to Safarian (1985). A line load of 750 kg/m^2 was considered in the design. Table A1.9 shows the results from this analysis.

Table A1.9. Concrete and Steel Required For Bin Roof.

	Bin		Intercell	
Diameter (m)	Concrete Vol m^3	Steel Vol m^3	Concrete Vol m^3	Steel Vol m^3
5	2.36	0.031	0.136	0.004
7	5.77	0.063	0.235	0.021
8	8.55	0.119	0.303	0.031
9	10.82	0.170	0.339	0.039
10	15.7	0.229	0.442	0.061

1.2.4 Foundation Design

Extra care has to be taken when designing the silo foundations. Several silo batteries have failed because of a misconception of the foundation's behavior (Ravenet, 1977).

To design the foundations, the following recommendations from Safarian (1985), are suggested.

1. Emphasis is given to the fact that silo-group foundation loads differ from those for an usual building. The main differences are:

   a. Full live load is certainty.

   b. The ratio of line load to dead load is bigger than in other types of structures.

c. The load changes quickly when bins vary from full to empty or vice-versa, in a matter of hours.

d. Extreme variations occur in the load position. The content may be removed from certain silos and shifted to others, causing a large shift in the location of the total load.

2. Soil test should be of considerable depth. Some authorities suggest a minimum of 20 m to prevent unforeseen settlements.

3. When calculating pressures on the soil, the following loading conditions should be considered.

   a. All silos full

   b. Half of the silos full and half empty. Consider the condition in two arrangements in order to consider maximum load eccentricities.

4. Soil bearing pressures under the raft should not exceed allowable soil bearing capacity

$$\begin{matrix}\max\\\min\end{matrix} = \frac{P}{A} \pm \frac{M_1}{S_1} \pm \frac{M_2}{S_2} \leq \text{allowable} \qquad \text{Eq. 3}$$

P = Total gravity loading on the foundation due to most unfavorable loading combination.

A = Foundation area

$M_{1,2}$ = Bending moments in main directions 1 and 2

$S_{1,2}$ = Section Module in direction 1 and 2.

5. Safarian, (1985) recommends increasing the computed bending moments and shearing stresses, multiplying by a factor Cr (or

more) depending on the soil type.

Type of Soil	Factor Cr
1. Sound bedrock	1
2. Natural Soils	
a. Uniform Subsoil	1.05 - 1.15
b. Non Uniform Soils	1.3 - 1.75
3. Controlled Fill	1.10 - 1.25

6. Reinforce both the top and the bottom of the raft. The spacing of reinforcing at bars should not exceed 30 cm.

7. In both the top and the bottom of the raft, provide the same basic reinforcement in the direction of the major axis, based on some average value of flexure, then, add extra steel when needed.

8. The raft slab should preferably be thick enough to resist the shear forces without stirrups or bent-up bars.

9. Length of the cantilever extension of the raft slab beyond the outside wall should not exceed 1/4 of the silo diameter.

To compute the foundation materials required for different batteries, the following assumptions and procedures were followed:

a. The weight of the stored materials was computed based on the volume capacity for each battery. A density of $0.779 T/m^2$ which corresponds to wheat, the grain with the highest bulk density, was used. This weight corresponds to the live load for the foundation.

b. Having already designed the walls, hopper, supports and roof, the weight of this material was computed for each battery. This weight corresponds to the dead weight that has to be supported for the foundation.

c. To simplify the computation, a rough analysis and design was made to the arrangement foundations of 2 x 8 bins and 4 x 4 bins. The analysis was made to each combination of diameter and height in accordance with Table A1.1. From this analysis, the quantities of concrete and steel for the foundation of 2 bins wide and one bin long were found. Fig N E explains this simplification. To compute the concrete and steel required for other batteries, 2 x 4, 2 x 6 until 2 x 14, the number of pairs of bins was multiplied by the materials obtained for the 2 bins wide analysis. The same procedure was followed for the 4 bins wide batteries.

d. The ACI 313-77 specifies a seismic coefficient of 0.2 if a dynamic analysis is not done for the project under design and a minimum of 0.10 when a dynamic analysis is performed. For this study a seismic factor of 0.15 was used to compute the seismic force. A zone coefficient Z = 1 was also used.

e. The allowable soil capacity was 30 T/m^2 which is a regular soil.

f. The seismic coefficient, the dead load and 80% of the live load (ACI-313-77) was used to compute the overturning moment of the structure through the Equation 4.

$$M = .15(DL + .8LL) \times Hc \qquad \text{Eq. 4}$$

Where:

M = Overturning moment
DL = Dead load
LL = Live load
Hc = Centroid of the bin mass
Seismic coefficient = .15.

g. The area of the raft foundation was computed using Equation 3 considering the overturning moment and the gravity load without exceeding the permissible soil capacity.

h. To compute the concrete and steel required in the foundation area under the bins, the formulas from Safarian, 1985 for roof slabs were used. The tangential and radial moments were computed for the area under one bin and then multiplied by the number of bins in each battery.

In the cases when a cantilever extension of the raft slab was required beyond the outside wall, the cantilever bending moment and shearing stress were analyzed to compute the concrete and steel required for this area.

1.3 RESULTS

The summarizing results from this analysis are presented in Tables A1.10 to A1.15. In these tables, the quantities of concrete and reinforcement steel required for the bin body (walls, hopper, roof) and for the bin foundation are summarized. If very different soil conditions exist in a specific project, the reinforcement concrete for the foundations can be subtracted from the summarizing tables and then, specific estimations can be added to the bin body to obtain better cost estimations.

Using the data from tables A1.10 to A1.15 and Multiple Regression Analysis through the SAS Computer Program, the following equations were developed:

$$CV = 0.19\ CAP + 35.27\ H/D - 21.13\ NB + 423.37 \qquad \text{Eq. 5}$$

$$RS = 0.016\ CAP - 53.91\ H/D - 2.08\ NB + 227.26 \qquad \text{Eq. 6}$$

Where:

CV = Concrete volume required (m^3)

CAP = Storage Capacity (m^3)

H = Silo Height (m)

D = Silo Diameter (m)

NB = Number of Bins

RS = Reinforcement Steel Weight (T).

The R^2 value of these equations was 0.97 and 0.98. If these equations are multiplied by the concrete unit cost ($\$/m^3$) and reinforcement steel unit cost ($/T), the costs of concrete and reinforcement steel for the battery are obtained. These equations are a very simple way to obtain a good estimate of the cost of a concrete silo battery and can be used for feasibility studies.

Curves showing the influence of H/D ratio in the design and graphics of cost vs. storage capacity are shown in figures 3.11, 3.12 and 3.13.

Table A1.10. Concrete (m^3) and Reinforcement Steel (T) Required For Different Storage Capacitites. Bin Diameter = 5.0 m.

Layout Height	Bins Wide x Bins Long	2 x 8 4 x 4	2 x 12 4 x 6	2 x 16 4 x 8
15 m 2 bins wide	St.(m^3)	3622.0	5458.0	7293.0
	Con. for Bin (m^3)	808.6	1213.0	1617.4
	Reinf. Steel (T)	40.2	60.4	80.5
	Found. Conc. (m^3)	233.6	350.4	467.2
	Found. Reinf. Steel (T)	21.4	32.3	43.2
15 m 4 bins wide		3720.0	5653.0	7587.0
		808.9	1310.4	1618.2
		40.3	60.6	80.7
		222.8	334.2	445.6
		22.1	33.6	45.2
20 m 2 bins wide		5391.0	8125.0	10858.0
		1002.2	1503.4	2004.6
		50.40	75.6	100.8
		274.4	411.6	548.8
		26.2	39.5	52.8
20 m 4 bins wide		5543.0	8429.0	11314.0
		1002.5	1503.9	2005.4
		50.5	75.7	101.0
		244.8	367.2	489.6
		25.0	38.1	51.1
25 m 2 bins wide		7150.0	10773.0	14404.0
		1197.4	1796.2	2395.0
		60.7	91.0	121.4
		364.9	528.1	691.3
		29.1	43.9	58.6
25 m 4 bins wide		7357.0	11190.0	15022.0
		1197.7	1796.8	2395.8
		60.7	91.2	121.6
		345.7	485.3	624.9
		29.8	44.1	58.3

Table A1.11 Concrete (m^3) and Reinforcement Steel (T) Required for Different Storage Capacities. Bin Diameter = 7m.

Layout Height (m)	Bins Wide X Bins Long	2x3	2x5	2x8 4x4	2x12 4x6	2x16 4x8
25 2 bins wide	Values Explained in Table A1.10	4852.0 696.5 50.29 286.5 19.9	8207.0 1161.0 83.92 458.9 33.0	13240.0 1857.7 134.37 717.5 52.7	19950.0 2786.7 201.6 1062.3 78.9	26660.0 3715.6 268.90 1407.1 105.2
25 4 bins wide				13600.0 1858.2 134.70 6563.0 51.6	20671.0 2787.6 202.29 969.1 78.0	27741.0 3717.0 269.88 1281.9 104.5
30 2 bins wide		6110.0 797.9 59.63 399.3 24.6	10337.0 1330.0 99.49 609.7 39.6	16679.0 2128.1 159.28 925.3 62.1	25134.0 3192.3 239.0 1346.1 92.2	33589.0 4256.9 318.72 1766.9 122.2
30 4 bins wide				17142.0 2128.6 159.61 802.4 60.5	26061.0 3193.2 239.65 1131.4 89.2	34980.0 4257.8 319.70 1460.4 118.0
35 2 bins wide		7367.0 898.7 68.0 658.9 26.5	12467.0 1498.0 113.51 956.5 42.3	20117.0 2396.9 181.71 1402.9 65.9	30317.0 3595.5 272.6 1998.1 97.5	40517.0 4794.0 363.59 2593.3 129.0
35 4 bins wide				20683.0 2397.4 182.0 1255.7 63.9	31450.0 3596.4 273.3 1705.5 93.4	42216.0 4795.4 364.57 2155.3 122.9

Table A1.12. Concrete (m^3) and Reinforcement Steel (Tons) Required for Different Storage Capacities. Bin Diameter = 8.0 m

Layout Height (m)	Bins Wide X Bins Long	2x3	2x5	2x8 4x4	2x12 4x6	2x16 4x8
25 bins wide	Values Explained in Table A1.10	6160.0	10415.0	16798.0	25308.0	33819.0
		882.0	1470.3	2352.6	3529.1	4705.5
		78.0	130.2	208.4	312.7	417.1
		399.5	645.9	1015.5	1508.3	2001.1
		25.6	42.5	67.8	101.7	135.5
25 4 bins wide				17244.0	26200.0	35157.0
				2353.2	3530.3	4707.3
				208.9	313.7	418.5
				947.0	1403.8	1860.6
				69.5	105.3	141.0
30 2 bins wide		7801.0	13194.0	21285.0	32072.0	42859.0
		997.2	1662.3	2659.8	3989.9	5319.9
		89.9	150.0	240.1	360.3	500.3
		439.7	697.9	1085.2	1601.6	2118.0
		26.9	44.3	70.4	105.2	140.0
30 4 bins wide				21864.0	33230.0	44597.0
				2660.4	3991.1	5321.7
				240.6	261.3	481.9
				1185.6	1696.8	2208.0
				74.3	111.3	148.3
35 2 bins wide		9442.0	15973.0	25771.0	38835.0	51898.0
		1112.4	1854.3	2967.0	4450.7	5934.3
		103.6	172.8	276.7	415.2	553.6
		722.1	1093.7	1651.1	2394.3	3137.5
		31.8	52.0	82.3	122.7	163.0
35 4 bins wide				26483.0	40259.0	54035.0
				2967.6	4451.9	5936.1
				277.2	416.1	555.1
				1635.6	2235.0	2834.4
				85.2	124.9	164.6

Table A1.12 (cont).

Layout Height (m)	Bins Wide X Bins Long	2 x 3	2 x 5	2 x 8 4 x 4	2 x 12 4 x 6
40 2 bins wide	Values Explained in Table A1.10	11101.0	18790.0	30323.0	45701.0
		1542.6	2571.3	4114.2	6171.5
		117.6	196.2	314.0	471.1
		1220.9	1726.7	2485.4	3497.0
		38.9	61.5	95.3	140.5
40 4 bins wide				31187.0	47428.0
				4114.8	6172.7
				314.5	472.1
				2547.9	3343.1
				101.8	145.7

Table A1.13 Concrete (m^3) and Reinforcement Steel (Tons) Required
D = 9 m.

Layout Height (m)	Bins Wide x Bins Long	2 x 3	2 x 5	2 x 8 4 x 4	2 x 12 4 x 6
30m 2 bins wide	Values Explained in Table A1.10	9649.0	16315.0	26315.0	39647.0
		1208.6	2014.6	3223.5	4835.4
		128.8	214.9	344.1	516.3
		724.8	1127.8	1732.3	2538.3
		35.8	59.3	94.6	141.7
30 m 4 bins wide				27017.0	41051.0
				3224.2	4836.8
				344.7	517.5
				1581.5	2282.7
				95.6	143.6
35 m 2 bins wide		11724.0	19830.0	31989.0	48201.0
		1337.6	2229.6	3567.5	5351.4
		144.6	241.3	386.2	579.5
		1190.5	1742.5	2570.5	3674.5
		44.0	70.8	111.0	164.6
35 m 4 bins wide				32858.0	49940.0
				3568.2	5352.8
				386.8	580.7
				2181.2	3015.6
				107.5	158.5
40 m 2 bins wide		13819.0	23384.0	37730.0	56860.0
		1819.4	3032.6	4852.3	7278.6
		165.5	276.0	441.9	662.9
		1689.2	2382.0	3421.2	4806.8
		55.7	87.3	134.6	197.6
40 m 4 bins wide				38786.0	58971.0
				4853.0	7280.0
				442.5	664.2
				3293.0	4349.0
				127.5	183.6

Table A1.14. Concrete (m^3) and Reinforcement Steel (T) Required
D = 10.0 m

Layout Height (m)	Bins Wide x Bins Long	2 x 3	2 x 5	2 x 8 4 x 4	2 x 12 4 x 6
30 m 2 bins wide	Values Explained in Table A1.10	9649.0 1208.6 128.8 724.8 35.8	16315.0 2014.6 214.9 1127.8 59.3	26315.0 3223.5 344.1 1732.3 94.6	39647.0 4835.4 516.3 2538.3 141.7
30 m 4 bins wide				27017.0 3224.2 344.7 1581.5 95.6	41051.0 4836.8 517.5 2282.7 143.6
35 m 2 bins wide		11724.0 1337.6 144.6 1190.5 44.0	19830.0 2229.6 241.3 1742.5 70.8	31989.0 3567.5 386.2 2570.5 111.0	48201.0 5351.4 579.5 3674.5 164.6
35 m 4 bins wide				32858.0 3568.2 386.8 2181.2 107.5	49940.0 5352.8 580.7 3015.6 158.5
40 m 2 bins wide		13819.0 1819.4 165.5 1689.2 55.7	23384.0 3032.6 276.0 2382.0 87.3	37730.0 4852.3 441.9 3421.2 134.6	56860.0 7278.6 662.9 4806.8 197.6
40 m 4 bins wide				8786.0 4853.0 442.5 3293.0 127.5	58971.0 7280.0 664.2 4349.0 183.6

APPENDIX II

COST AND CLASSIFICATION OF GRAIN CLEANERS

Table A2.1. Grain Cleaners. Type: Air Screen Separator (ASS)

Brand Name	Description	Capacity T/H	Cost $	Power KW	No. of Aspirators
Clipper Form Size Cleaner	ASS	1	1846	0.5	Single
Ball Tray Screen Cleaner	ASS	3.1 to 7.5	4134	2.25	Single
Ball Tray Screen Cleaner	ASS	3.5 to 10	4770	3.75	Single
Double Cap Cleaner	ASS	17.5 to 22.5	24133	7.5	Double
Double Cap Cleaner	ASS	25 to 30	24227	7.5	Double
High Cap Cleaner	ASS	62.5 to 75	26449	7.5	Double
High Cap Cleaner	ASS	62.5 to 75	30251	7.5	Double
Scalper	ASS	20	15107	2.25	Single
Scalper	ASS	40 to 75	17963	2.25	Single

Description: Separation by aspiration and reciprocating sieves, for a precleaning or primary and main cleaning operation. Source: Chung (1986).

Table A2.2. Grain Cleaners. Type: Rotatory Cylinder Cleaner - Grade (RCG)

Brand Name	Description	Capacity T/H	Cost $	Power KW	No. of Aspirators
Roto Klean Scalper	RCG	17.5	4196	.75	--
Roto Klean Scalper	RCG	50	4867	.75	--
High Capacity Grain Cleaner	RCG	40	1375	.37	--
High Capacity Grain Cleaner	RCG	55	1850	.75	--
High Capacity Grain Cleaner	RCG	75	5150	2.25	--

Source: Chung et al. (1986)

Description: Separation and sizing according to width and thickness by a set of wire mesh cylinders with or without the use of air aspiration.

Table A2.3. Grain Cleaner. Type: Air Separator (AIS)

Brand Name	Description	Capacity T/H	Cost $	Power KW	No. of Aspirators
Portable Aspirator	AIS	37.5	12550	5.6	--
Portable Aspirator	AIS	60.0	16635	15	--

Source: Chung et al. (1986).

Description: Separator by air aspiration only.

Table A2.4. Grain Cleaner. Type: Gravity Screen Separator (GSS)

Brand Name	Description	Capacity T/H	Cost $	Power KW	No. of Aspirators
Gravity Grain Cleaner	GSS	25 25	1286 1278	-- --	-- --
Gravity Grain Cleaner	GSS	75 75	2390 3456	-- --	-- --
Gravity Grain Cleaner	GSS	175 175	5866 7953	-- --	-- --
Newton Gravity Grain Cleaner	GSS	200	14000	5.6	--
Newton Gravity Grain Cleaner	GSS	200	9000	--	--
Newton Gravity Grain Cleaner	GSS	100	10000	3.75	--
Newton Gravity Grain Cleaner	GSS	100	6300	--	--
Newton Gravity Grain Cleaner	GSS	300	19800	11.25	--
Newton Gravity Grain Cleaner	GSS	600	34500	22.5	--
Newton Gravity	GSS	900	49000	37.5	--

Source: Chung et al. (1986).

Description: Separation utilizing a static square body screen set through which grain mass flows by gravity.

ACKNOWLEDGMENTS

I wish to express my sincere gratitude to Dr. Do Sup Chung for his guidance of this thesis and in a special way for his collaboration in improving Costa Rican Technical development.

My appreciation is also extended to Dr. Ekamual Haque and Dr. Ching-Lai Hwang for their advice as committee members.

Special thanks are given to the Consejo Nacional de Production and to the Food and Feed Grain Institute for their financial support.

Mr. Rolando and Mrs. Sandy Flores are also thanked for their encouragement in realizing graduate studies and for their support in all our family life during my studies.

To my parents and parents-in-law, my sincere appreciation for encouragement and support in all our goals.

My deepest gratitude to my wife Lucia and my sons Rodrigo and Adrian, who shared with me and provided support and confidence in every step of my graduate studies.

Finally, my appreciation to Ms. Christine Keating for typing this project.

DESIGN OF GRAIN HANDLING AND STORAGE FACILITIES FOR TROPICAL COUNTRIES

by

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AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1987

The general objectives of this study are first to examine the advantages and disadvantages of using concrete or steel bins for storing grain under tropical conditions; second, to study the parameters involved in the design of commercial grain storage facilities capable of handling two crops, such as corn and rice; third, to conduct cost analysis for the processing equipment and storage structures used in commercial facilities; and fourth, to apply systems analysis for optimum selection of storage structures and optimum design of commercial grain handling and storage facilities.

A detailed literature search was conducted regarding the use of concrete and steel bins. Parameters such as cost of the alternative, grain preservation, longevity and the structure, construction aspects, associated benefits and operation flexibility need to be considered for selecting the proper storage system.

A detailed explanation of the grain flow, required flow flexibility and design considerations for commercial grain handling and storage facilities was provided through a literature review. Planning guides and recommendations for selecting the best location, organizing the system, determining storage and truck receiving capacities and drying rates were outlined. Grain parameters most frequently used for designing and analyzing grain storage, drying and handling facilities were summarized. Mathematical cost models based on cost analysis obtained through multiple regression analysis and summarized in table form. Practical guides for choosing the size of concrete and steel bins and for obtaining the size of processing equipment were derived from the cost analysis.

A multiple attribute decision making method, TOPSIS, was applied to decide whether to use concrete or steel bins. Sensitivity analysis was conducted to show the solution when varying the weight factor and the cost difference between alternatives. Precise answers on the preferred alternative were obtained considering not only the cost, but also the other parameters cited in the literature as the most important to consider. The Unconstraint Minimization Technique (SUMT) was used to obtain the optimum relation of bin diameter, height and number of bins when designing different drying systems for commercial facilities.

The methodology used in the cost study and the cost structure obtained for grain processing, handling equipment and storage structures are useful for designing grain storage facilities.

Multiple attribute decision making methods employed are suitable to select a proper alternative on grain storage systems.