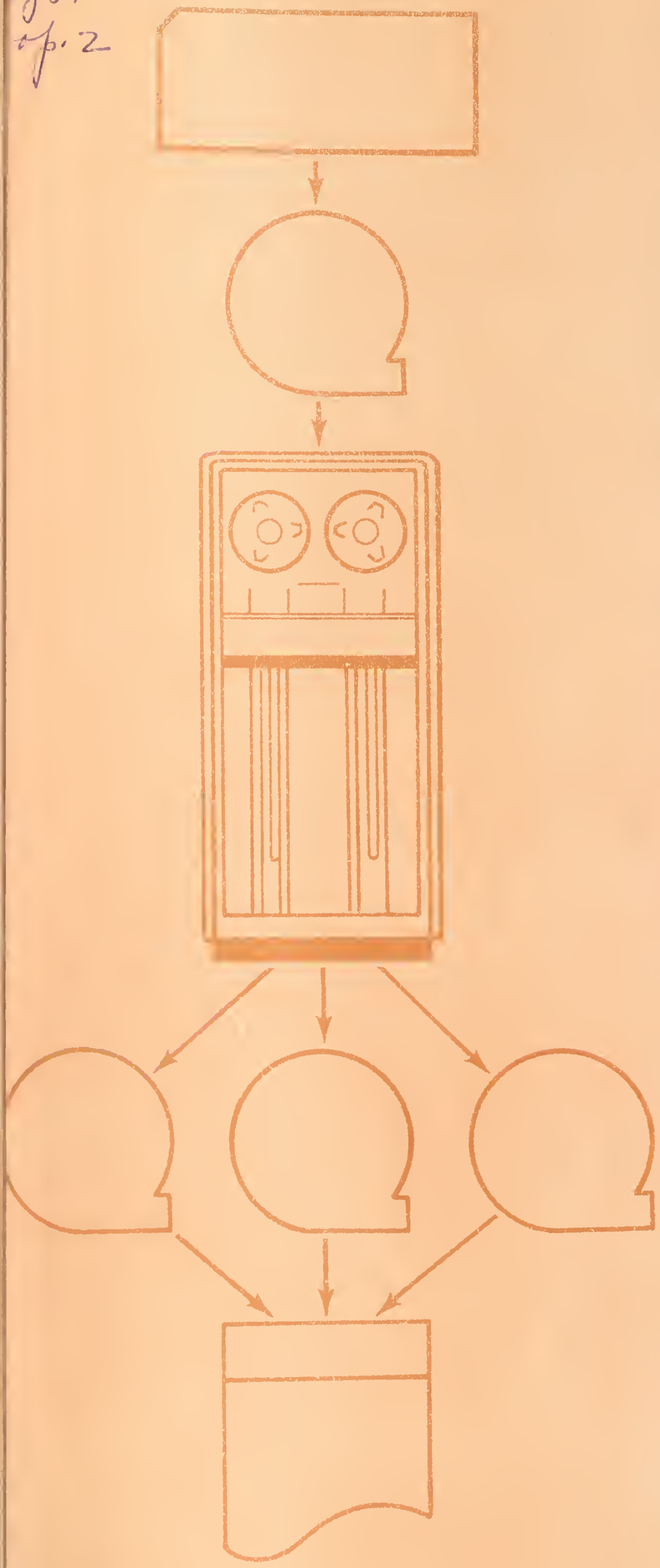

Marketing Research Report No. 671

SELECTING THE BEST CAPACITY OF TRUCK RECEIVING FACILITIES FOR COUNTRY GRAIN ELEVATORS

U.S. DEPARTMENT OF AGRICULTURE
Agricultural Research Service
Transportation and Facilities
Research Division

PREFACE

This is the second of two related reports based on research to improve the design of commercial grain storages. The first was Marketing Research Report No. 387 (June 1960), "A Small Country Elevator for Merchandising Grain - Designs and Recommendations." The research is part of a broad program to aid in holding down costs of marketing agricultural products.

An operations research approach, rather than a conventional engineering approach, was used in this study. For example, truck waiting times were determined through use of an electronic computer and statistical analysis. The report is intended primarily for the grain storage owner or operator and for engineers designing grain elevators.

The work was under the general supervision of Leo E. Holman, agricultural engineer, Transportation and Facilities Research Division, Agricultural Marketing Service, U.S. Department of Agriculture.

Many storage operators made their facilities available for this study. Also grain elevator designers, custom combine operators, truckers, and others provided useful information. The Kansas State Highway Commission provided the traffic recorders.

Effective July 1, 1964, the responsibility for research on increasing the efficiency of the physical handling and distribution of agricultural products was transferred from the Agricultural Marketing Service to the Agricultural Research Service.

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Selecting the Best Capacity of Truck Receiving Facilities for Country Grain Elevators

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HIGHLIGHTS

The grain elevator manager can save money if he plans his methods and facilities for receiving truckloads of grain so that he minimizes his total receiving costs--including the cost of having trucks wait too long to be unloaded, as well as his ownership and operating costs. Excessive truck waiting costs the elevator manager money--either in loss of customer good will or as a direct cost when the elevator is farmer owned. Under certain critical situations, waiting in line may cost as much as $25 an hour per truck.

To determine how long trucks wait for service it was necessary to study the arrival pattern of trucks at the elevator and the service pattern--the time taken to weigh truckloads of grain and unload trucks. Most of the information for this study was obtained from elevators in the Hard Red Winter Wheat area of the Central Great Plains where harvesting is fast and truck waiting is a problem.

It was found that in this area about 20 percent of the total grain received at the elevator arrived in only 1 day of the average 10-day harvest season and that although the elevator is open about 16 hours a day, more than 10 percent of the day's receipts arrived in 1 hour, usually late in the afternoon. During the hour, trucks arrive in a random manner. But 20 percent or more of the hourly receipts may arrive in a 5-minute period.

The time required to weigh and unload trucks was studied for crews of one to four men at the scales and of one to three men at the dump pits. Because different types and sizes of trucks are used, service times will vary considerably; at one elevator always using the same crew, the time to dump a truck ranged from 1 to 6 minutes. Several statistical distribution curves are shown for both arrival and service patterns.

From the distribution curves truck movement was simulated and waiting times were determined (using the Monte Carlo approach and an electronic computer) for three types of receiving units--small, medium, and large capacity (see figs. 18, 19, and 20). Results of these computations are given in several charts which show, for example, average and maximum truck waiting for different daily arrival rates. It was noted that waiting times increased rapidly when the daily arrival rate of trucks went above 50 or 60 percent of the daily potential service rate. (The daily potential service rate is the number of trucks the elevator could handle if they arrived at a steady rate during a 16-hour day). When arrival rates are as high as 80 percent of the daily potential service capacities, trucks may wait as long as 1 hour and 20 minutes.

Waiting times were converted into waiting costs; these were added to ownership and operating costs to find the most economical range of operation for the three types of receiving units studied. For example, it was found that the small receiving unit with one man at the pit and one man at the scale is economical only if fewer than 600 trucks are received per harvest season; the medium-sized receiving unit with a 2-man crew at the scale and a 2-man crew at the pit is most economical in the range of 600 to 1,450 trucks per harvest season; and the large receiving unit with four men at the scale and two men at each of three dump pits is economical only if more than 1,450 trucks are received per harvest.

Several simplified approximate methods for determining waiting times are described in this study. Also, some methods for improving the truck receiving and grain harvesting operations are discussed, such as:

1. Evening out the arrival pattern by paying a premium for truckloads of dry grain arriving before noon.

2. Providing plenty of room between scales and dump pit where trucks can wait.

3. Providing one-way traffic across the scale with the driver always on the side facing the office and scale.

4. Using portable auxiliary unloading equipment such as pneumatic conveyors.

BACKGROUND OF STUDY AND THE RESEARCH PROBLEM

Receiving or Unloading Operation--Size and Scope

One of the main functions of the country grain elevator is to receive grain from the farm at harvesttime. Trucks loaded with grain come from the fields to the elevator, the trucks are weighed, the grain is sampled and then dumped from the truck, and the empty trucks are weighed and returned to the fields for more grain. Considered on a national basis--and even on a local basis--the receiving or unloading of grain trucks is a big and expensive operation.

In the United States in 1962, there were about 20,000 grain elevators, including terminal elevators. Estimating that each elevator had $50,000 invested in truck-unloading facilities, such as truck scales, dump pits, truck hoists, and bucket elevators, the total national investment amounts to $1 billion. If 10 percent of the billion dollars is assumed for depreciation, interest, taxes, and insurance, these annual ownership costs are $100 million. And if each of the elevators spent $2,500 per year for the necessary labor and power to unload the trucks, operating costs could easily amount to $50 million annually.

Another cost--one that is often overlooked--is the cost for truck waiting time at the elevator. When trucks arrive faster than the elevator can weigh and unload them, they often have to wait in long lines. The 20,000 elevators normally receive something like 2 billion bushels of grain a year or about 10 million truckloads per year. If we assume that each truck has to wait in line 15 minutes to get unloaded, 2.5 million hours are wasted.[1] Estimating this time at $8 per hour, we have a total annual waiting time cost of $20 million (more discussion on what waiting time costs and who pays the cost is given on page 8).

Summarizing, we have estimated national annual cost for receiving or unloading trucks at grain elevators to be:

	Million dollars
Annual ownership cost.....	100
Annual operating cost......	50
Annual waiting cost.........	20
Total annual cost........	170

Receiving Operation--A Part of the Grain Harvesting System

The unloading operation is part of the overall harvesting system as shown schematically in figure 1. The overall system is made up of several groups or members, each with different objectives.

The one who makes the decision as to type and capacity of truck unloading facilities to be built is the grain storage owner and operator, who usually bases his decision upon the recommendation of the design engineer and others. The storage owner's objectives normally are to provide maximum service for his customers, to maintain or increase his share of the grain market, and to obtain maximum profits.

The farmer's objectives are to have his trucks unloaded as rapidly as possible so as to speed up the harvesting operation. The custom operator has the same objective as the farmer--to get the grain harvested and hauled as rapidly as possible. The workers--elevator help and truck drivers--want good pay, good working conditions, and steady hours. The competitor's objectives are to draw farmers to his own elevator. The public wants the grain marketed as efficiently as possible to aid in holding down

[1] A specific truck in the harvesting system may bring several loads to the elevator in a day. But it is normally not necessary to distinguish between a specific truck and truckload. In this report "truck" and "truckload" used in connection with arrival patterns and rates mean a truck loaded with grain. An exception is in the appendix under Simulation program (page 50) where specific trucks in the harvesting system are referred to.

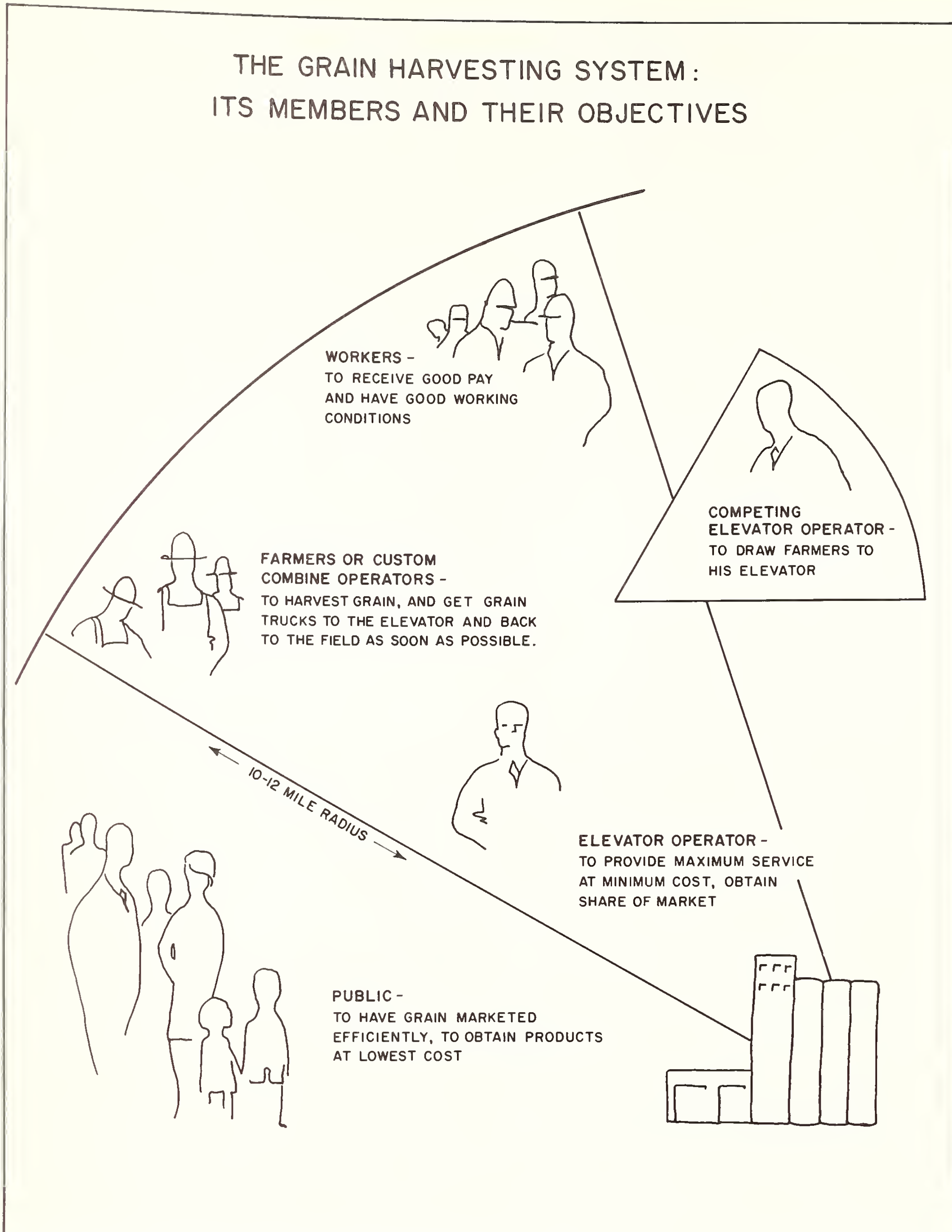
THE GRAIN HARVESTING SYSTEM:
ITS MEMBERS AND THEIR OBJECTIVES
WORKERS - TO RECEIVE GOOD PAY AND HAVE GOOD WORKING CONDITIONS
COMPETING ELEVATOR OPERATOR - TO DRAW FARMERS TO HIS ELEVATOR
FARMERS OR CUSTOM COMBINE OPERATORS - TO HARVEST GRAIN, AND GET GRAIN TRUCKS TO THE ELEVATOR AND BACK TO THE FIELD AS SOON AS POSSIBLE.
10-12 MILE RADIUS
ELEVATOR OPERATOR - TO PROVIDE MAXIMUM SERVICE AT MINIMUM COST, OBTAIN SHARE OF MARKET
PUBLIC - TO HAVE GRAIN MARKETED EFFICIENTLY, TO OBTAIN PRODUCTS AT LOWEST COST

Figure 1

the cost of grain products. Efficient, well-balanced truck receiving facilities can meet most of the objectives of these various members of the harvesting system.

This is the problem setting.

Formulation of the Problem

Problem Symptoms

Some grain elevators have truck receiving facilities that have too little capacity; for example, some storages have truck waiting lines over a mile long (fig. 2). When truck waiting lines are too long:

1. There is a possible threat to the market value of the grain crop; if trucks cannot be returned to the fields to move grain out as soon as it is combined, harvesting is delayed, the crop may deteriorate, or there may be a total crop loss due to wind or hailstorms. (Certain high moisture grains, particularly rice, will deteriorate in the truck if the truck has to wait too long to unload at the dryer.)

2. The elevator owner may lose his share of the grain market because of customers going to other storages to unload.

3. The cost of waiting or idle truck-drivers, trucks, harvest machinery, and field crews can be high.

On the other hand, some elevators have unloading equipment with unnecessarily large capacity. For example, in areas producing little grain, some elevators have two truck scales and two or more dumping areas. Much of this equipment is never used. When receiving facilities are too large, waiting lines may be short, but:

1. The investment in machinery and equipment is costly.

2. Labor, power, and other operating costs are high.

3. Idle unloading crews and idle equipment waiting for trucks are unproductive and costly.

Some elevators have high-capacity equipment and large crews and still have long waiting lines because of poor layout of equipment and poor coordination of unloading operations.

Storage owners and operators, design engineers, and others need a scientific basis for selecting unloading facilities that minimize total receiving cost including the cost of having trucks wait for service. The elevator operator wants to know what capacity his receiving system should have--how many trucks he should be prepared to handle per hour, per day and per harvest season. If the trucks were all the same size and type and arrived at a constant rate through the harvest season there would be little or no problem. But trucks are not alike, and they arrive irregularly. Even though the number of trucks arriving in an hour may be within the elevator's receiving capacity, a long waiting line could develop because: (1) Half the trucks may reach the elevator during one 15-minute period during the hour; (2) many trucks take longer than average to service. On the other hand, for limited periods, trucks have arrived at elevators at a higher rate than the average receiving capacity of the elevator but have not had to wait long.

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Figure 2.--Trucks waiting in line to unload wheat at the elevator.

The Problem and the Research Objectives

The symptoms just mentioned are all a part of the basic problem of efficiently moving the grain from the farm at harvesttime and delivering it to the consumer in the form, at the time, and to the place desired. The basic problem might be solved by lengthening the harvest season with the use of new varieties of grain or even by weather control; by using harvesting equipment which processes the grain into more usable form right in the fields; or by using much larger trucks which would bypass the country elevators and carry the grain directly to the terminal markets.

However, for the purpose of this study, we must restrict our objectives to the problem of the capacity of truck unloading facilities at country elevators.

The objectives of this research, therefore, are to provide grain storage operators and design engineers with a scientific basis for planning and designing the capacity of truck unloading systems for grain elevators that minimize operating, ownership, and waiting costs. The purpose is to help the elevator manager select the best capacity of receiving facilities for different ranges of truck receipts.

As it is impossible for this limited study to provide answers for every type of unloading situation, emphasis has been given to the wheat harvest. The short period in which wheat can be harvested efficiently by combines makes its harvest very critical. The scientific method for planning truck unloading facilities is illustrated by the study of three types of grain elevators in the Hard Winter Wheat area of the Central Great Plains. Emphasis has been given to truck waiting time and its cost. Little previous work on grain truck waiting time has been done.

Method of Study

The first step was to review available publications on grain handling, grain harvesting, waiting or queuing theory, and other related subjects. Much of this information is listed in the Bibliography, page 46. The project was discussed with researchers and others.

Data were collected on truck arrival rates, truck receiving rates, and the cost of idle or waiting trucks in northwest Kansas, southwest Nebraska, and northeast Colorado during the 1962 wheat harvest season. This area is a producer of Hard Red Winter wheat. Information was collected from six grain elevators as well as from truckers, farmers, and custom combine operators. Preliminary field studies of a similar nature were conducted in southwestern Kansas during the 1961 grain sorghum harvest. Other related field studies were previously made in grain-producing areas of Indiana, Illinois, Texas, and the Southeastern States. These previous field studies served as a background to this phase of the research project.

The data on truck arrival patterns and service patterns were used to determine truck waiting times. These waiting times were determined by simulating the movement of trucks through the elevator and through the complete harvesting cycle, using an electronic computer. Truck flow was simulated for three different types of unloading facilities. The receiving costs were computed for each of the three facilities. The three types were selected because: All are somewhat typical grain elevators and represent a practical choice to the elevator manager planning new facilities; each is considered to be a reasonably efficient unloading facility; and they represent a variety in handling capacities. Based on the field studies and a comparison of costs for the three types of unloading facilities, recommendations are given for determining the most economical receiving system for different ranges of truck receipts and for improving receiving methods.

Field studies were later conducted at 10 elevators in north-central Kansas during the 1963 wheat harvest to test out research findings.

Assumptions

The following paragraphs set forth the main assumptions and criteria used in this study. More details of the various assumptions are given in later parts of the report. These assumptions and criteria are mainly based on information obtained from the field studies.

General Assumptions

It is assumed that the elevators are typical country elevators receiving grain from the farm usually at harvesttime, storing the grain, and then moving the grain forward into marketing channels as it is needed. About 90 percent of the grain is received by truck and most of the grain is shipped by rail. The storage capacity of the elevators ranges from 100,000 to 1,000,000 bushels.

The receiving capacities of the elevators in the study range from 10 to 65 trucks per hour.

Many different sizes and types of grain trucks unload at the elevator. Where it is necessary to consider a typical or average type of truck, a 230-bushel capacity self-dumping grain truck with sliding endgate is assumed. Most of the trucks arriving at the elevator during harvest in the area surveyed were of this size and type.[2]

There are not enough grain trucks available so that they can be brought in and left at the elevator to be unloaded at the elevator's convenience; the farmer is eager to get his trucks back to the field.

The permanent crew used at the elevators throughout the year ranges from 1 to 4 workers. Additional labor is used at the peak harvest season, and the crew size then ranges from 2 to 10.

It is assumed that there are sufficient numbers of rail cars or storage bins to handle or store the received grain. In some areas or for some elevators it is the lack of rail cars or space to put the grain that causes delay and waiting lines rather than low capacity of truck receiving facilities.

Cost Estimates

The estimated construction costs given in this report are based on labor rates and material prices for 1962 in central Kansas and on information from estimating handbooks, technical publications, manufacturers, and grain elevator contractors.

Annual ownership costs include depreciation, interest, taxes, and insurance--or the fixed costs for owning truck unloading facilities. These costs are based on information from technical publications or from previous research studies.

Operating costs include labor for unloading trucks (assumed at $1.80 per hour) as well as power and maintenance costs for operating unloading facilities.

Waiting costs are the indirect cost to the elevator owner of idle harvesting machinery and crews or idle trucks and drivers waiting in line to unload. Further discussion on waiting costs is given in the following section.

Other direct and indirect costs such as advertising, accounting, and management have not been included in the cost comparisons as they are not materially affected by the design of the receiving facility.

COST OF WAITING TRUCKS-- A MEASURE OF PERFORMANCE

To measure the performance of certain types of unloading facilities it would be convenient if truck waiting times could be converted into dollars. Waiting costs then could easily be added to ownership and operating costs to find the total minimum cost for unloading trucks. This section seeks to show that truck waiting time is a cost to the elevator owner and to determine how waiting time can be converted into cost. The purpose, however, is not to standardize or recommend a certain cost figure for waiting time (say dollars per hour) but rather to stimulate the elevator manager's thinking and help him evaluate waiting time for his own conditions.

One justification for assuming that truck waiting time is a cost to elevator owners is that many of the elevators are cooperatives or farmer owned. So, at least theoretically, an unloading cost to the farmer is a cost to the elevator or vice versa. At least 10 or 20 percent of the grain elevators in this country are cooperatives. In the Central Great Plains, where waiting times are particularly critical, probably more than 50 percent of the country elevators are cooperatives.

A few privately owned elevators are also in the trucking and grain handling business. Waiting time for elevator-owned trucks would be a direct cost to the elevator. The remaining privately owned elevators must compete with the cooperatives or with privately owned elevators that truck grain.

Therefore, we must assume truck waiting time is a cost--either direct or indirect--to the grain elevator. We have assumed a truck waiting cost of $8 per hour per truck. Detailed discussion on waiting costs is given in the appendix.

[2] During the 1963 wheat harvest in north-central Kansas, the average truckload was only 160 bushels.

TRUCK ARRIVAL PATTERNS

Long-Term Pattern

It is important that the manager make the best decision possible on the long-range pattern of arrivals. The remainder of this study is based on this decision--how many bushels of grain the elevator will handle in a season.

The long-term pattern of truck arrivals--over the next 5 to 30 years--is largely affected by the amount of grain produced and harvested. Grain production in turn, is affected by technological changes in production and harvesting, weather conditions, government or trade programs, changes in consumer wants, and overall world conditions--peace, war, prosperity, and depression. Also the arrival pattern at a particular elevator may be affected by what competitors do.

Figure 3 shows the changes in wheat production in the United States from 1935 to 1961. The elevator operator, however, should not infer from this chart that there will necessarily be a general upward trend in his local area.

We have not considered long-range forecasting, or decision making under uncertainty or under competitive strategy to be within the scope of this study. For more information on these approaches, the storage operator might consult Miller and Starr (10, pp. 85 to 89).[3]

Although the elevator manager may not want to use some of these more involved approaches, he should gather and study as much information as he can before deciding on the long-range handling capacity of his elevator. The manager might obtain information or reports from: Local farmers, trade associations, State experiment stations, crop reporting services, Government officials, other elevator operators, and other sources.

Yearly Pattern

The yearly pattern of truck arrivals varies consideraly in the different grain-producing areas. A few of the major grain-producing areas are discussed below, with emphasis on the Hard Winter Wheat area of the Central Great Plains.

During the wheat harvest in the Hard Winter Wheat area of the Central Great Plains probably more grain is brought to the elevator in fewer days than in any other area. Ninety to 99 percent of the wheat harvested usually arrives at the elevator in a 2-week period, and 50 percent or more may arrive in only 3 or 4 days (fig. 4). The general yearly pattern of receipts shown in figure 4 is typical for country elevators in central Kansas, but there may be a great difference in the pattern from one elevator to another. Many elevators in southwest Kansas will receive as much grain sorghum as wheat, but not in as short a time.

Not only corn is produced in the Corn Belt of Indiana-Illinois, but also soybeans, wheat, oats, and other small grains. Much of the corn and soybeans will move to the elevator from farm storage in the spring rather than from the fields at harvesttime. The variety of grains produced and the extensive use of farm storages allow trucks to arrive at the commercial elevator at a relatively even rate with probably less than 10 percent of the yearly receipts arriving in any one week (fig. 5).

Most of the Southeastern States produce large quantities of corn, along with soybeans, oats, and other small grains. The yearly pattern of deliveries at country elevators might be somewhat similar to that shown for Illinois and Indiana in figure 5, but a larger percentage of the receipts would arrive at corn harvest and a smaller percentage at other times of the year.

When this study was made, elevators in many parts of the Southeast received a large percentage of the grain as ear corn; sometimes the shelling operation delayed truck unloading. Most of the elevators served small diversified farms and the arrival rate of trucks was relatively low.

Most of the elevators in the Texas grain sorghum area receive over 90 percent of their grain in a 2- to 4-week period in the summer during the harvest (fig. 6).

Seasonal Pattern--During Harvest

As wheat has a more critical harvest period than other grains, we will concentrate on arrivals during this period.

[3] Underscored numbers in parentheses refer to items in the Bibliography, page 46.

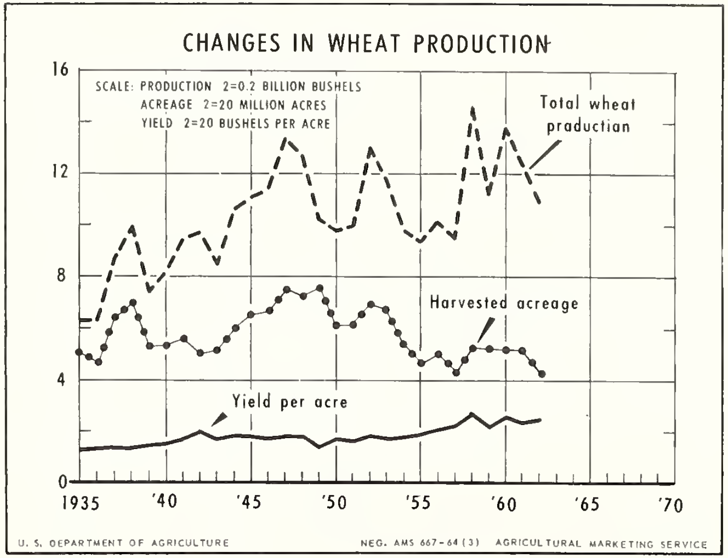

Figure 3

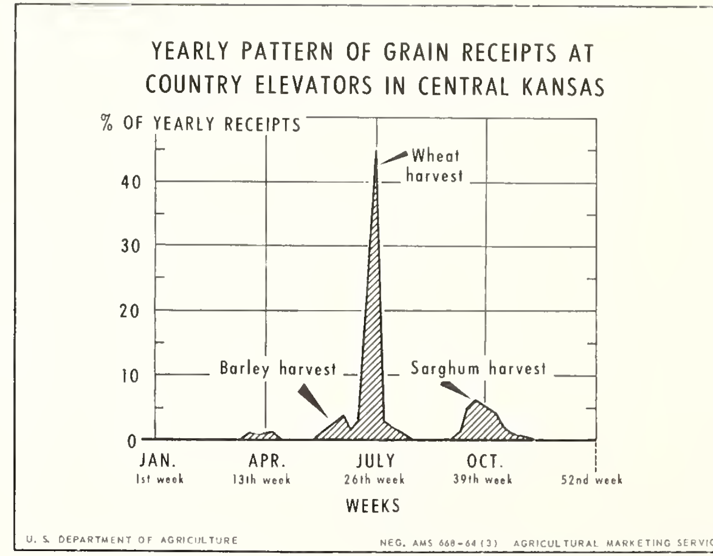

Figure 4

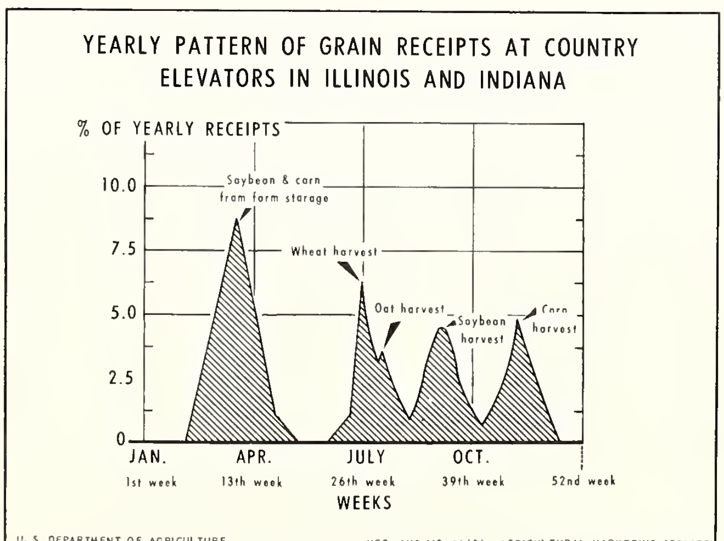

Figure 5

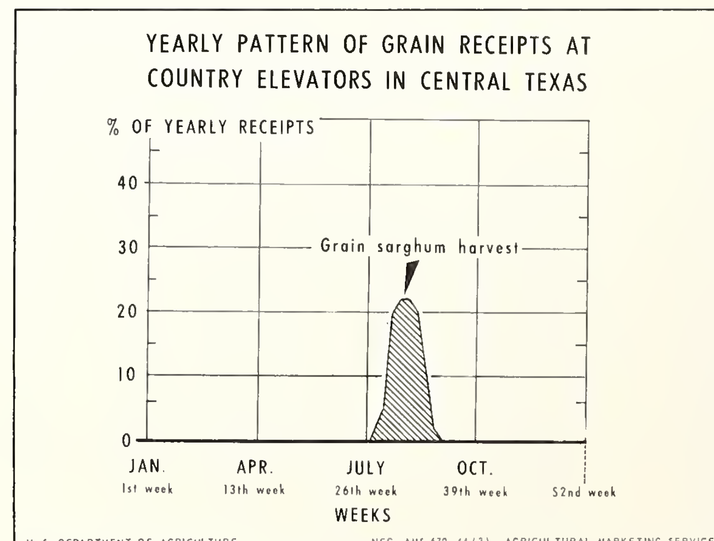

Figure 6

Figure 7 shows the daily arrival pattern of trucks during the 1962 wheat harvest; these data were obtained from three elevators--one in northwest Kansas, one in southwest Nebraska, and one in northeast Colorado. Most of the grain was harvested in 10 days; about 22 percent was harvested in 1 day. This day, when the maximum number of trucks arrived, is called the critical day.

Data obtained from an elevator in north-central Kansas during the 1963 wheat harvest indicated a less concentrated pattern, mainly because rain interrupted the harvest (fig. 8). Even so, more than 18 percent of the harvest arrived in one day.

A study of wheat receipts in Oklahoma in 1949-55 showed a variation in the yearly arrival pattern in the different areas of the State (1). Most of the areas in the Oklahoma study did not have a harvest concentrated in so few days as that shown in figure 7. During large crop years, however, the peak delivery period was shorter than usual. As the trend is toward shorter harvests, figure 7 may also be a rather realistic pattern for arrivals in Oklahoma today.

Daily Pattern

The pattern of truck arrivals during the day is about the same for grain harvests in all areas. There is a low arrival rate in the early morning, with the first trucks arriving at the elevator about 8 a.m. Sometimes these first trucks are ones that were loaded in the fields the night before. Then around 9 or 10 o'clock in the morning, as conditions permit and as more harvesting equipment moves into the fields, the arrival rate picks up. At about noon the rate drops off for a while as harvesting crews eat lunch. After lunch the rate increases and reaches a peak around the middle or later part of the afternoon when harvesting conditions are ideal. After this peak the rates start dropping. In the evening, combining stops because of darkness and increased moisture in the grain.

To determine the daily arrival patterns of trucks, highway traffic recorders were set up at several grain elevators (fig. 9). Figure 10 shows the daily pattern for truck arrivals as measured at one elevator in Kansas during the 1961 grain sorghum harvest. Figure 11 shows the daily arrival pattern for trucks as measured at four elevators in the Hard Winter Wheat area (two in northwest Kansas, one in southwest Nebraska, and one in northeast Colorado) during the 1962 wheat harvest. Note that more than 10 percent of the receipts arrived in 1 hour of the 17-hour day.[4] Figure 12 shows a similar arrival pattern. This information was taken at one elevator in north-central Kansas during the 1963 wheat harvest.

If arrival rates are much higher than the receiving capacity of the elevator, the normal daily pattern of arrivals may be different from those shown in the charts, as many of the trucks will be waiting in line at the elevator and cannot return to the fields for reloading.

Hourly or Short-Term Pattern

As grain trucks arrive at the elevator from several different fields and are more or less independent of each other, they normally arrive at random intervals throughout the hour. However, the frequency of arrivals in certain fixed intervals during the hour--say 5-minute periods--usually follows a certain pattern. In most theoretical waiting-line analyses, a Poisson distribution is assumed (12, p. 126) for arrival patterns.

Figure 13 shows both the actual and theoretical arrival distribution for an average arrival rate of 34 trucks per hour--number of trucks arriving in a 5-minute period plotted against the frequency or probability of such an arrival. For example, the theoretical curve shows that an arrival rate of two trucks per 5-minute period is probable 24 percent of the time. The actual data show that an arrival rate of two trucks per hour occurred 19 percent of the time. Note that it is possible for 7 trucks (or 20 percent of the total trucks arriving in an hour) to arrive during a 5-minute period. Other actual arrival rates were also plotted; some fit the theoretical Poisson curve better than figure 13 and some not as well. The tendency was for the lower arrival rates to fit the Poisson distribution and the higher rates to fit a uniform or other statistical distribution.

[4] Because such an insignificant amount arrives during the first or last hour, a 16-hour day is used in most computations in this report.

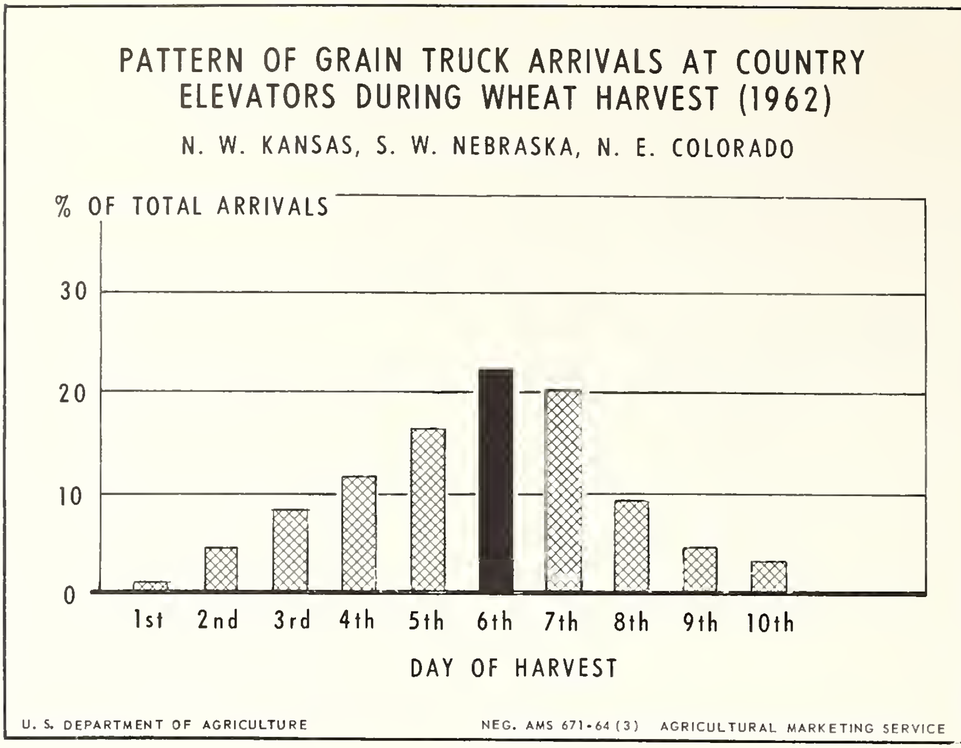

Figure 7

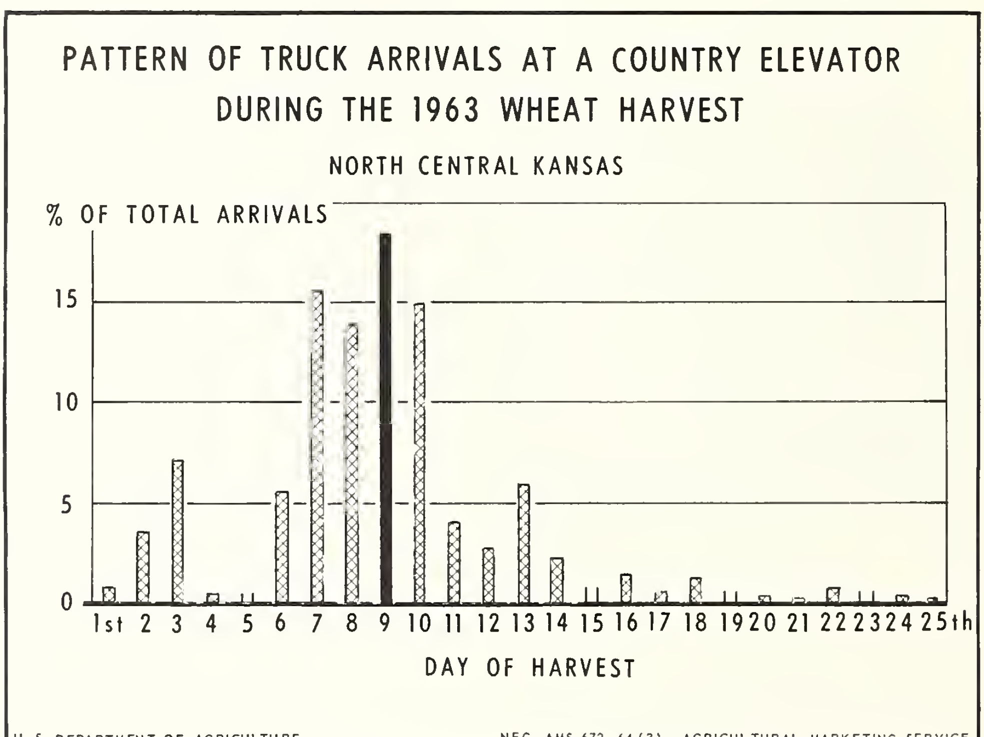

Figure 8

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Figure 9.--A highway traffic recorder set up at a grain elevator.

If the data used in figure 13 are transformed into a cumulative distribution of time between arrivals, they fit the theoretical curve better, as shown in figure 14. Note that for 34 trucks per hour, the time between arrivals can vary from less than 1 minute to as much as 11 minutes. It is this irregularity of arrivals, along with the irregularity of service times as discussed in the next section, that causes some trucks to have to wait.

SERVICE TIMES IN THE HARVESTING SYSTEM--THE TRUCK LOADING AND UNLOADING CYCLE

The time it takes to load grain trucks in the field and to unload them at the elevator varies considerably throughout the country and even varies in one grain-producing area or at one elevator. Many operations are performed during harvesting, such as loading trucks in the field, and weighing and unloading at the elevator. The time it takes to perform these operations is affected by: Size and type of harvesting equipment; capacity and type of the grain trucks; distance from the farm to the grain elevator; type of grain sampling and testing done at the elevator; crew sizes used at the elevator; and the capacity of handling equipment at the elevator.

Two studies by the Department give service times for receiving trucks at grain elevators (6, 13).

Truck Loading

At harvesttime the trucks are loaded in the grain fields. They are sometimes loaded from the combine spout as they drive alongside the combine while it is cutting the grain. Or, more commonly, the truck is loaded from the holding bin on the combine after the combine has harvested a binful (fig. 15).

The time it takes to load the trucks depends on the cutting capacity of the combine, the condition of the standing grain, the size of the holding bin on the combine, the capacity of the truck, and the number of trucks working with each combine.

In the wheat area studied, large combines were used which had a harvesting capacity of about 140 bushels per hour, and they were equipped with large bins holding 60 to 70 bushels. As custom operators usually hauled their combines from place to place on the grain truck, one truck and one combine would work together as a team in the field. The capacity of the trucks ranged from 65 to 400 bushels and averaged about 230 bushels per truck. The time to load trucks, estimated from the capacity of the trucks and the cutting capacity of the combine, was 69 minutes.[5]

Truck Traveling Time To The Elevator

Travel time of trucks, of course, depends on the distance from the farm to the elevator and on road and traffic conditions. Elevators surveyed in this study served an area within a radius of 10 or 12 miles (see fig. 1). It is assumed that it takes trucks from 6 to 18 minutes or an average of about 12 minutes to reach the elevator. These estimates are considered close enough for our purpose, for they are used mainly to determine

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5 230 bu. Average size of truck
-70 bu. Size of bin or combine

160 bu. To be loaded while truck is in field

$$\text{Average time to load truck} = \frac{\text{160 bu. to be loaded}}{\text{140 bu. per hr. (Cutting rate of combine)}}$$

= 1.14 hours = 69 minutes

Assumes one truck working with one combine. A distribution of the truck sizes measured at elevators was used to compute variations in this loading rate. These computations fit the exponential curve shown in figure 42 in the appendix where k = 1.

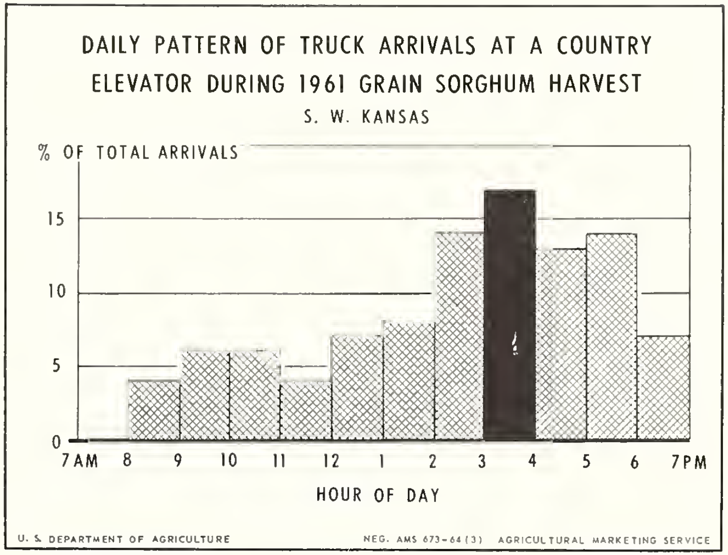

Figure 10

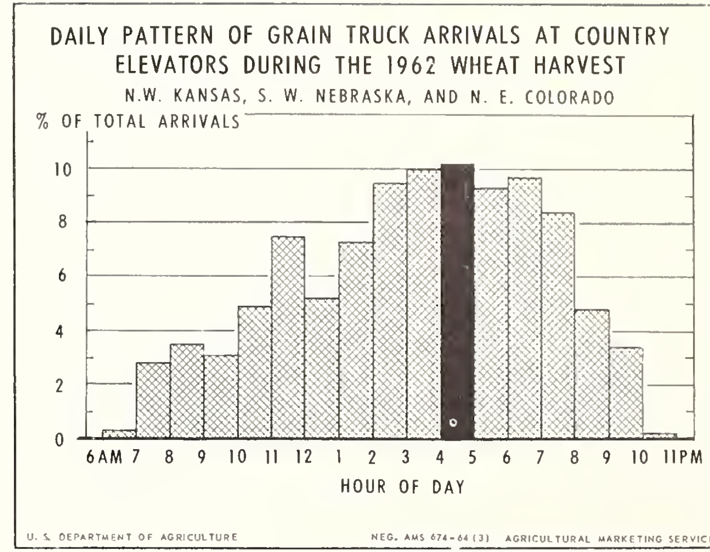

Figure 11

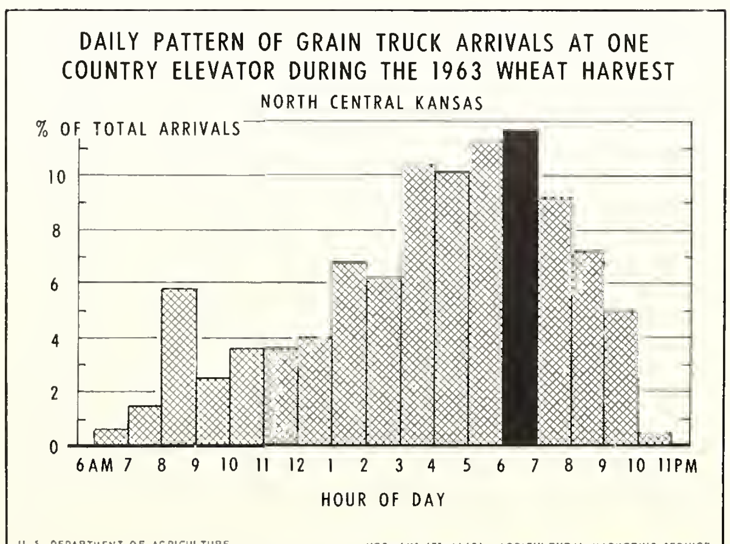

Figure 12

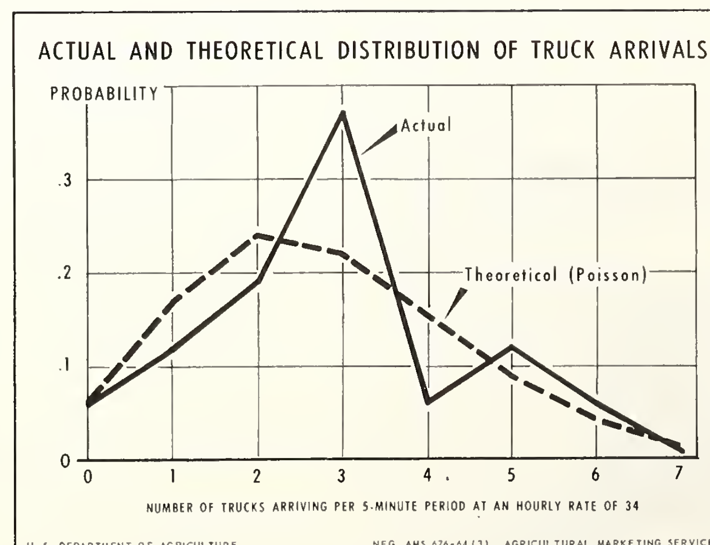

Figure 13

truck cycle time--time from field to elevator and back. (See Simulation Program in appendix.)

Receiving Operations At The Elevator

We timed the receiving operations with a stopwatch at 17 grain elevators in the Hard Winter Wheat area. These elevators were all considered to have a fairly efficient receiving operation (how to increase operation efficiency is described in a report by Graves and Kline (6)).

Weighing Loaded Trucks

Weighing begins when the truck moves to the scale and ends when the truck clears the scale, but it includes more than just the actual weighing. While the loaded truck is on the scale, a grain sample is usually taken, the testing of the sample usually is begun, and a receipt or ticket is filled out (fig. 16). When trucks are moving through the receiving line at a steady rate, the testing operation is closely connected with the weighing of the empty truck. Certain parts of grain testing may be going on during the weigh-loaded phase and other parts during the weigh-empty phase.

The amount of time loaded trucks spend on the scales depends upon the size of the weighing and testing crew; how the grain is sampled--using a probe or just getting a handful; the types of tests run on the grain sample; and the type of weight-indicating device for the scale (6).

The elevators studied during the 1962 wheat harvest season used 1-, 2-, or 4-man crews at the scale. Most of the elevators had dial scales with printing mechanisms. Samples were usually taken from the top of the grain pile with a can similar to a coffee can. In the early morning or for a few other special cases, samples were sometimes taken with a grain probe. A test weight measurement was made on most truckloads, and a small sample was put aside for a later sedimentation test. On a few trucks selected at random or in certain special cases a moisture test was run.

In the elevators studied during the 1963 harvest in north-central Kansas, most operators made moisture tests, but few made test weight measurements. These operators also segregated more grain samples for each farmer for sedimentation tests than was observed in 1962. This segregation of samples usually required an extra man at the scale.

In the study made during the 1961 grain sorghum harvest a 2-man scale crew was used, grain was sampled with a probe, and both a test weight and a moisture test were run. The observed weighing times for grain sorghum trucks at one elevator are listed below:[6]

Operation	Mean observed time
	Minutes
Weigh loaded truck, 2-man crew	2.3
Weigh empty truck, 2-man crew	.9
Total weighing time .	3.2

Dumping or Unloading Trucks

After the loaded truck is weighed at the scale it is driven to the dump pit to be unloaded. The operation begins when the truck enters the unloading drive and ends when the truck leaves the unloading drive.

The time it takes for this operation depends upon the type of truck (whether the truck is self-dumping or has to be raised by a cradle hoist), the type of endgate on the truck (5, 6), and the size of the unloading crew (fig. 17).

Unloading at the dump pit at elevators studied was done by 1-, 2-, or 3-man

[6] The observed times in this study were not leveled or rated (adjusted to an average or normal pace) as is done in the industrial engineering approach. In all cases, trucks, not people, were being timed, but the operations usually involved two or more persons--some working fast and others working slowly. Often workers did not know the trucks were being timed.

Almost all of the observed times were recorded--even those that might be considered abnormal or avoidable. However, these so-called avoidable delays seem a part of a realistic unloading operation--when considering truck waiting--and these observed times fit fairly well in the theoretical curves. (See fig. 42 in the appendix.)

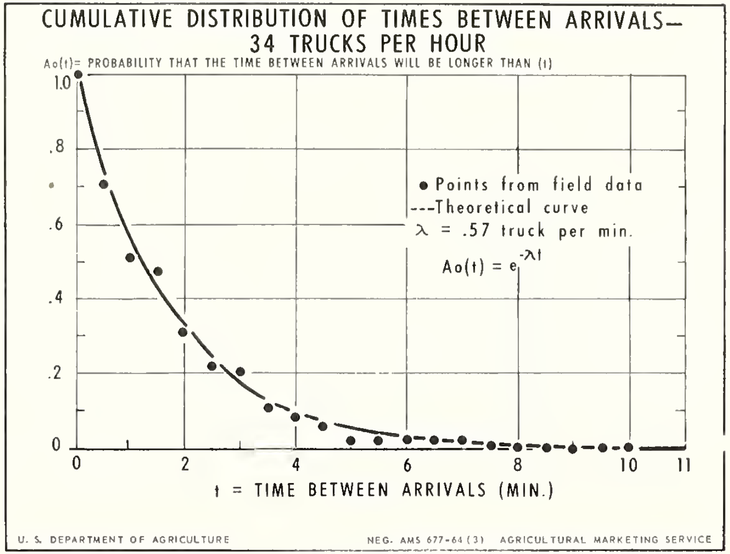

Figure 14

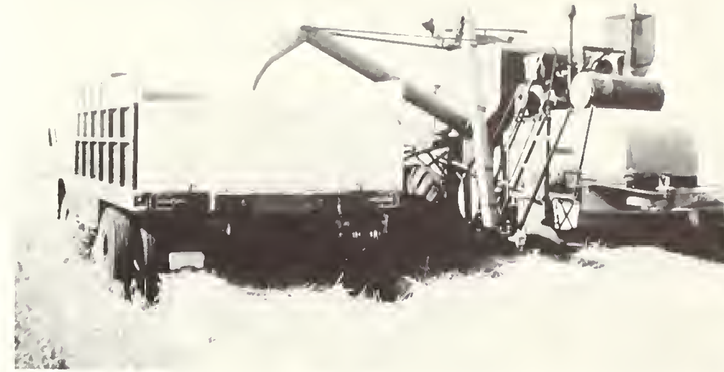

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Figure 15.--Loading grain trucks in the field.

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Figure 16.--A loaded grain truck on the scale.

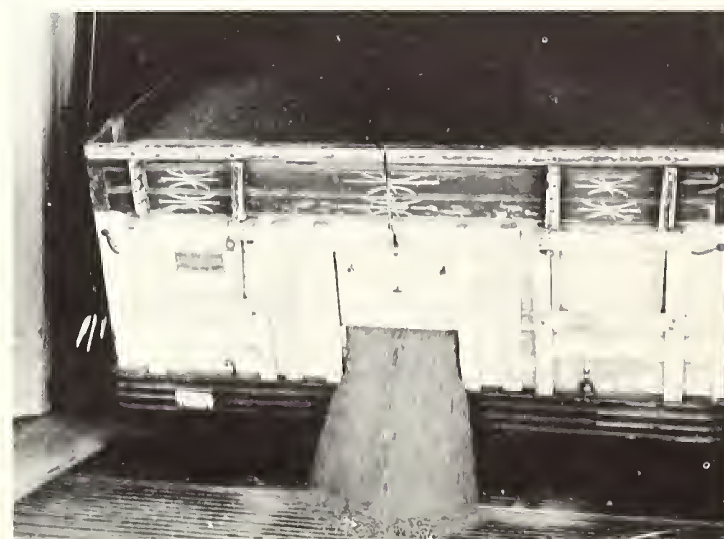

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Figure 17.--A truck being unloaded.

crews. The types of trucks observed in the 1962 wheat harvest are shown below:

Type of truck	Percentage of trucks[1]
Self-dumping grain truck with sliding endgate	78
Standard farm grain truck:	
Sliding endgate	13
Removable endgate	4
Complete endgate	2
Pickup truck:	
Sliding endgate	2
Removable endgate	1
Total	100

[1] From a sample of 97 trucks.

The types of trucks found during the 1963 wheat harvest in north-central Kansas are shown below:

Type of truck	Percentage of trucks[1]
Self-dumping grain truck with sliding endgate	50
Standard farm truck with sliding endgate	9
Pickup with complete endgate .	36
Other	5
Total	100

[1] From a sample of over 100 trucks.

The types of trucks used during the sorghum harvest were somewhat similar to those shown for the 1962 wheat harvest. The data from the grain sorghum harvest indicated it took 2.1 minutes for a 2-man crew to unload a truck.

Weighing Empty Trucks

After the trucks are dumped they return to the scale to be weighed empty. The operation begins when the truck moves to the scale and ends when it clears the scale. At most of the elevators the receipt or ticket is usually returned to the driver while the truck is still on the scale.

Empty trucks are normally given priority at the scale over waiting loaded trucks.[7]

Weighing and Dumping at One Location

At some elevators the scale and dump pit are located together (fig. 18). Here weighing loaded, dumping, and weighing empty are combined into one operation. The operation begins when the truck enters the drive and ends when the truck leaves.

Returning to the Field

After the empty trucks are weighed they return to the field to reload. This completes the truck loading and unloading cycle.

In this study we have assumed that empty trucks can return to the field 2 minutes faster than the loaded trucks can travel to the elevator.

Mean Observed Receiving Truck Times

Tables 1 and 2 list the average or mean observed times for receiving a truckload of wheat.

There was considerable variation in these service times. The mean rate for a 2-man crew to unload a truck was 2.44 minutes (table 1), but the observed time varied from 1 to 6 minutes. These observed times normally follow a statistical distribution or pattern somewhat similar to the hourly patterns for arrivals, page 11. This is discussed in more detail in the appendix.

WAITING TIMES FOR THREE TYPES OF RECEIVING SYSTEMS

Truck arrival times and servicing times at three types of receiving systems were simulated through use of electronic computations and statistical analysis. The methods are described in the appendix. Simulation and electronic computations made available data on truck waiting times which would otherwise have taken 10 or 15 years of field study to obtain. These simulated data were verified as much as possible through field studies.

[7] See appendix, p. 50, for method used in simulated truck movement across the scales.

Table 1.--Mean observed time to receive one wheat truck at country elevators during the 1962 harvest[1]

Operation	Crew size			
	1-man	2-man	3-man	4-man
Weighing and unloading at separate locations[2]:	Minutes	Minutes	Minutes	Minutes
Weighing:				
Loaded truck..................................	1.04	0.65	([3])	0.51
Empty truck...................................	1.04	1.33	([3])	.42
Total....................................	2.08	1.98	([3])	.93
Dumping or unloading truck....................	2.90	2.44	1.72	([3])
Weighing and unloading at the same location[2]....	([3])	5.24	([3])	([3])

[1] The number of trucks timed in each operation varied between 12 and 81.
[2] Includes time to take samples of grain and determine its test weight and, in a few cases, moisture content.
[3] No observations made.

Table 2.--Mean observed time to receive one wheat truck at country elevators during the 1963 harvest[1]

Operation	Crew size			
	1-man	2-man	3-man	4-man
Weighing and unloading at separate locations[2]:	Minutes	Minutes	Minutes	Minutes
Weighing:				
Loaded truck..................................	([3])	1.29	[4] 1.37	0.70
Empty truck...................................	([3])	1.19	[4] 1.30	.86
Total....................................	([3])	2.48	[4] 2.67	1.56
Dumping or unloading truck....................	3.01	2.18	1.80	([3])
Weighing and unloading at the same location[2]...	([3])	([3])	5.18	([3])

[1] The number of trucks timed in each operation varied between 4 and 40.
[2] Includes time to take sample of grain and determine its moisture content and to segregate samples of grain for sedimentation tests.
[3] No observations made.
[4] 3-man crew is slower than observed 2-man crew because of difference in sampling and weighing methods.

The receiving system with a small capacity for receiving grain is designated as number 1, the medium system as number 2, and the large system as number 3. They are illustrated in figures 18, 19, and 20 and are described in table 3.

Because truck arrivals at elevators are not evenly spaced, and the servicing time per truck is irregular, some trucks may wait in line to be serviced even when the total number arriving does not exceed the elevator's average handling capacity; but

Table 3.--Handling capacity of three types of truck-receiving units at grain elevators

Receiving unit	Crew size		Service capacity[1]	Average hourly handling capacity[2]
	At Scale	At pit		
	Men	Men	Trucks per min.	Trucks
1. Truck scale and dump pit together.....	1	1	0.173	10.4
2. Truck scale and dump pit separated....	2	2	.374	22.4
3. Truck scale and 3 dump pits separated.	4	[7] 6	.980	[2] 62.7

Receiving unit	Daily potential service capacity[3]	Seasonal potential service capacity[4]	Critical daily rate[5]	Minimum time trucks must spend at elevator[6]
	Trucks	Trucks	Trucks	Minutes
1. Truck scale and dump pit together.....	166.4	1,664	102	5.76
2. Truck scale and dump pit separated....	358.4	3,584	220	5.74
3. Truck scale and 3 dump pits separated.	1,003.0	10,030	615	4.58

[1] Determined from table 1 using the reciprocal of the elapsed time for the slower receiving operation--weighing or dumping; a 10% coordination factor was also used (see page 38).

[2] Service capacity in trucks per minute times 60. For receiving unit 3, the simulation resulted in an actual receiving capacity of 62.7 trucks per hour instead of 58.8 trucks per hour. For receiving units 1 and 2, the theoretical capacity was within 1% of the simulated results.

[3] The number of trucks the elevator can handle if they arrive at a steady rate during a 16-hour day (handling capacity in trucks per hour times 16).

[4] The number of trucks the elevator could handle in a 10-day season if the trucks all arrived at a steady rate.

[5] The number of trucks the elevator can handle in a day without exceeding its hourly handling capacity. This is based on figure 11 which indicates that 10.2 percent of the daily arrivals arrive in 1 hour. Thus, for receiving unit 2: $\frac{22.4}{.102}$ = 220 trucks per day. As shown later, waiting times are not excessive unless the critical rate is exceeded.

[6] The total of the elapsed times for the various operations plus the 10-percent coordination factor plus 0.28 minute travel time from scale to pit and 0.60 minute turnaround and travel time from pit to scale.

[7] 2 men at each pit.

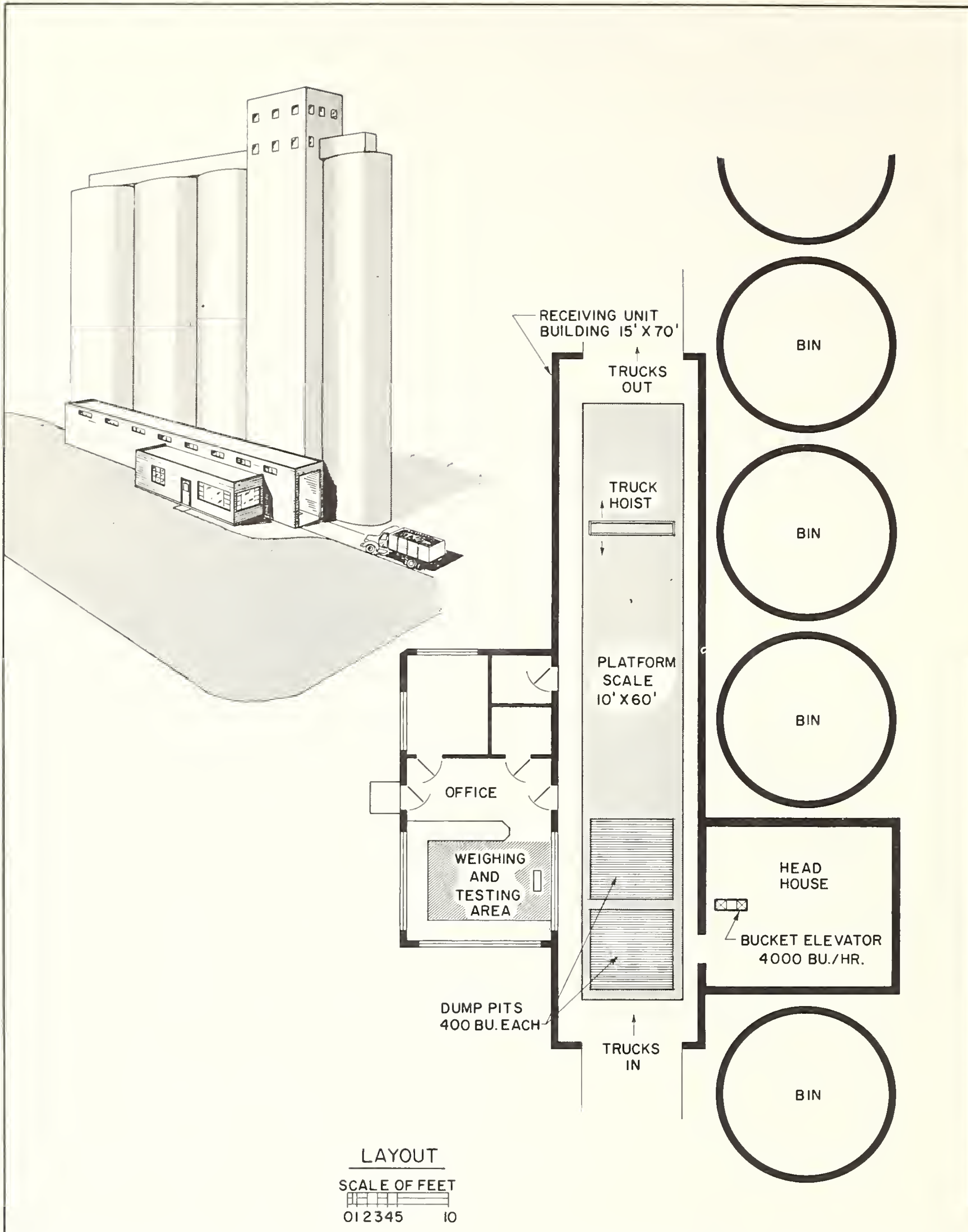


Figure 18.--Receiving Unit 1. Small handling capacity (10.4 trucks per hour).

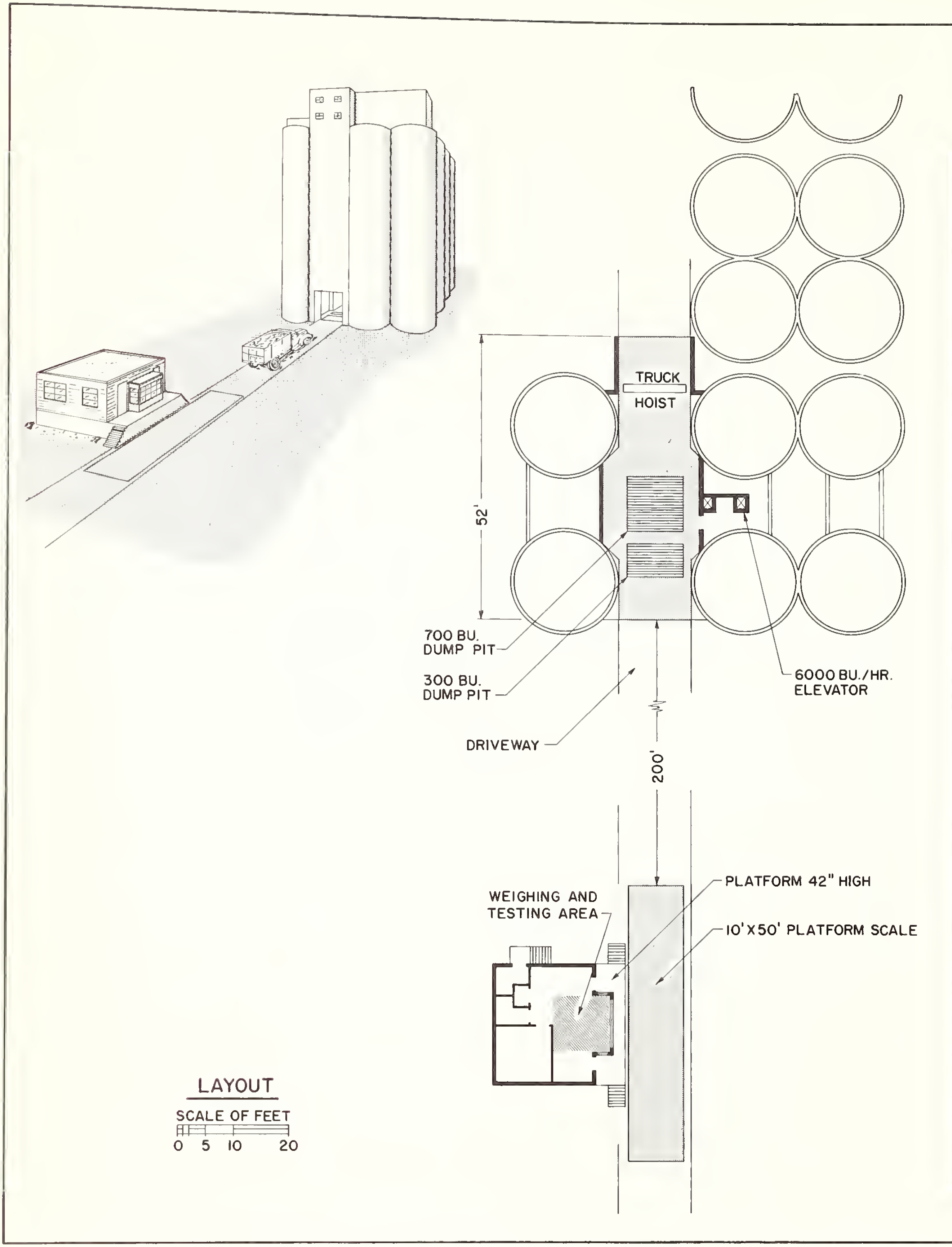


Figure 19.--Receiving Unit 2. Medium handling capacity (22.4 trucks per hour).

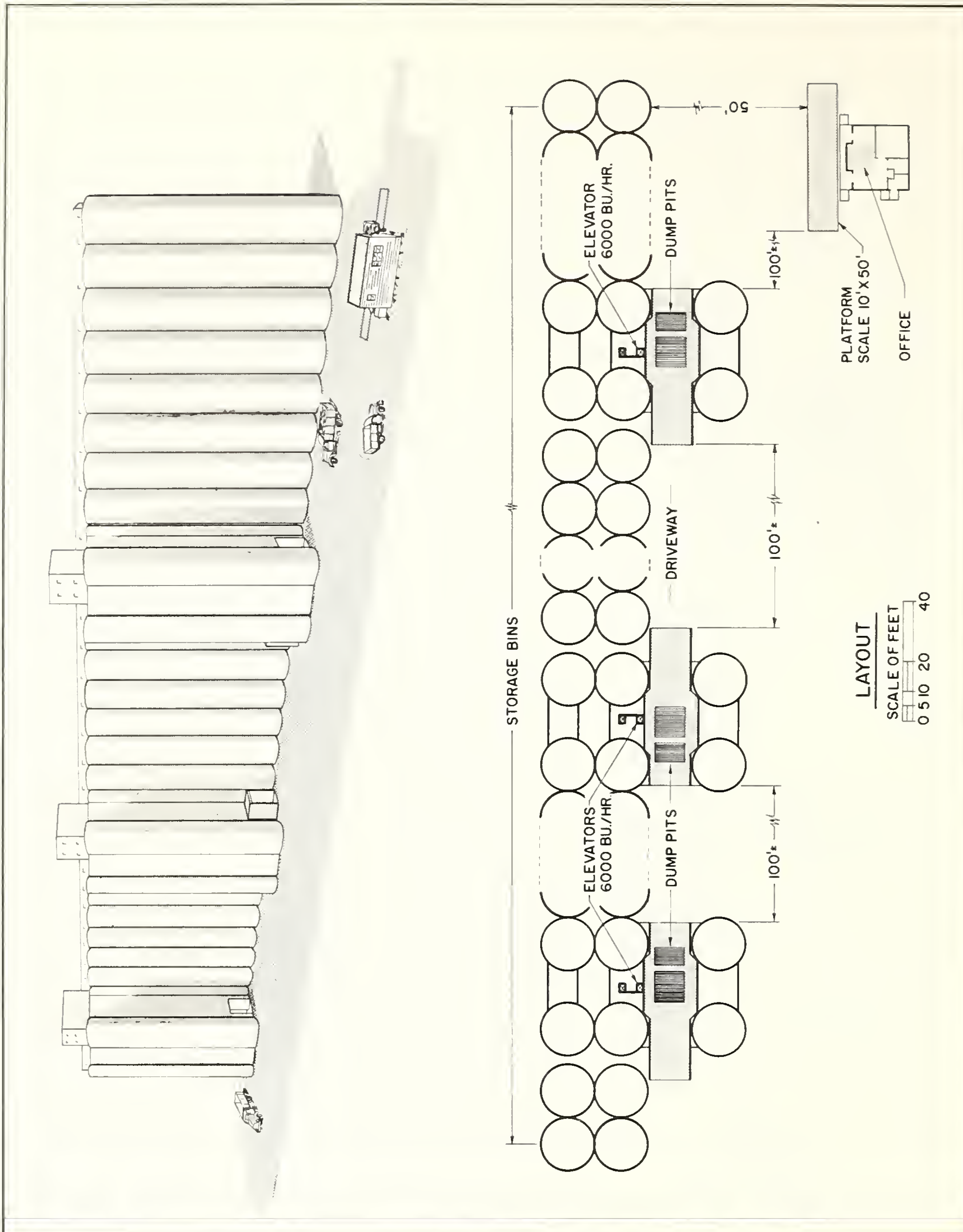


Figure 20.--Receiving Unit 3. Large handling capacity (62.7 trucks per hour).

the number of waiting trucks and the length of time they must wait rise rapidly when the handling capacity is exceeded. This is shown in the charts that are given in the following sections.

As the handling capacity of receiving unit 3 comes out to be about 6 percent higher by simulation than by the service capacity obtained from table 1, the waiting times shown in figures 23, 26, and 27 are probably a little too short for receiving unit 3. The handling capacity is higher because of the method of programing loaded and empty trucks across the scale; this is discussed in the appendix under Simulation.

Total Waiting Time for Trucks and Combines

Total waiting times were plotted against arrival rates in trucks per day for each of the three receiving units, as shown in figures 21, 22, and 23.[8] For example, in figure 22 for receiving unit 2 when trucks arrive at a rate of 250 per day, the total waiting time per day for trucks is about 62 hours and for combines, 30 hours.

Notice that for each of the three receiving units the combine waiting times in the field follow closely the pattern of truck waiting times at the elevator.[9] Combine waiting is less than truck waiting because the combine can continue to operate for a half hour or so without the grain truck by loading the grain into the bin on the combine.

To keep the combines operating and reduce combine waiting time, combines should have large storage bins (if bins become too large, excessive power will be required to drive the combine) and there should be a sufficient number of trucks in the system to operate with the combine.

[8] These times were determined from the totals of columns 12 and 13 of the simulated data. See figure 45 in the appendix.

[9] The simulated program assumes one truck working with each combine. In the 1963 harvest it was found that one combine often worked with two trucks; in this case, there would be a wider spread between truck and combine waiting times.

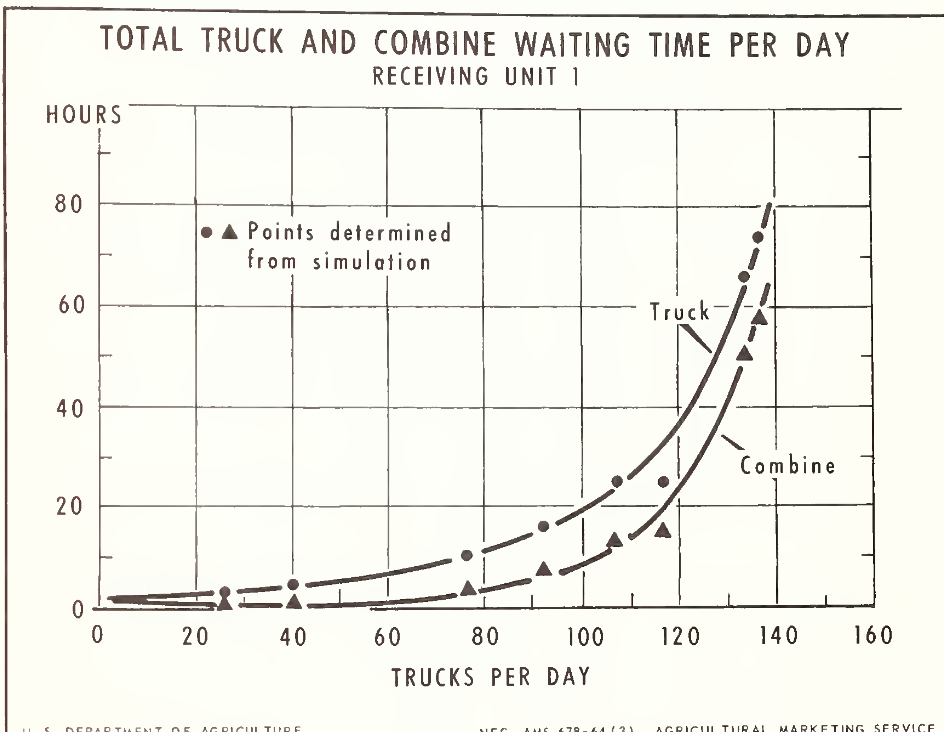


Figure 21

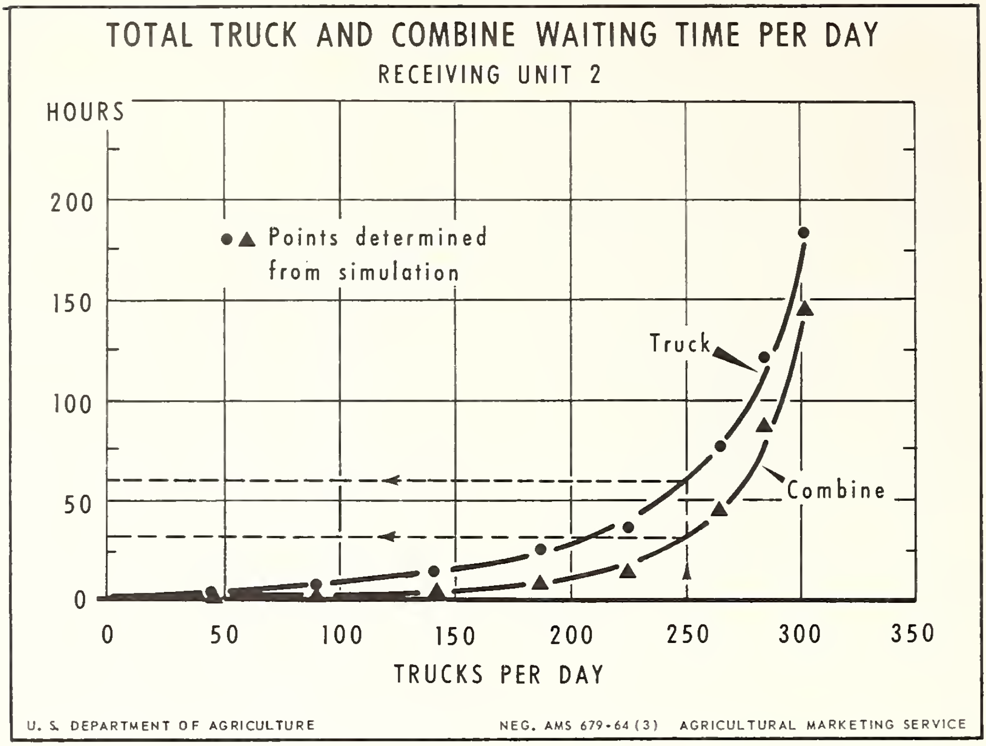


Figure 22

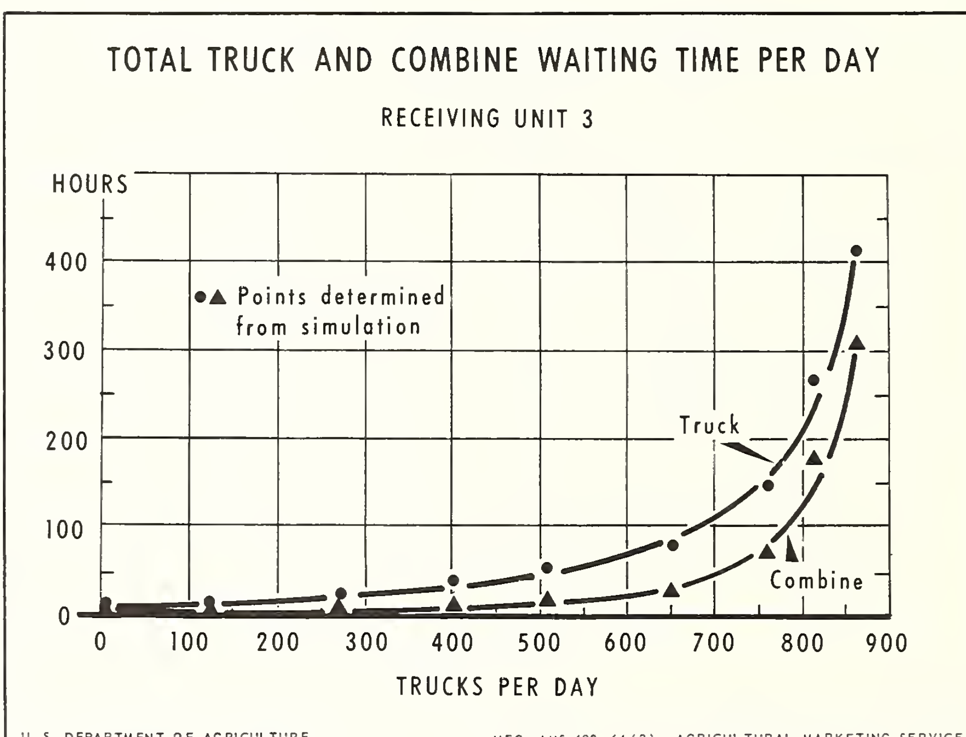


Figure 23

Average and Maximum Waiting Times Per Truck

The average and maximum waiting times per truck are shown for different daily arrival rates in figures 24, 25, and 26.[10] When 260 trucks arrive in a day at receiving unit 2, they wait an average of 17 minutes per truck; the maximum time a truck will wait is about 40 minutes (fig. 25).

Average waiting times for receiving units 1 and 2 and for unit 3 were plotted on the same graph in terms of daily arrival rates as a percentage of daily potential service capacity (fig. 27). When the arrival rate goes above 50 or 60 percent of the daily potential service capacity, average waiting time increases rapidly. The daily potential service rate is the number of trucks the elevator could handle if they arrived at a steady rate during a 16-hour day. The daily potential service rate was found by multiplying the average service rate in trucks per minute by 960 (number of minutes in a 16-hour day). Notice the curve for unit 3 is similar to that for units 1 and 2.

A limited test was conducted to verify the curves in figure 27. Random samples of waiting times were taken at five elevators during the 1963 wheat harvest season. These waiting times were averaged and plotted as shown in figure 27. The elevators studied were of various types, and there seemed to be no correlation between the type of receiving unit and the curve it fit; they all seemed to fit the curve for receiving units 1 and 2 better than for receiving unit 3, but showed waiting times slightly higher than either of the curves.

Curves for maximum waiting times were also plotted on a similar graph (fig. 28). These followed a pattern similar to the curves in figure 27. Field data from the 1963 harvest were also used to verify these curves. Here again there seems to be no correlation between the type of elevator and the curve that the data fit. Again the curves for receiving units 1 and 2 fit the test data better than the curve for receiving unit 3. The reason the one circled point is so far off the curve is discussed under item 2 on page 44.

[10] These times were determined from column 13 of the simulated data. See appendix on Simulation Program.

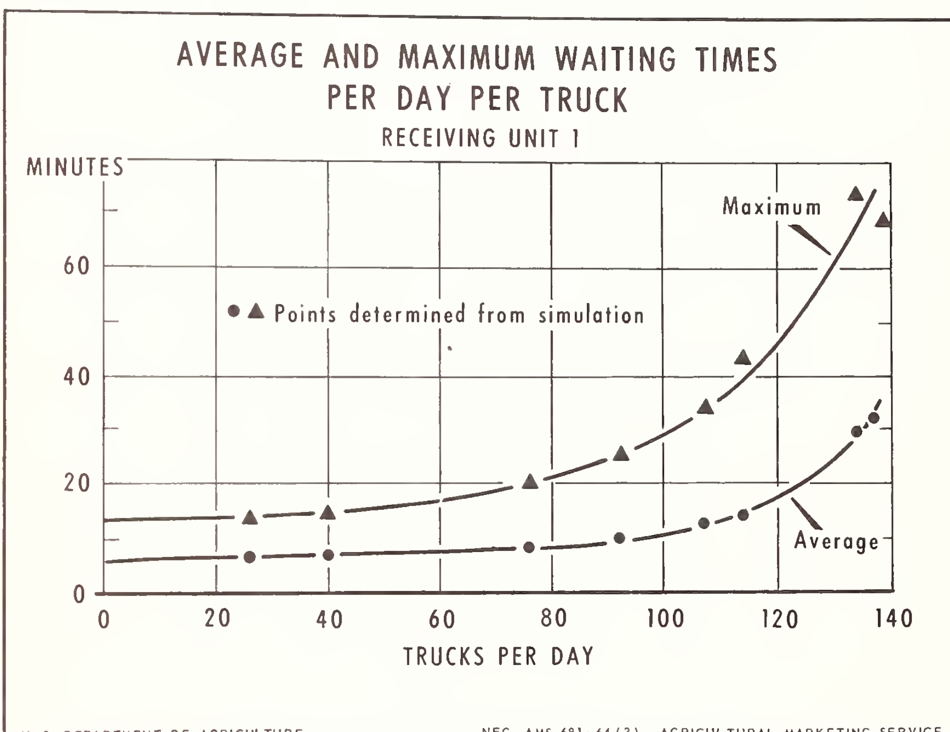


Figure 24

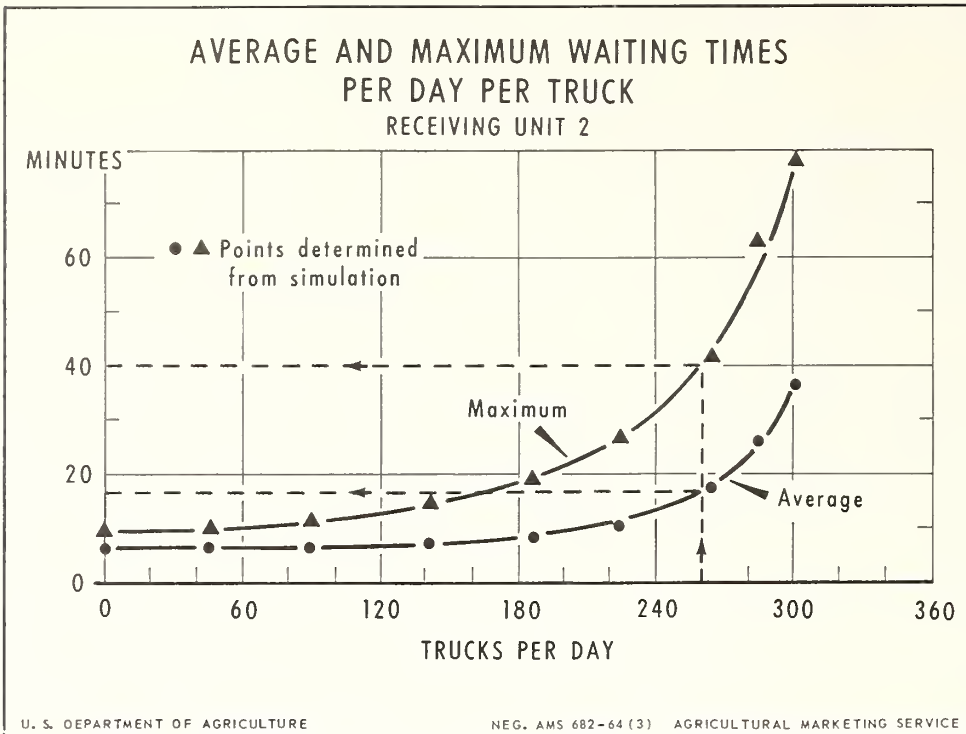


Figure 25

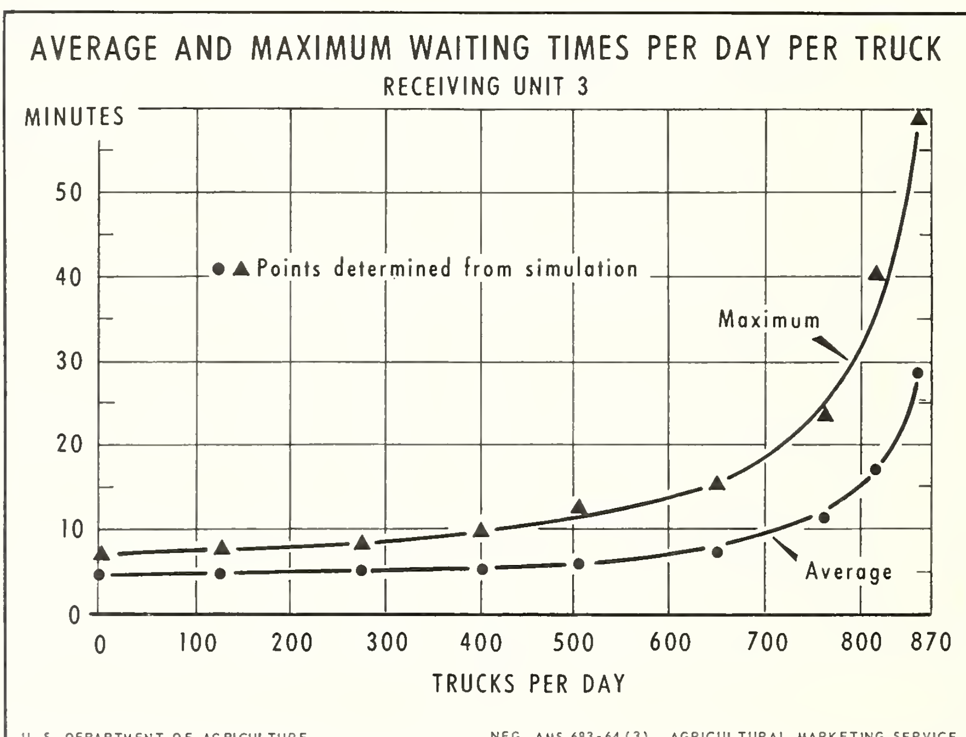


Figure 26

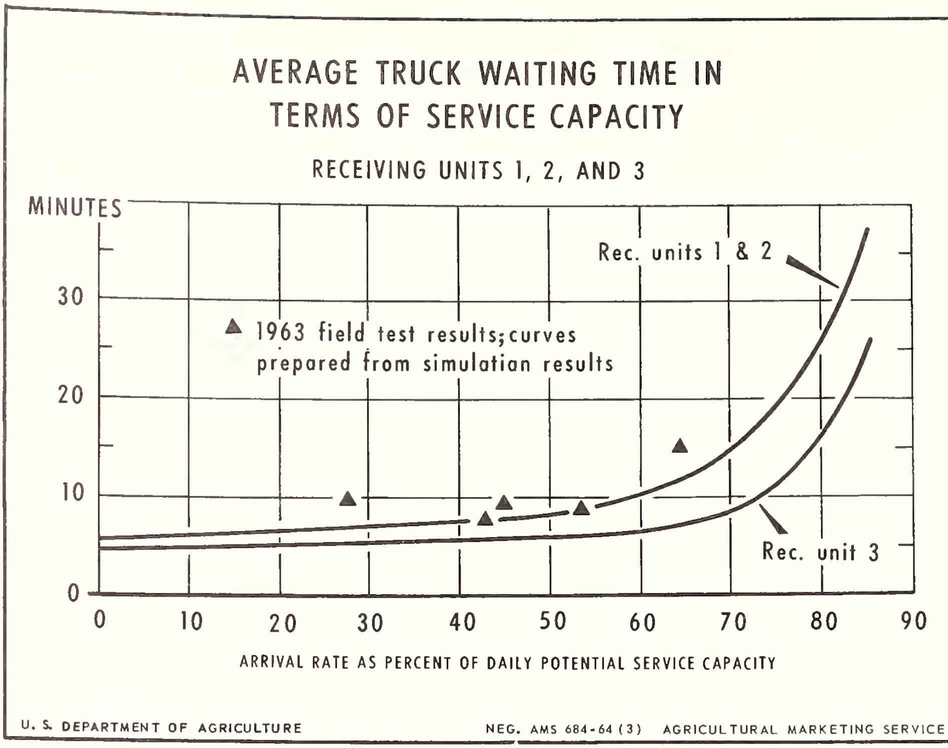


Figure 27

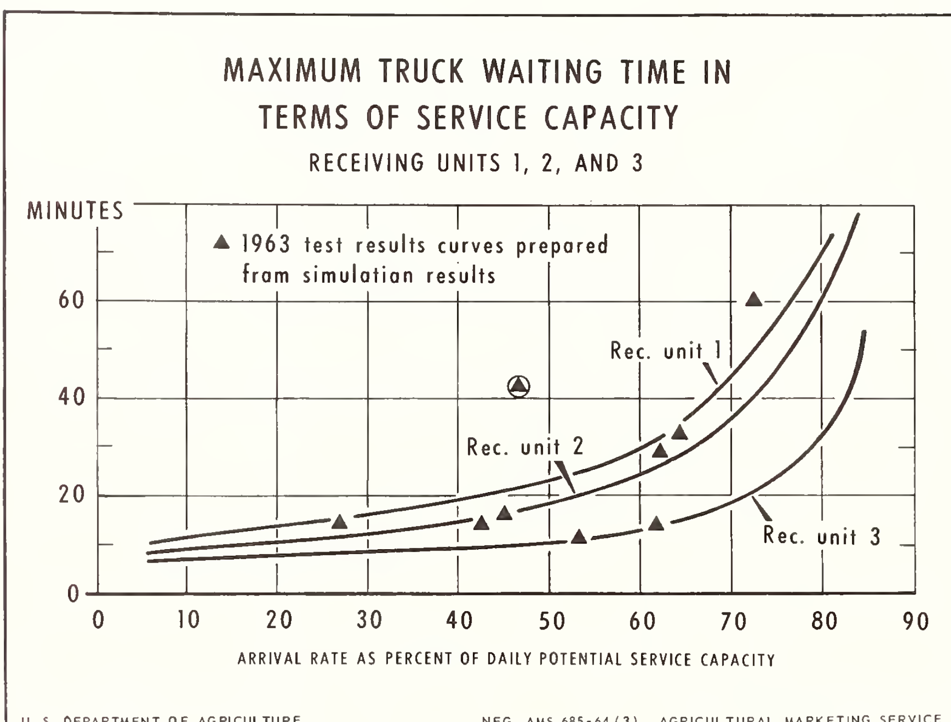


Figure 28

Truck Waiting Time Per Season

The data from the total truck waiting time curves shown in figures 21 through 23 along with the seasonal pattern of truck arrivals shown in figure 7 were used to draw the curves for total truck waiting time versus number of trucks per season. (See figures 29, 30, and 31.) For example, in figure 29 for receiving unit 1, when 500 trucks arrive during the season the trucks wait a total of about 73 hours.

The curves for total seasonal waiting time for the three receiving units were converted into average seasonal waiting time per truck and plotted on the same graph with seasonal arrival rates in terms of percent of seasonal potential service capacity (fig. 32). Seasonal potential service rate is the number of trucks the elevator could handle in a 10-day season if the trucks all arrived at a steady rate during the season.

The seasonal potential service rate was found by multiplying the average service rate in trucks per minute by 9,600 (number of minutes in ten 16-hour working days).

Notice the waiting time increases rapidly when the arrival rate goes above 30 percent of the seasonal potential service rate.

Length of Waiting Line

The length of the waiting line--or the number of trucks in line--is not considered a reliable indicator in estimating time that trucks have to spend at the elevator. For example, some elevators with high capacity might have long lines during certain parts of the day but the trucks in line would move quickly through the elevator and not have long to wait. Also, elevators with several dumps may have a short line at the entrance to the elevator (at the scale where loaded trucks are weighing) but have other waiting lines at the dump pits or at the scale waiting to weigh empty.

The main reason for determining the length of waiting lines is to plan roadways and other space where trucks can wait. This is discussed further on page 44. The maximum number of trucks in line can be estimated by subtracting the handling capacity of the receiving unit in trucks per hour from the maximum number of arrivals

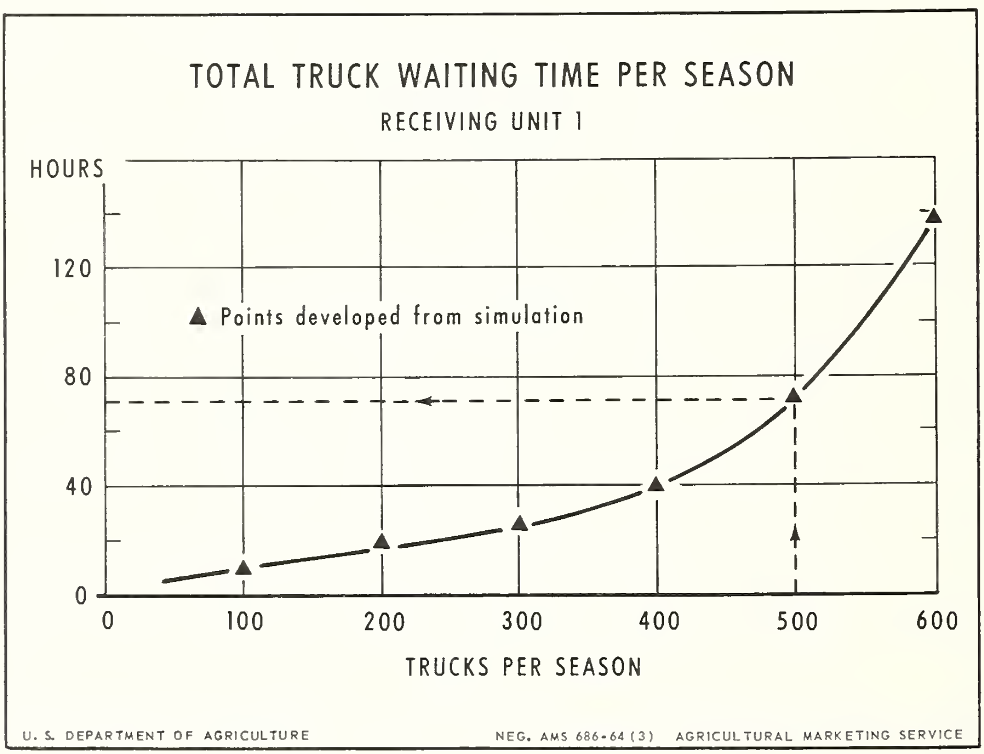


Figure 29

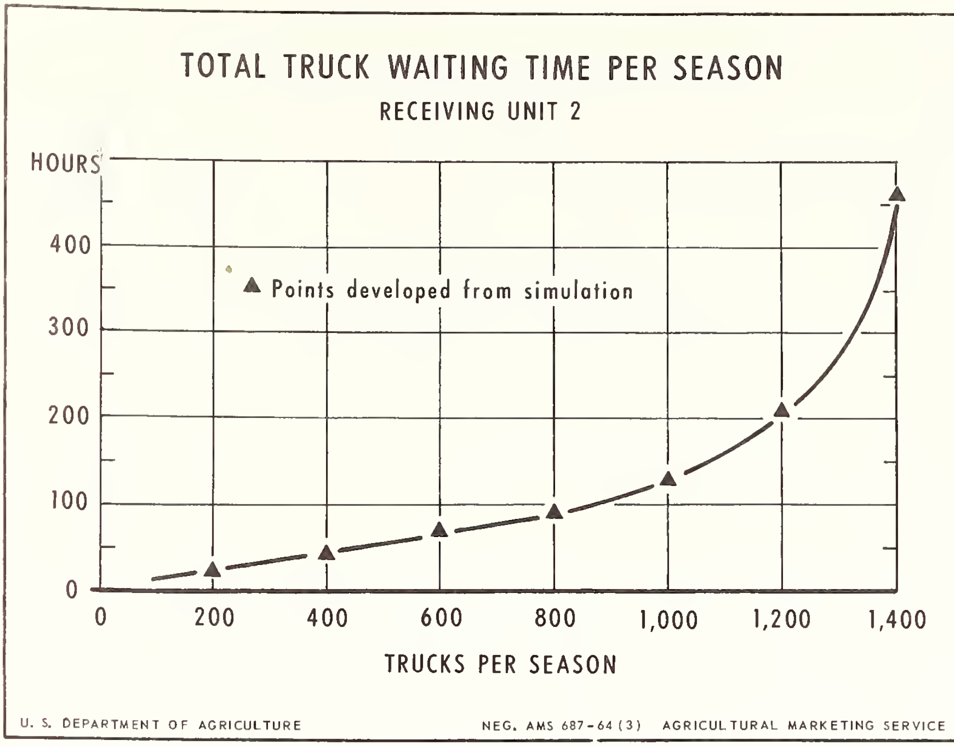


Figure 30

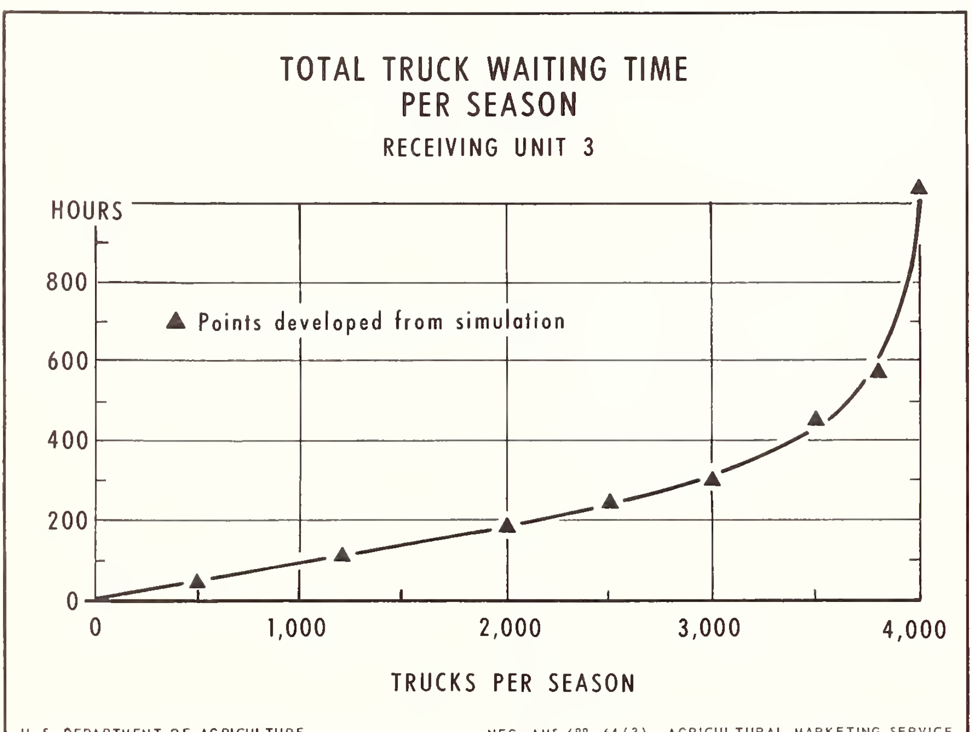


Figure 31

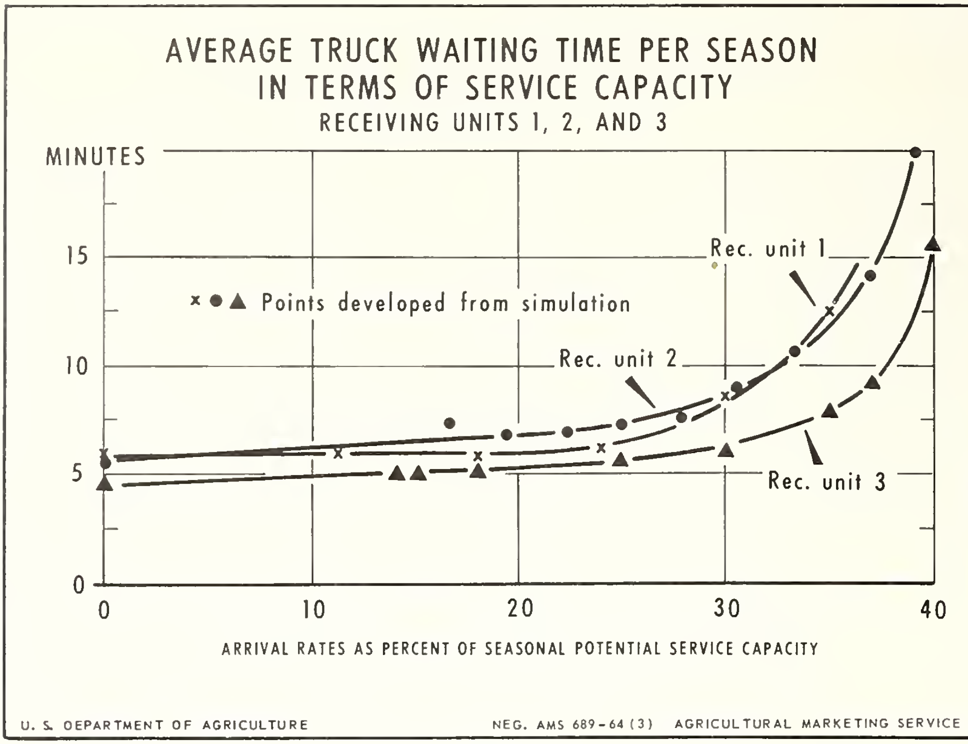


Figure 32

expected in one hour. The answer will be the number of trucks in line. However, at receiving units similar to 2 and 3, where the pits are separated from the scale, the number of trucks in line may be divided into several shorter lines--at the scale weighing loaded, at the dump pits, and at the scale weighing empty.

RECEIVING COST PER SEASON

The elevator manager should minimize total receiving costs--ownership and operating costs as well as waiting costs. The elevator manager's objective might better be stated as maximizing profits. But because of problems in determining income from the receiving operation as well as all indirect costs, we have worked in terms of minimum cost. Management can use this as a tool in evaluating profits. Total seasonal costs--ownership, operating, and waiting costs--have been determined for each of the three model receiving units studied. It was assumed that the yearly pattern for truck receipts is similar to figure 4 and that truck waiting is a problem only during the wheat harvest season.

Construction

To determine ownership costs, it was first necessary to estimate the construction costs for the three receiving unit facilities. A breakdown of these costs is shown in tables 4, 5, and 6.

Ownership

A depreciation rate of 2 percent, or a useful life of 50 years, was assumed for buildings. For the equipment, the following formula was developed to determine depreciation rate:[11]

Annual equipment depreciation rate in percent of initial cost = 4.5 percent + 0.25 percent (each 1,000 trucks received).

Other annual ownership costs (based on information from technical publications or

[11] This formula is a compromise between the years-of-useful-life approach based on deterioration from heat, cold, dampness, rust, obsolescence, etc., and the hours or amount-of-use approach. However, the formula is based more on the years-of-useful-life approach because the rate of use of equipment is relatively low and wheat and many other grains are not heavily abrasive materials that rapidly wear out buckets, belts, and other equipment.

Table 4.--Construction cost - receiving unit No. 1[1]

Item	Construction cost	Utilization factor[2]	Cost attributed to receiving
	Dollars	Percent	Dollars
Building			
Driveway building..................	7,000	90	6,900
Dump pits..........................	1,600	100	1,600
Office area for weighing...........	1,900	90	1,700
Total building cost............	--	--	10,200
Equipment			
Platform scales 10' x 60'..........	9,500	90	8,600
Bucket elevators...................	9,000	50	4,500
Truck hoist........................	2,200	100	2,200
Gallery belt 20" x 100'............	5,100	75	3,800
Belt tripper.......................	3,000	75	2,200
Distributor........................	300	50	200
Miscellaneous......................	1,000	50	500
Total equipment cost...........	--	--	22,000
Grand total receiving unit cost	--	--	32,200

[1] See figure 18.
[2] Assumed percentage of use attributed to the receiving operation.

Table 5.--Construction cost - receiving unit No. 2[1]

Item	Construction cost	Utilization factor[2]	Cost attributed to receiving
	Dollars	Percent	Dollars
Building			
Driveway building..................	6,000	90	5,400
Dump pits..........................	2,000	100	2,000
Office area for weighing...........	1,900	90	1,700
Total building cost............	--	--	9,100
Equipment			
Platform scale 10' x 50'...........	9,000	90	8,100
Bucket elevators...................	13,400	50	6,700
Truck hoist........................	2,200	100	2,200
Gallery belt 24" x 100'............	6,100	75	4,600
Tripper............................	3,100	75	2,300
Distributor........................	400	50	200
Miscellaneous......................	1,200	50	600
Total equipment cost...........	--	--	24,700
Grand total receiving unit cost	--	--	33,800

[1] See figure 19.
[2] Assumed percentage of use attributed to the receiving operation.

Table 6.--Construction cost - receiving unit No. 3[1]

Item	Construction cost	Utilization factor[2]	Cost attributed to receiving
	Dollars	Percent	Dollars
Building			
Driveway building	18,000	90	16,200
Dump pits	6,000	100	6,000
Office	1,900	90	1,700
Total building cost			23,900
Equipment			
Platform scale 10' x 50'	9,000	90	8,100
Bucket elevators	40,200	50	20,100
Truck hoists	6,600	100	6,600
Gallery belts 24" x 100' (3)	18,300	75	13,700
Trippers	9,300	75	7,000
Distributors	1,200	50	600
Miscellaneous	3,600	50	1,800
Total equipment cost	--	--	57,900
Grand total receiving unit cost	--	--	81,800

[1] See figure 20.
[2] Assumed percentage of use attributed to the receiving operation.

previous research studies), were assumed as follows:

Interest - 6 percent of the average cost
Taxes - 1.3 percent of the initial cost
Insurance - 0.2 percent of the initial cost

For the single harvest season a cost of one-half the total annual ownership cost was used. This is based on the assumption that about half the grain received in a year arrives during the harvest season. (See tables 7, 8, and 9.)

Labor

An hourly wage rate of $1.80 was assumed; the computed costs are shown in table 10. As computed in the table, the labor cost is a function of the type of elevator and not of the amount of grain received. However, to be more realistic, the labor cost was increased $200 for each 1,000 trucks received per season. This is shown in tables 7, 8, and 9.

Power and Maintenance

A power and maintenance cost of $0.18 per truckload of grain was based on information from industrial engineering handbooks and other sources.

Waiting Costs

The total truck waiting times were taken from figures 29, 30, and 31. A rate of $8 an hour was assumed. This is discussed in more detail in the appendix.

Total Seasonal Receiving Cost

The total seasonal receiving costs for receiving units 1, 2, and 3 were computed as shown in tables 7, 8, and 9. These costs, shown in graph form in figures 33, 34, and 35, are computed for a season and are mainly for illustrative purposes. Each elevator operator should compute his own receiving costs on an annual basis, using the same approach used in this report.

Table 7.--Receiving costs per season - receiving unit No. 1

Cost	Trucks per season			
	0	200	400	600
Annual ownership				
Depreciation:				
Building[1]	$204	$204	$204	$204
Equipment[1]	990	1,001	1,012	1,023
Insurance, interest, taxes	1,449	1,449	1,449	1,449
Total ownership	2,643	2,654	2,665	2,676
1/2 annual ownership cost	1,321	1,327	1,332	1,338
Labor	576	616	656	696
Maintenance, power	0	36	72	108
Waiting	0	136	328	1,090
Grand total	1,897	2,115	2,388	3,232

[1] Initial Cost: Building - $10,200
Equipment - 22,000
Total - $32,100

Table 8.--Receiving cost per season - receiving unit No. 2

Costs	Trucks per season				
	0	400	800	1,200	1,400
Annual ownership					
Depreciation:					
Building[1]	$182	$182	$182	$182	$182
Equipment[1]	1,111	1,136	1,161	1,184	1,198
Insurance, interest, taxes	1,520	1,520	1,520	1,520	1,520
Total ownership cost	2,813	2,838	2,863	2,886	2,900
1/2 annual ownership cost	1,406	1,419	1,431	1,443	1,450
Labor	1,152	1,232	1,312	1,392	1,432
Maintenance, power	0	72	144	216	252
Waiting	0	380	734	1,665	3,610
Grand total	2,558	3,103	3,621	4,716	6,744

[1] Initial Cost: Building - $ 9,100
Equipment - 24,700
Total - $33,800

Table 9.--Receiving cost per season - receiving unit No. 3

Costs	Trucks per season				
	0	1,000	2,000	3,000	4,000
Annual ownership					
Depreciation:					
Building[1].........................	$478	$478	$478	$478	$478
Equipment[1]........................	2,605	2,750	2,895	3,040	3,185
Insurance, taxes, interest.........	3,681	3,681	3,681	3,681	3,681
Total ownership cost............	6,764	6,909	7,054	7,199	7,344
1/2 annual ownership cost.............	3,382	3,454	3,527	3,599	3,672
Labor..............................	2,880	3,080	3,280	3,480	3,680
Maintenance and power.................	0	180	360	540	720
Waiting............................	0	640	1,440	2,400	8,000
Total..........................	6,262	7,354	8,607	10,019	16,072

[1] Initial cost:

Building - $23,900
Equipment - 57,900

Total - $81,800

Table 10.--Seasonal labor costs for receiving grain in 3 receiving units

Receiving unit	Crew size	Hours per man	Total hours per crew	Cost
	Men	Hours	Man-hours	Dollars
No. 1..........	2	160	320	576
No. 2..........	4	160	640	1,152
No. 3..........	10	160	1,600	2,880

It should also be noted that receiving costs listed here include the indirect cost of waiting, but do not include other direct or indirect costs such as bookkeeping, telephone calls, advertising, and management.

Simulated waiting times for receiving unit 3 probably are a little low (see page 55); the total receiving costs for receiving unit 3 shown in table 9 and figures 35 and 36 are estimated to be about 10 percent too low.

The total receiving costs for the three receiving units are drawn on one graph (fig. 36). From this graph the economical ranges for handling capacities were determined and are shown in table 11. The table also compares the theoretical data from this chart with the handling rates of a small sample of existing elevators.

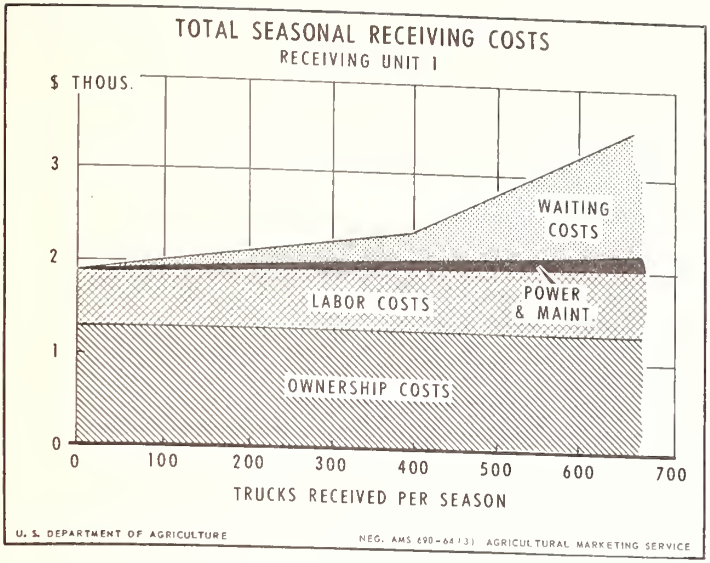
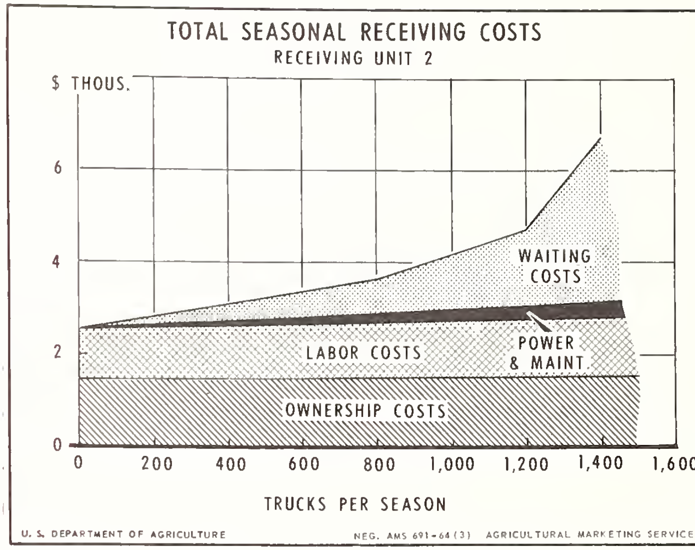


Figure 33

Figure 34



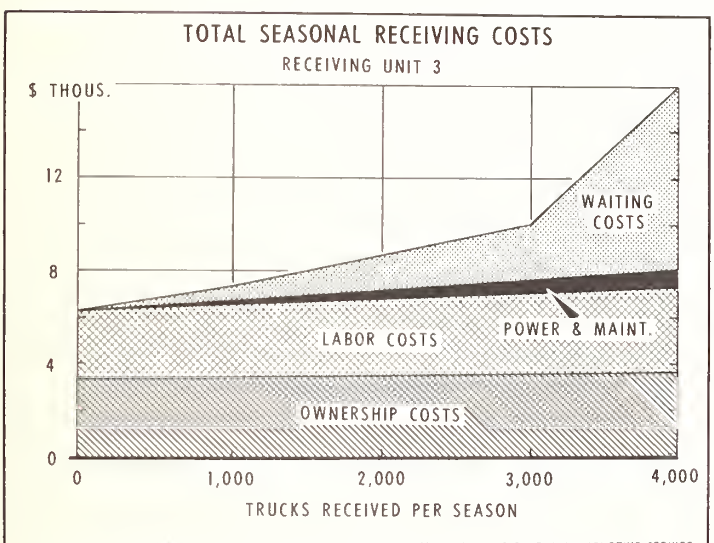


Figure 35

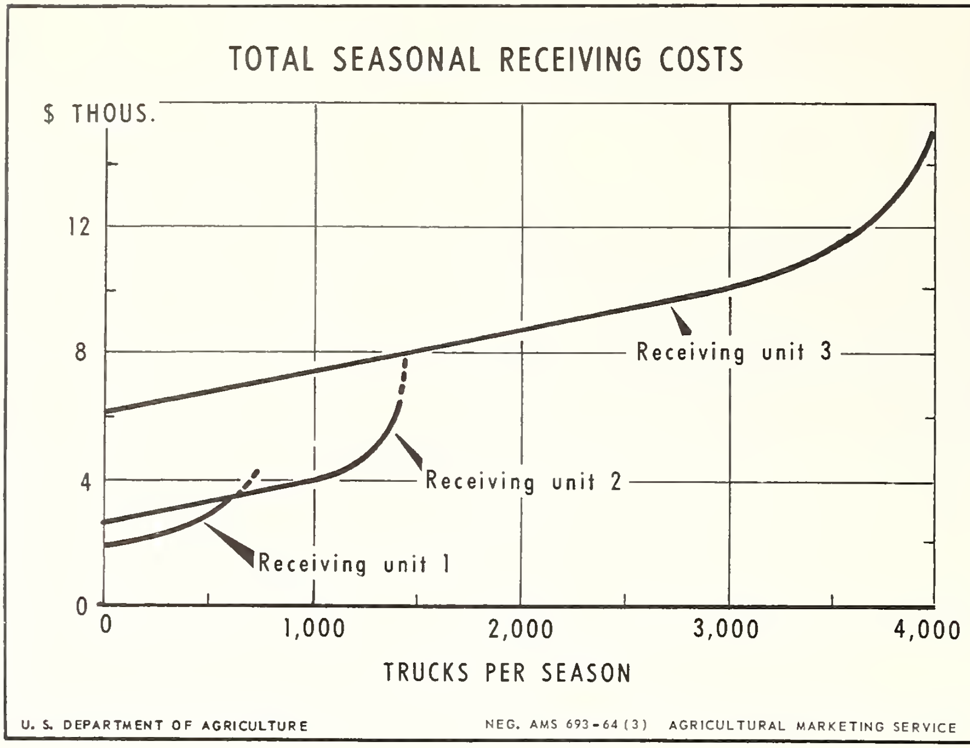


Figure 36

Table 11.--Economical and actual capacity, 3 types of receiving units

Receiving unit type	Economical handling capacity from theoretical analysis	Trucks actually handled at a small sample of elevators	
		Average	Maximum
	Trucks per season	Trucks per season	Trucks per season
1...............	Below 600	285	320
2...............	600 to 1,450	900	1,500
3...............	Over 1,450	2,600	3,500

If the elevator operator's situation is similar to the assumptions and arrival patterns used in this report, he can use figure 36 and table 11 as a guide in selecting the type of receiving facility that will best fit his needs. For example, if fewer than 600 trucks per harvest season are anticipated, receiving unit 1, with the scale and dump pit together and a total crew of two men, would be the most economical. If 600 to 1,450 trucks per season are anticipated, the manager should choose receiving unit 2--where the scale and dump pit are separated and there is a 2-man crew at the pit and a 2-man crew at the scale. The capacity of this type of facility can be increased by adding one man at the scale and another man at the pit. Receiving unit 3, with three dump pit drives and a total crew of 10, would not be an economical choice unless at least 1,450 trucks per harvest season were anticipated.

Another type of receiving facility not included in this study has a double driveway and single scale and uses a total crew of six to eight men. This type of facility has a receiving capacity greater than receiving unit 2, but less than receiving unit 3. The economical range of truck receipts per harvest season might fall between 1,200 and 1,800 trucks.

APPLICATION OF RESEARCH FINDINGS

Determining the Capacity of Receiving Facilities

In order to determine most accurately the best capacity of receiving facility for an elevator, the elevator designer or manager would have to go through the involved simulation approach used in this study. However, the elevator designer can use many of the charts and tables in this report and use some simplified approaches to find the best capacity.

For information on grain harvest patterns, types of trucks used, and like subjects for his locality, the elevator manager or designer might contact State agricultural experiment stations, grain trade associations, other elevator operators, or similar sources.

In most of the methods of solving this problem, the following steps are necessary:

A. Estimate the Arrival Pattern of Trucks:

Design Steps or Methods	Example
1. Determine the general yearly pattern of grain receipts (see figures 4, 5, and 6).	Assume that from information obtained from the State agricultural marketing specialist, a harvest pattern similar to figure 4 was indicated with only one peak or critical harvest.
2. For the critical harvest or harvests (where truck waiting would be a problem), estimate the bushels that would be received per harvest, considering acreage planted, area to be served by the elevator, amount of farm storage, future trends, etc.	Assume an estimate of 270,000 bushels per harvest.
3. Determine the types of trucks that would be used during the harvest or other critical periods and the average truckload in bushels. Note that during harvest, as custom combiners and truckers move into an area, larger-than-average trucks are frequently used.	Assume an average truckload of 200 bushels, all trucks with sliding endgates, 75 percent of the trucks are self-dumping and 25 percent are standard farm trucks.
4. From the average size of truckload, convert the number of bushels found in steps 1 and 2 into numbers of trucks per harvest.	$\frac{\text{270,000 bushels}}{\text{200 bushels per truckload}} = 1{,}350$ trucks
5. Estimate the seasonal pattern of truck receipts as was done in figures 7 and 8. Give particular attention to the maximum number of trucks that arrive in any one day. For example, at the elevators studied, 15 to 25 percent of the total trucks received during wheat harvest arrived in one day. During corn or grain sorghum harvest probably only 3 to 15 percent of the trucks would arrive in any one day.	Assume a pattern similar to figure 7, with a maximum of 22.2 percent of the total seasonal trucks arriving in one day. 1,350 trucks per season x 0.22 = 300 trucks per day (max.). To find the number of trucks for other days in the harvest, use the appropriate percentages as shown in figure 7.

Design Steps or Methods	Example
6. Estimate the daily pattern of truck arrivals as in figures 11 and 12. Give particular attention to the maximum number of trucks that would arrive in any one hour. Studies during the wheat harvest indicate that between 10 and 13 percent of the total daily trucks arrive during 1 hour and elevators operate 15 to 17 hours a day during harvest.	Assume a daily pattern similar to figure 11 with a maximum of 10.2 percent of trucks arriving in 1 hour. 300 trucks per day x 0.102 = 31 trucks per hour (t.p.h.) (max.)
7. Convert the maximum number of trucks arriving in an hour into trucks per minute. This can be used as a guide for determining the needed service rate.	$\frac{31}{60}$ = .52 truck per min. (t.p.m.) or the reciprocal $\frac{1}{.52}$ = 1.93 minutes per truck (m.p.t.)

B. Estimate the service rate in trucks per minute of one or more selected receiving systems. The service rate of the selected receiving systems can be estimated by one or more of the following methods:

Design Steps or Methods	Example
1. Use tables 1 and 2 as guides, considering the types of trucks used and the types of weighing, sampling, and testing done.	Assuming only test weights are conducted along with a few moisture tests, the types of trucks listed in step A-3 are somewhat similar to those used in the 1962 harvest (see page 17). Then using table 1 as a guide, with a 2-man crew at both the scale and dump pit, trucks will be on the scale a total of 1.98 minutes and at the dump 2.44 minutes. The maximum value (bottleneck) of 2.44 m.p.t. determines the receiving capacity of the elevator. However, in the simulation approach used in this study we have increased these observed elapsed times by a coordination factor of 10 percent (to compensate for possible delays as trucks move on and off scales and to and from pits).[12] Using this approach: 2.44 m.p.t. observed time +.24 10% coordination factor 2.68 m.p.t. and $\frac{1}{2.68 \text{ m.p.t.}}$ = 0.374 t.p.m. service rate or 0.374 x 60 = 22.4 t.p.h. Compare this with the 31 trucks per hour arrival rate found in step A-6.

[12] On the other hand, some of these observed times may be improved as described by Graves and Kline (6).

Design Steps or Methods	Example
2. Use the elapsed time values given by Graves and Kline (6) to estimate service rates considering truck types and sampling and testing methods. These are standard times; so-called abnormal times (readings when there were jammed tailgates, trucks stalled at the dump pit, farmers leaving their trucks on the scale while they get out to discuss a transaction, etc.) were eliminated from the sample. To get more realistic values for evaluating waiting times it is suggested that 8 to 15 percent be added to the standard truck-dumping times and that 20 to 25 percent be added to standard weighing and sampling times. Also, the 10-percent coordination factor might be added.	From table 5 of Graves and Kline (6): 2-man crew, weighing and making test weights: 1.58 m.p.t. +.35 -- 22% additional for abnormal times 1.93 m.p.t. (compare the 1.98 m.p.t. found by method in step B-1) +.19 10% coordination factor 2.12 m.p.t. From table 2 of above reference: 3-man crew, improved dumping method, assuming trucks as listed in step A-3: Trucks with hoist, 1.38 x 0.75 = 1.03 m.p.t. Standard trucks, 1.60 x 0.25 = .40 m.p.t. Weighted average = 1.43 m.p.t. 1.43 m.p.t. +.17 -- 12% additional for abnormal time values 1.60 m.p.t. +.16 10% coordination factor 1.76 m.p.t. The maximum value of 2.12 m.p.t. for weighing determines the service rate: $\frac{1}{2.12 \text{ m.p.t.}}$ = 0.47 t.p.m. = service rate or 0.47 x 60 = 28.2 t.p.h.
3. Make time studies of receiving facilities; consider the types of trucks being unloaded and weighed, and the kinds of sampling and testing being done.	See Graves and Kline (6) and Slay and Hutchison (13).

C. Estimate truck waiting by one or both of the following methods:

1. Where the daily arrival pattern is similar to figure 11 or 12, figures 27 and 28 can be used to estimate truck-waiting times as follows:	
a. From the service rate found in step B, determine the daily potential service capacity by multiplying service rate in trucks per minute by 960 (minutes in a 16-hour workday).	Using service rate found in step B-1: 0.374 t.p.m. x 960 min. per day = 359 trucks per day
b. Divide the daily arrival rate in trucks per day (found in step A-5) by the potential daily service capacity.	$\frac{\text{300 trucks per day}}{\text{359 trucks per day}} = 0.83$

Design Steps or Methods	Example
c. From figure 27 determine the average waiting time, or from figure 28 determine the maximum waiting time.	Reading 0.83 on the horizontal axis of figure 27, receiving unit 2 shows an average waiting time of about 35 m.p.t. Figure 28 gives a maximum waiting time of about 78 m.p.t.
d. Multiply the average waiting time by the number of trucks arriving in a day, to get total waiting time.	$\frac{\text{35 m.p.t. x 300 trucks per day}}{\text{60 minutes}}$ = 175 hours total waiting time per day for 300 trucks
e. Repeat steps b, c, and d, for each day of the harvest and add up totals of step d to get total waiting time for the season.	
2. Where the daily pattern of arrivals is different from figures 11 and 12, use the following approximate method:	
a. Estimate the arrival pattern.	See step A.
b. For each day of the harvest, work out approximate waiting times by estimating the number of trucks in line each hour of the day.	See table 12 for a unit receiving 300 trucks per day. Total waiting time = 231.8 hrs.
c. Add necessary correction factors to waiting times determined from step b, by computing the daily arrival rate in terms of critical arrival rate (see table 3, footnote 5 for definition) and using figures 37 and 38, and table 13. Note that below the critical arrival rate, waiting times are too low by the approximate method, and that a little past the critical arrival rate, waiting times are too high by the approximate method.	Determining the critical arrival rate: $\frac{\text{22.4 t.p.h. (See step B1)}}{\text{0.102--proportion of daily arrivals in critical hour (see step A-6)}}$ = 220 trucks per day. $\frac{\text{Truck arrivals per day}}{\text{Critical arrival rate}} = \frac{300}{220} = 1.36$ See table 13--estimate a reduction of about 25 percent. 231.8 hours -58.0 = 25% correction factor. 173.8 or 174 hours total waiting time per day.

D. For each of the preliminary selected receiving systems compute total receiving costs--ownership, labor, power and maintenance, and truck waiting--as described in the section on receiving costs (page 30) and make final selection on basis of lowest total receiving costs. See tables 7, 8, 9 and figure 36.

Table 12.--Illustration of approximate method for determining truck waiting times

Receiving unit 2, 300 trucks received in a day

[Service capacity of elevator = 22.4 trucks per hour--see step B]

Hours of day[1]	Percent received each hour[2]	Number of trucks arriving each hour[3]	Number not handled[4]	Number of trucks in line, end of hour[5]	Maximum waiting time, end of hour[6]	Average waiting time during hour[7]	Total waiting time during hour[8]
	Percent	Trucks	Trucks	Trucks	Minutes	Minutes	Minutes
1.......	0.3	0.9	-21.5	0	5.73	5.73	5.16
2.......	2.8	8.4	-14.0	0	5.73	5.73	48.13
3.......	3.3	9.9	-12.5	0	5.73	5.73	56.73
4.......	3.3	9.9	-12.5	0	5.73	5.73	56.73
5.......	4.9	14.7	-7.7	0	5.73	5.73	84.23
6.......	7.5	22.5	+0.1	0.1	6.00	5.87	132.08
7.......	5.2	15.6	-6.8	0	5.73	5.87	91.57
8.......	7.3	21.9	-0.5	0	5.73	5.73	125.49
9.......	9.5	29.5	+7.1	7.1	24.69	15.21	448.70
10.......	10.0	30.0	+7.6	14.7	44.98	34.84	1,045.20
11.......	10.2	30.6	+8.2	22.9	66.87	55.93	1,711.46
12.......	9.5	29.5	+7.1	30.0	85.83	76.35	2,252.33
13.......	9.5	29.5	+7.1	37.1	104.79	95.31	2,811.65
14.......	8.4	25.5	+3.1	40.2	[9] 113.06	108.93	2,777.72
15.......	4.8	14.4	-8.0	32.2	91.70	102.38	1,474.27
16.......	3.4	10.2	-12.2	20.0	59.13	75.42	769.28
17.......	.2	.6	-21.8	0	5.73	32.43	19.46
Total..	--	--	--	--	--	--	13,919.19
							Hours
							231.8

[1] Hours the elevator receives trucks--step A-6.

[2] Determined from step A-6

[3] Multiply column 2 by total trucks received during the day (300)

[4] Column 3 minus 22.4. A minus sign in this column indicates number of additional trucks that could have been handled during the hour. A plus sign means trucks not handled.

[5] A summation of trucks not handled.

[6] Equals x(column 5) + y; where x equals receiving capacity of elevator in minutes per truck and y equals total average time truck spends at elevator (weighing, loaded and empty, dumping time, plus travel times between scale and pits). In this illustration x = 2.67 min., y = 5.73 min. (see table 3)

[7] Average waiting times from column 6 at beginning and end of hour; for example, average waiting time for 10th hour = $\frac{24.69 + 44.98}{2}$ = 34.84. Value y is a minimum value for this column.

[8] Equals column 7 times column 3.

[9] Maximum waiting time during the day.

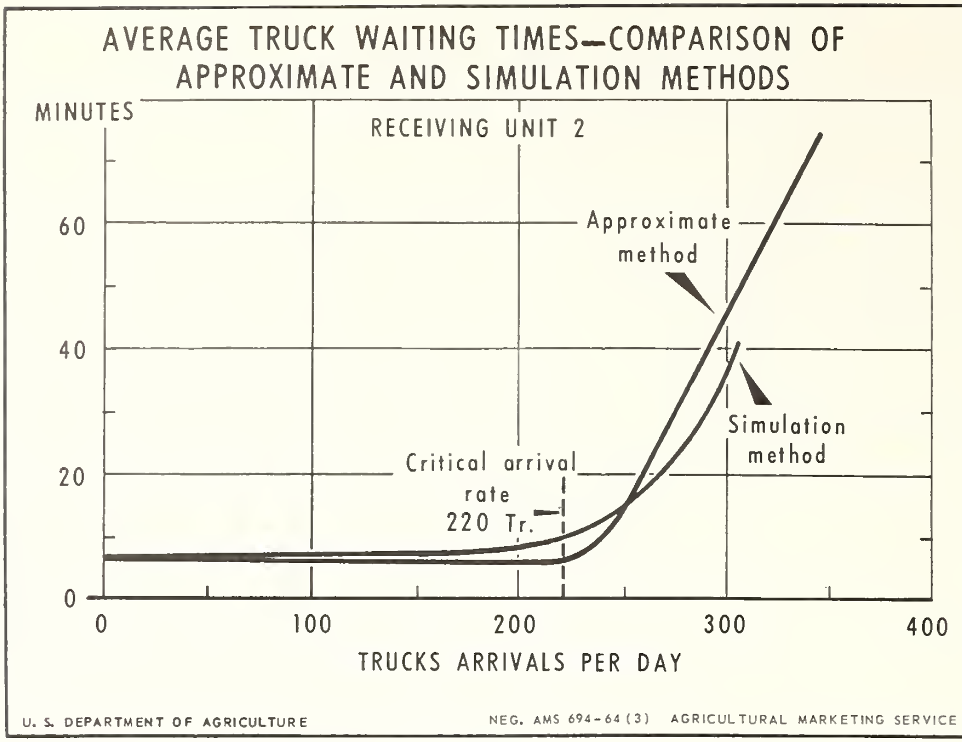


Figure 37

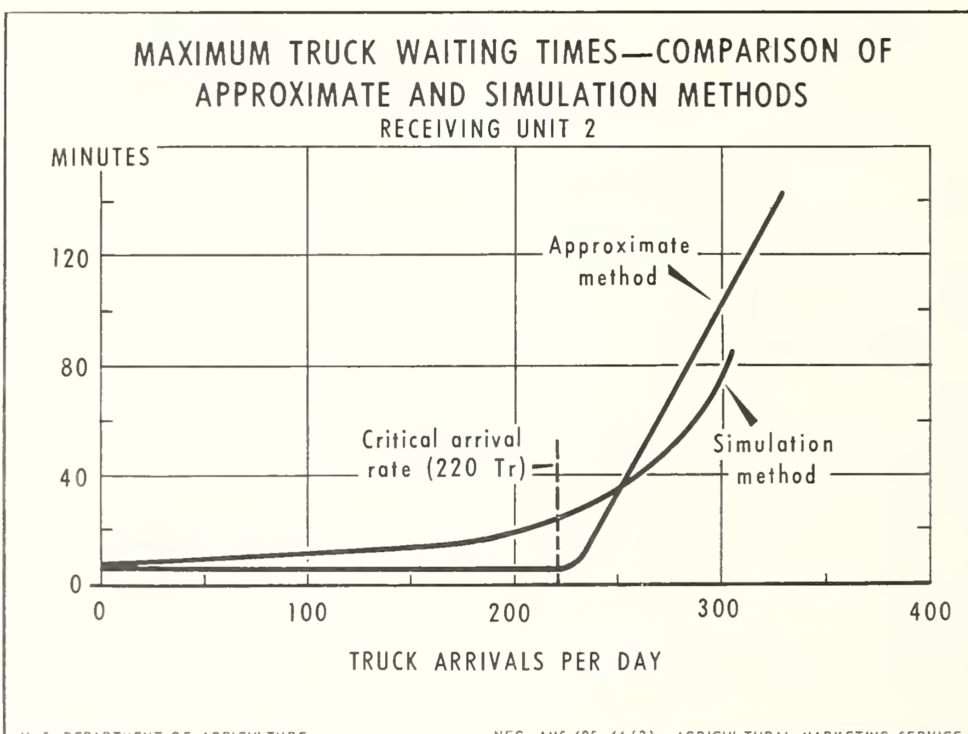


Figure 38

Table 13.--Correction factors to be added to or subtracted from waiting times determined by approximate method[1]

Ratio of daily arrival rate to critical arrival rate	Correction for average waiting times	Correction for maximum waiting times
	Percent	Percent
Under 0.4	0	+ 16
.5	+10	+ 84
.6	+13	+118
.7	+20	+150
.8	+26	+180
.9	+42	+240
1.0	+65	+320
1.1	+25	+ 28
1.2	-22	- 18
1.3	-29	- 27
1.4	-18	- 25

[1] Based on figures 37 and 38.

Improving Truck Receiving

The main purpose of this report is to study how to select the best capacity of a truck receiving system. But in conducting this study, several possible methods for improving truck receiving were discovered or noted. Many of these methods have not been tested but are suggested for consideration. The methods discussed here are related to three areas of improvement: (1) The harvesting system as a whole; (2) work methods for weighing, sampling, and unloading; and (3) facility design.

Improving the Harvesting System

To improve the harvesting system takes the cooperation of all the farmers, truckers, custom cutters, and elevator operators. Here are a few suggestions:

1. Encourage farmers and truckers to install better truck tailgates as described by Graves (5).

2. Try to even out the arrival of trucks. For example, a small premium might be paid for truckloads of dry grain arriving before noon and after 9 p.m.[13]

3. Change the working hours of receiving crews at the elevator to better fit the harvesting operation--say from 10 a.m. to 12 midnight.

4. Use sufficient trucks in the field so combines do not have to wait. Sometimes assigning two trucks and only one truck-driver to each combine works satisfactorily.

5. When arrivals are slow, assign receiving crews to other jobs such as loading boxcars.

6. In case trucks do have to wait a long time to unload, elevators could pay a small bonus to keep customers satisfied, instead of investing in excessive receiving facilities.

7. Provide better communications during harvest between harvesting crews, truckers, farmers, and elevator operators, by means of radio, television, helicopters, etc.

8. When extra-large harvests develop, be prepared both in the field and at the elevator for emergency methods, such as dumping grain on the ground.

9. Use larger grain bins on the combines to store grain while it is being harvested.

[13] Most farmers and truckers will try to bring their grain to the elevator before the afternoon rush if possible; the premium is designed to keep the farmer who is not in a hurry (who, for example, has completed his harvest) away from the elevator during the rush.

Improving Work Methods at the Elevator

By improving work methods at the elevator--such as keeping the drivers in the trucks, putting the farmer's name in large letters on the side of the trucks, having only one employee at the dump pit to give directions to the driver--the receiving rate at the elevator can be increased by 25 percent or more.

Details on improved work methods are discussed in several Department reports (5, 6, 13).

Improving the Design of Receiving Facilities

Several methods for improving the design of receiving facilities are listed:

1. Where scales and dump driveways are separated, provide plenty of space where trucks can wait between them. If this space is extremely small, the receiving unit is almost reduced to a one-stage operation (fig. 18) where a truck cannot enter the elevator until the previous one has left.

2. Provide plenty of room at the exit to the dump pit where trucks can turn around without backing up. This suggestion along with suggestion 1 are probably the two most important. For example, one elevator studied that did not provide adequate space between scale and pits and for trucks to turn around after dumping had a maximum waiting time of 42 minutes. Trucks could not move on or off the scale as rapidly as they should have. Another elevator with similar unloading crews and methods but with adequate site planning had a 14-minute maximum truck-waiting time. See page 25.

3. Provide level approaches to scales and dump pits so the trucks can move quickly without stalling.

4. Provide one-way traffic across the scales and place the office and the scale dial on the side where the truckdriver sits. In this way the truckdriver can communicate with the scale operator or tester without getting out of the truck.

5. Use traffic signals to direct trucks on and off scales and to and from the dump pits.

6. Have two large dump pits--over 1,000-bushel capacity each--in each driveway. Use one for wet grain when necessary.

7. Locate dump driveways close together where possible as shown in figure 39--rather than separated as shown in figure 20. When located together, unloading crews can coordinate their work better. (There may, however, be additional handling of the grain required to move it to the storage bins.)

8. Provide plenty of good lighting for night work at the elevator.

9. Provide dust control at the dump pit to improve working conditions.

10. Provide for auxiliary unloading equipment--such as pneumatic conveyors for unloading trucks into boxcars or flat storages--for periods of unusually rapid receipts.

11. Use electronic scales and other automatic weighing and sampling devices.

Figure 39 represents an improved layout for a medium-to-high-capacity truck receiving facility.

For a low-capacity facility, where fewer than 600 trucks are received per harvest season, receiving unit 1, shown in figure 18, is probably a good design. However, the size of dump pits might be enlarged and two bucket elevators used instead of one.

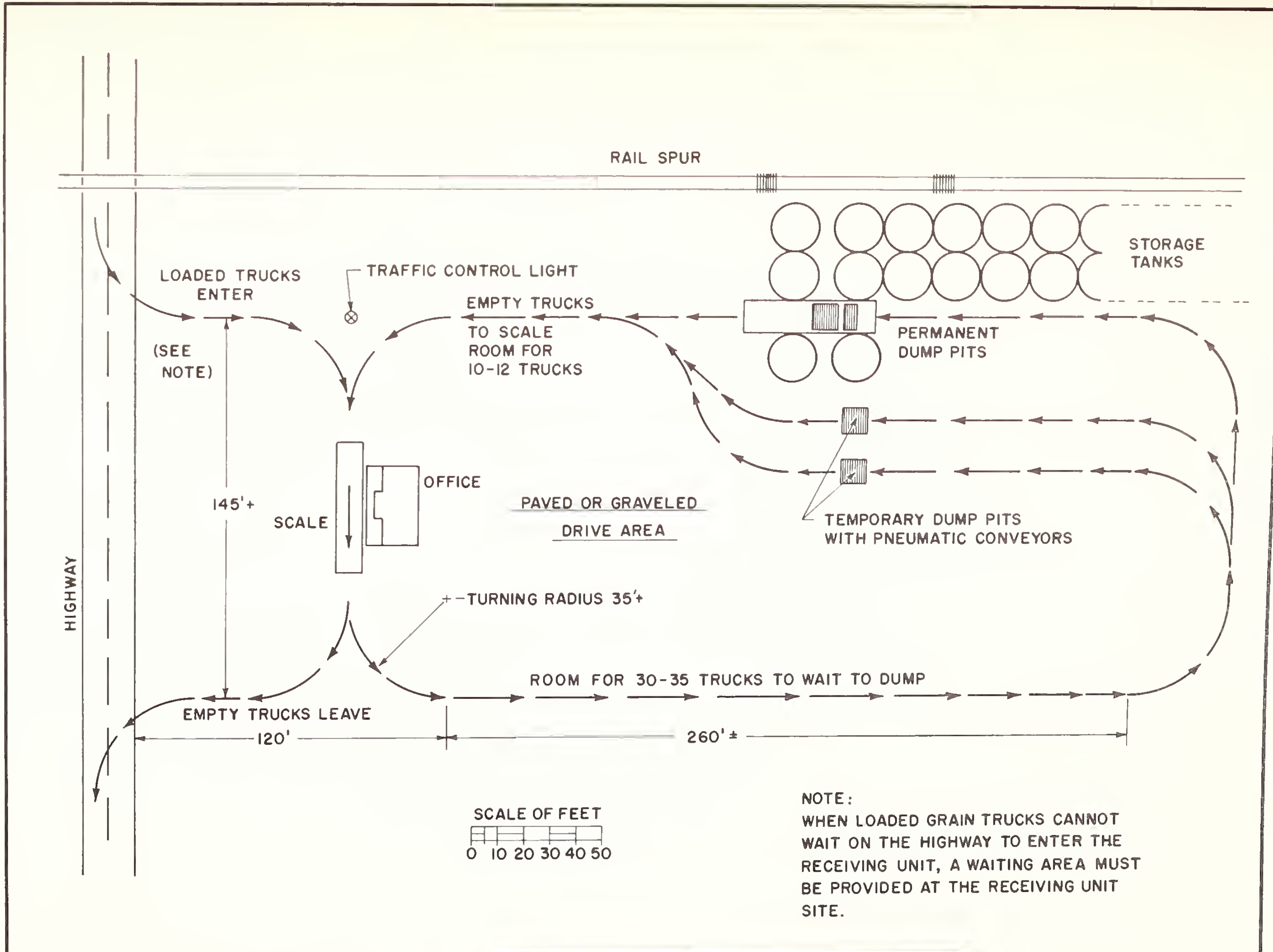


Figure 39.--An improved layout of medium-to-high-capacity truck receiving facility.

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APPENDIX

Computing Truck Waiting Costs

Several methods of evaluating truck waiting time and their limitations are discussed below:

Cost of Grain Deterioration Due to Weather

In the Central Great Plains the harvest-time for wheat is a very critical period. There are usually only several days, or one or two weeks at the most, in which this high-value crop can be harvested at maximum efficiency. If the harvest is delayed, it can cost the farmer money.[14] A waiting cost of $2.72 per hour per truck was assumed when harvest was delayed because of adverse weather. This was computed as shown in table 14, and as described below.

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[14] Other small grains--rye, oats, barley, etc.--also have a rather critical harvest period but their cash values are not as high as that of wheat. Corn, grain sorghum, and soybeans normally do not have as short and critical a harvest.

Wind, hail, and heavy rains are the greatest potential threats to the wheat crop at harvesttime. These adverse weather conditions can completely destroy a field of ripe wheat, and it is this threat that makes the farmer very anxious about any delays in the harvest and the delivery of his grain to the elevator. However, discussions with crop insurance actuaries indicate that the danger is probably not as acute as the farmer fears.

Other weather conditions will not completely destroy the grain but can lower its market value. In normal variable weather there is the chance of high temperature ripening the grain too rapidly with resulting kernel damage and grain losses during combining. Light rains or high humidity can increase the moisture content of the grain. If harvest is delayed because trucks have to wait, these changes in the grain can lower the grade of the crop and may reduce its value by 10 cents or more to the bushel.

Although it may cost the farmer in the long run only something like $3 per hour for truck waiting during less than ideal weather (see table 14), many farmers probably place a larger value than that on harvesting delays because they are not willing to chance a complete crop loss.

Cost of Trucking Grain to the Elevator

The cost of trucking grain is estimated to be between $3.80 and $11 per hour per truckload as explained in the following paragraphs.

In the Central Great Plains most truckers charge the farmer around 5 to 8 cents per bushel to haul grain to the local elevator at harvesttime. The distance the grain is hauled usually affects the rates as most truckers have rate scales for various distances. Normally most trucks charge on the bushel-hauled basis rather than an hourly basis, but the anticipated waiting time at elevators probably has some effect on this hauling rate. How much is not known.

If these hauling rates per bushel were converted into hourly rates they would average about $11 per hour per truck, depending on size of trucks, distances grain is hauled, and the time it takes to unload.[15] But since grain is hauled on a bushel basis, this hauling rate of $11 per hour is usually not a direct cost to the farmer or elevator owner.

The direct hourly cost of a truck and driver might be a better indication of the cost to the farmer and elevator owner. The direct cost of the truck and driver in 1962 in this area was probably less than $4 per hour as shown below:

Wages for truckdriver . .	$1.80 per hour
Cost for owning and operating a truck	2.00 per hour
Total trucking cost .	$3.80 per hour

Cost of Harvesting the Crop

The cost of combines waiting because trucks have to wait at the elevator may be a better criterion for measuring waiting costs than truck waiting. It is estimated that combine waiting cost is between $5.80 and $14 an hour as described in the following paragraphs.

Large combines harvest most of the grain crop in this country. Besides wheat and other small grains, combines harvest soybeans, grain sorghum, rice, and even some corn. Many of the combines are owned and operated by custom operators who travel through the grain-producing areas. For example, during the wheat and other small grain harvest season, combine crews will move from Texas northward to the Canadian border; harvesting moves slowly northward at the rate of 10 to 20 miles per day. Custom combine operators usually hire out on the basis of cutting and hauling, but often hire out just to cut grain and sometimes just to haul grain. Many grain farmers own one or more combines, but if weather is critical at harvest the farmer may also hire custom combines to get the job done in a hurry.

A short wait by trucks at the elevator to unload may not delay the combines, which can often operate up to a half hour loading grain into the storage tank on the combine. Sometimes trucks may not have

[15] If waiting lines are not too long at the elevator, trucks can usually make the complete cycle of loading, going to the elevator and dumping the load, and returning to the field in 1 to 1-3/4 hours.

Table 14.--Estimated long range cost of grain truck waiting due to harvesting wheat under various weather conditions in the Central Great Plains[1]

Weather conditions at harvest	Probability of weather conditions	Estimated value of a truckload of grain		Estimated value weighted by weather probability	
		Trucks not waiting	Trucks waiting 1 hour	Trucks not waiting	Trucks waiting 1 hour
		Dollars	Dollars	Dollars	Dollars
Very adverse (hail, wind, etc.).....	[2] 0.01	[3] 134.17	0	1.34	0
Normal...........	[4] .60	402.50	[5] 400.20	241.50	240.12
Ideal............	[6] .39	[7] 404.80	404.80	157.87	157.87
Average expected value..........				400.71	397.99

Estimated cost of grain truck waiting = 400.71 - 397.99 = 2.72 dollars per hour

[1] A 230-bushel truck size is assumed and a market value of $1.75 per bushel under normal weather conditions with no waiting.

[2] Crop insurance data indicate that in Kansas about 50 million bushels of wheat were destroyed by hail, wind, and flooding from 1939 to 1962; in this same period about 4 billion bushels of wheat were produced or about 80 bushels for every bushel destroyed. Much of this damage occurred around harvesttime.

[3] One third of the value under normal conditions is assumed.

[4] A study in Kansas (14, page 10) found that 50 percent of the elevators receive high-moisture grain in 2 to 5 years out of 10. Damaged kernels, foreign material, and combining losses would also be common problems in a normal harvest.

[5] A loss of 1 cent per bushel is assumed.

[6] 1.00 - 0.01 - 0.60 = 0.39.

[7] An increase of 1 cent per bushel is assumed over normal weather conditions.

to wait at all to unload; but if the trucks have to travel a long distance to the elevator, the combines may be delayed waiting for the trucks to return. When truck waiting causes combine waiting, both combining and trucking costs might be considered as waiting cost.

During the 1962 wheat harvest in the Central Great Plains, custom combine operators charged about $3 per acre or about 10 cents a bushel to cut grain. To harvest and haul grain to the local elevator they charged about $5 per acre or about 16 cents a bushel. Normally, custom combine operators do not charge on an hourly basis, but if the rates were converted to hourly rates it would amount to about $14 an hour to cut grain and about $23 per hour to cut and haul. (Wheat can be combined at a rate of close to 5 acres an hour in this area.)

Since the farmers and elevators do not pay for combining on an hourly basis, these rates probably are not very realistic for waiting costs. A direct hourly cost for owning the combine and paying the operator may be more realistic. This is estimated to be about $6 per hour, as shown below:[16]

Wage for combine operator...........	$1.80 per hour
Direct cost for owning and operating combine .	4.00 per hour
Total...........	$5.80 per hour

[16] Some studies (8, 9) indicate combining cost from $7 an hour up for farm-owned machinery. Custom operators should have a lower hourly cost because depreciation and other fixed costs can be distributed over more hours.

Cost of Rehandling Grain Unloaded in the Field

It is estimated to cost about $6.70 to rehandle a truckload of grain unloaded in the field. This is important because if waiting lines are too long at the elevator, farmers may unload grain trucks in the field or somewhere on the farm. Grain may be dumped on the ground or on large plastic sheets, or put into some kind of temporary storage.[17] Grain will later be reloaded into trucks and carried to the elevator.

This extra handling and temporary storage costs money; exactly how much is not known. There is the direct labor and equipment cost for handling the grain, the possibility of damage to the grain from the extra handling, and a chance of spoilage or damage to the grain from being stored on the ground. One farmer in Kansas indicated that rather than wait an hour to unload at the elevator he would dump the grain on the ground and figured this cost would be 3 cents per bushel. Assuming a 230-bushel truckload, this would amount to a truck waiting cost of $6.90 per hour per truck.

Cost Farmers Place on Truck Waiting Time

A few informal interviews were made with wheat farmers in the Central Great Plains. These farmers indicated a waiting cost that averaged $8.12 per hour per truckload, and it would seem that the value farmers place on truck waiting time would be a good indication of waiting costs. They are the customers the elevator operator must please. They have balanced many of the factors and costs involved in waiting in their own minds--the cost of adverse weather, idle trucks, idle combines and crews, the possibility of dumping grain in the field, and other factors.

As part of a previous study on commercial grain sales in Missouri, farmers were asked what price discount they would be willing to accept to get their grain unloaded immediately rather than wait a certain period (15). (Conversely, this might be thought of as the premium the elevator operator would have to pay his waiting customers to keep them satisfied.) Data from that report were used to determine the cost farmers place on truck waiting. The results are shown in figure 40. The shape of this curve is probably more realistic than a straight line curve. Farmers are willing to wait short periods as this would probably not upset their harvesting operation; they get more impatient as waiting times approach one hour. After one hour there is little increase in cost of waiting time because the harvesting operations would have already been upset and the farmer would take such steps as dumping the grain in the fields, add more trucks to the system, or take his grain to another elevator. Plotting a straight line through the points on the curve gives a waiting cost of around 75 cents per hour.

This cost would not be applicable in the Wheat Belt of the Central Great Plains area, for in Missouri there are many small general farms and few big cash grain farms; the grain trucks used were one-third the size of the trucks used in Kansas, Nebraska, and eastern Colorado. Much of the grain harvested in Missouri is corn, which does not have a harvest period as critical as that for wheat.

Cost Elevator Operators Place on Truck Waiting

The Missouri study previously mentioned (15) indicated that 86 percent of the elevator operators consider speed of unloading an important factor.

A few informal interviews were conducted with operators in Kansas, Nebraska, and eastern Colorado to determine what value they placed on truck waiting. For example, they were asked what they would spend to improve unloading if trucks waited to unload a certain length of time. It was difficult to convert the limited information obtained into a truck cost per hour. The elevator operators were not particularly concerned about the 10- to 20-minute wait. The information from one operator indicated a truck time cost of about $7 per hour per truck. For lack of better information, let us consider this figure reasonable.

[17] Some grain may, of course, be put into more or less permanent storage on the farm under normal conditions; this has no relationship to waiting lines at the elevator. In some areas of the Corn Belt, most of the corn harvested is normally put into farm storage.

A Comparison of Truck Waiting Costs

As just shown, there are many ways to evaluate truck waiting cost (or combine waiting costs). The cost of threatening weather should probably be added to many of the other costs. For example, the farmer would not only have a direct cost of \$3.80 an hour for a truck but would also have a cost of \$2.72 an hour for threatening weather, or a total cost of \$6.52 per hour.

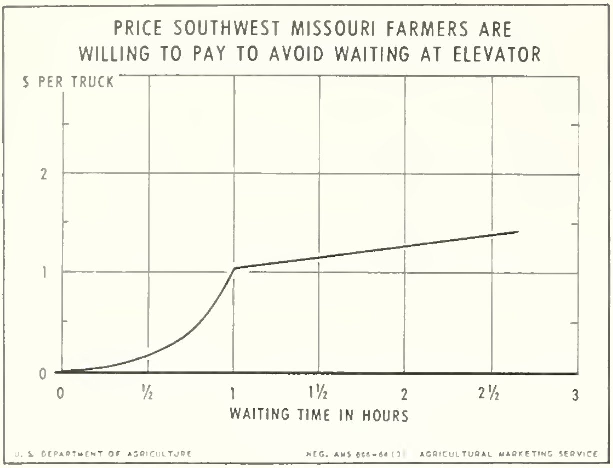

Figure 40

A comparison of the various waiting costs, as given in the previous discussion, and combinations of these costs are shown in figure 41. It is believed that some of the highest and lowest hourly costs are not very realistic. Averaging estimates for methods 6 through 14 gives \$8.43 per hour for truck waiting cost. Although some of these costs are not linear, for simplicity we shall assume a truck waiting cost of \$8 per hour per truck.

Truck waiting time is closely related to combine waiting time, but combine waiting time is sometimes a more useful measure of waiting costs. Methods 6, 8, 9, 12, and 14 were averaged to get a combine waiting cost of \$8.64 per hour per combine. We shall assume a combine waiting cost of \$9.00 per hour.

Service Time Distribution

In theoretical waiting line problems, the time to service an arriving unit (a grain truck in our case) follows one of the family of Erlang curves (11, page 143). This family of curves is shown in figure 42. The service times are shown on the horizontal axis and the frequency or probabilities are shown on the vertical axis.

In figure 42 the service times shown on the horizontal axis are given as a product of μ (the mean service rate) and t (time); to find the actual service times, divide the reading on the horizontal axis by μ.

The formula for this family of curves is shown below (8, p. 41):

$$So(t) = e^{-k\mu t} \sum_{n=o}^{k-1} \frac{(k\mu t)^n}{n!}$$

μ = mean service time
k = number of exponential service phases
So(t) = Service time distribution--the probability that the service operation takes longer than μt
t = time
n = whole numbers from o to k-1

This family of curves ranges from the exponential curve of k = 1 with its widest distribution of service times to the constant service-time situation where k = infinity.

Most of the service times observed at country elevators fit one of these curves reasonably well. Figure 43 shows the distribution of time to weigh loaded trucks. Curves for the other operations performed at the elevator were similar to figure 43. However, in most of these curves k varied from 4 to 10.

The Simulation Program

As mentioned on page 17, the flow of trucks through the elevator was simulated with time values, using an electronic computer. The data were programed by using Fortran and were run on an IBM 7074 computer. The method used was a rather typical Monte Carlo approach using random numbers to generate the samples from distribution functions developed from the field studies. The method is discussed by Miller and Starr (10) and Sasieni and others (12). Truck arrival times and service times are determined from statistical distribution functions such as the one shown in figure 43. A number from .00 to .99 is selected from a table of random numbers. From this number the service time is determined from the distribution function as shown in figure 44.

Using this approach, a complete day's movement of trucks was simulated for each receiving unit for eight different daily arrival rates of trucks. The eight different rates were used to provide a wide range of daily arrival patterns. These rates range from 20 to 160 percent of the critical daily

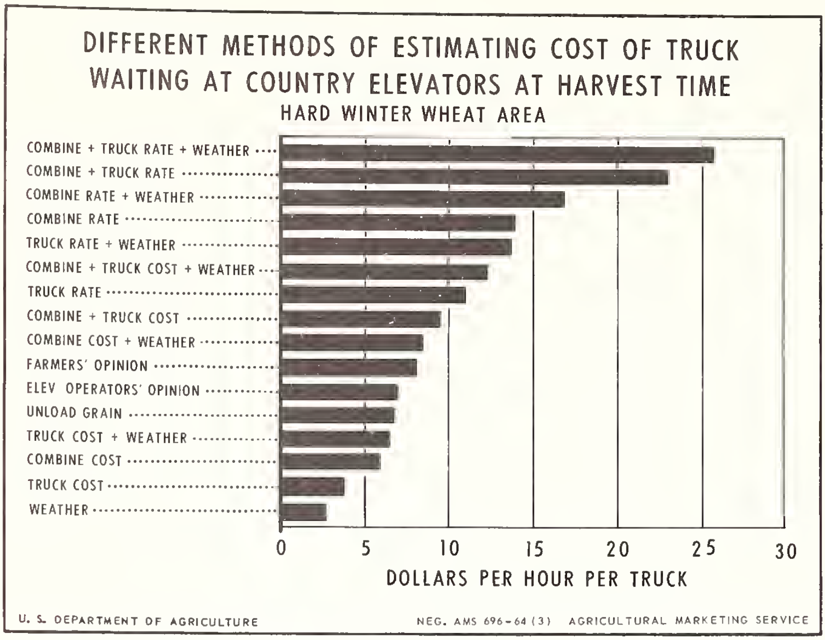

Figure 41

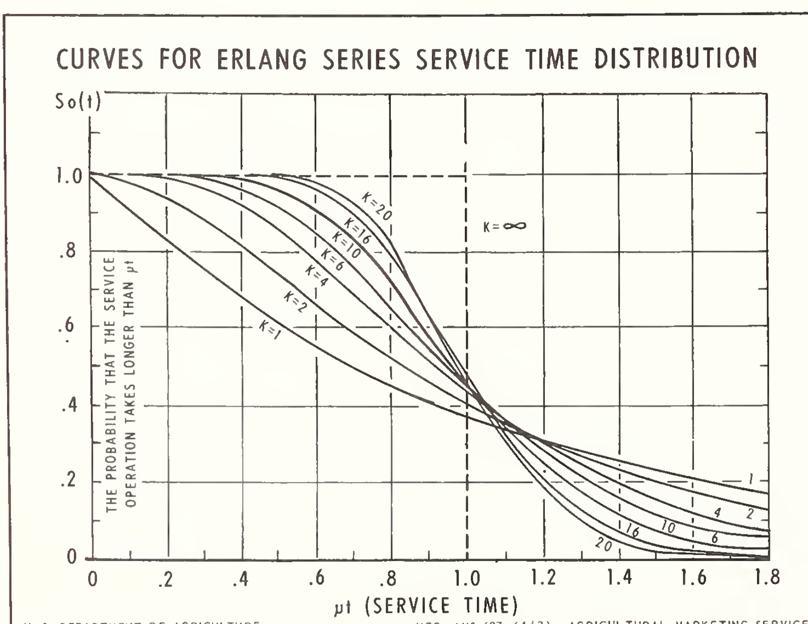

Figure 42

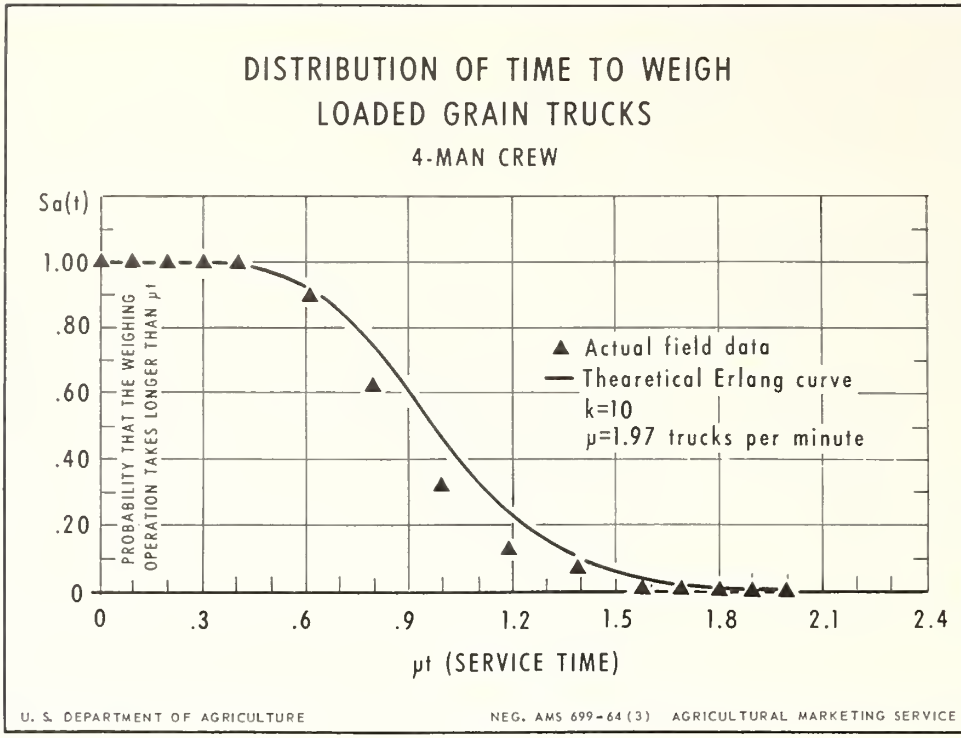

Figure 43

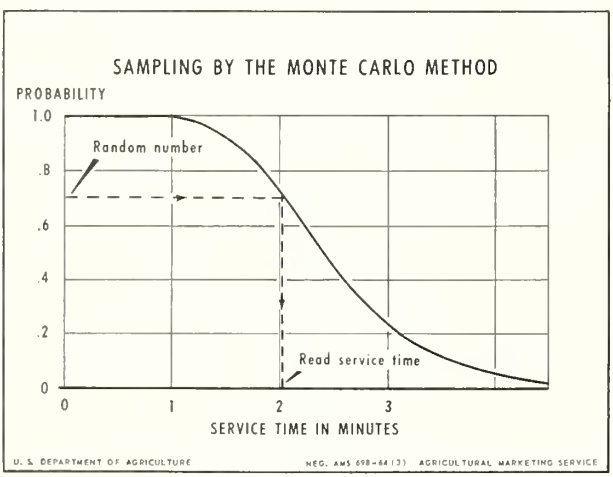

Figure 44

rate (see table 3). In order to have a sufficient sample, each of these daily rates was simulated three times; thus, when studying a daily rate of 300 trucks per day, the movement of 900 truckloads was simulated. It is estimated that the movement of about 15,000 truckloads was simulated for the entire program. Data from the simulation program were used to plot waiting times for different daily arrival rates (see figures 21 through 27). Data from these curves, along with the seasonal pattern of truck arrivals shown in figure 7, were used to determine seasonal waiting times (see figures 29-31).

A portion of data output from the computer for receiving unit 1 is shown in figure 45. To follow the movement of a truckload through the elevator, back to the field, loading up, and returning to the elevator, read horizontally across the data (fig. 45). See table 15.

A portion of the data output from the computer for receiving units 2 and 3 is shown in figures 46 and 47.

There were several special problems in this program. For example, one was the problem of determining truck arrival times at the elevator, (T3), (figs. 45, 46, and 47). The first method considered was to bring trucks to the elevator at random intervals during the hour using a Poisson distribution and to bring them in on a daily pattern according to figure 11. However, it was believed that if the daily arrival rate of trucks was very high, trucks would wait in line so long that they could not return

T1 TIME BETWEEN ARRIVALS OR DEPARTURES	T2 TIME TRUCK ENTERS OR LEAVES THE SYSTEM	TRK TRUCK NUMBER	T3 TIME TRUCK ARRIVES AT RECEIVING UNIT	T4 MOVES TO SCALE AND DUMP PIT	T5 WEIGHING AND DUMPING	T6 MOVES FROM SCALE AND DUMP PIT	T7 RETURNING TO FIELD	T8 LOADING UP IN FIELD	T9 RETURNING TO ELEVATOR	T10 ARRIVES AT ELEVATOR	T11 TIME TRUCK IS AWAY FROM FIELD	T12 TIME COMBINE WAITS FOR TRUCK	T13 TIME TRUCK SPENDS AT ELEVATOR X# 1.2
20.	560.	45	560.00	560.00	5.91	565.91	10.00	49.22	12.00	637.13	27.91	0.00	5.91
0.	0.	46	573.25	573.25	9.84	583.09	10.00	47.83	12.00	652.92	31.84	1.84	9.84
20.	580.	47	580.00	583.09	4.11	587.20	8.00	183.49	10.00	788.69	25.20	0.00	7.20
0.	0.	48	581.63	587.20	3.82	591.02	10.00	6.51	12.00	619.53	31.39	1.39	9.39
0.	0.	49	582.76	591.02	5.91	596.93	10.00	31.88	12.00	650.81	36.18	6.18	14.18
0.	0.	50	589.38	596.93	4.81	601.74	6.00	269.93	8.00	885.67	26.36	0.00	12.36
20.	600.	51	600.00	601.74	4.11	605.85	7.00	55.10	9.00	676.95	21.85	0.00	5.85
0.	0.	52	602.98	605.85	6.43	612.28	13.00	241.95	15.00	882.24	37.31	7.31	9.31
0.	0.	53	605.33	612.28	5.21	617.49	12.00	174.28	14.00	817.77	38.16	8.16	12.16
0.	).	54	608.39	617.49	5.91	623.40	12.00	95.65	14.00	745.06	41.01	11.01	15.01
0.	0.	55	619.53	623.40	6.43	629.83	6.00	95.65	8.00	739.49	24.30	0.00	10.30
0.	0.	56	620.43	629.83	4.81	634.64	10.00	27.63	12.00	684.28	36.21	6.21	14.21
0.	0.	57	624.41	634.64	4.11	638.75	10.00	52.10	12.00	712.85	36.34	6.34	14.34
0.	0.	58	637.13	638.75	8.57	647.32	10.00	41.25	12.00	710.57	32.19	2.19	10.19
0.	0.	59	650.81	650.81	4.81	655.62	10.00	11.21	12.00	688.84	26.81	0.00	4.81
0.	0.	60	652.92	655.62	5.67	661.29	10.00	26.61	12.00	709.91	30.37	0.37	8.37
0.	0.	61	668.06	668.06	5.21	673.27	10.00	74.44	12.00	769.71	27.21	0.00	5.21
0.	0.	62	675.82	675.82	6.72	682.54	9.00	8.82	11.00	711.36	26.72	0.00	6.72
0.	0.	63	676.95	682.54	5.44	687.98	5.00	206.71	7.00	906.68	23.03	0.00	11.03
0.	0.	64	684.28	687.98	2.78	690.76	9.00	66.76	11.00	777.52	26.48	0.00	6.48
0.	0.	65	688.84	690.76	3.82	694.58	12.00	101.41	14.00	821.99	31.74	1.74	5.74
0.	0.	66	694.97	694.97	9.84	704.81	5.00	130.90	7.00	847.71	21.84	0.00	9.84
0.	0.	67	709.91	709.91	4.11	714.02	12.00	12.86	14.00	752.87	30.11	0.11	4.11
0.	0.	68	710.57	714.02	7.41	721.43	1/						10.85

VALUES SHOWN ARE IN MINUTES

1/ BLANK SPACE INDICATES THE TRUCK LEFT THE SYSTEM (DETERMINED FROM COLUMN T2.)

Figure 45.--A portion of the simulation data for receiving unit 1 indicating the movement of trucks in minutes.

to the field, and this would upset the daily arrival pattern. Under these circumstances figure 11 would not represent the true pattern.

So a method was devised where new trucks (trucks that have not been to the elevator earlier in the day) entered the harvesting system (T1 and T2 in figs. 45, 46 and 47) or trucks in the system left. The method for bringing trucks into and out of the system was to use hourly coefficients or percentages of the total truckloads for the day. These coefficients were determined from a trial and error method until T3 would give an arrival pattern similar to figure 11 for the lower daily arrival rates. New trucks from T2 move through the

Table 15.--Example of simulated truck movement - truckload 51, receiving unit 1[1]

Column in figure 45, and operation	Service times	Cumulated time[2]
	Minutes	Minutes
T3-arrives at the elevator..........		600.00
T4-enters the receiving unit........		601.74
T5-weighing and unloading...........	4.11	
T6-leaves the receiving unit........		605.85
T7-returning to the field...........	7.00	
T8-loading up in the field..........	55.10	
T9-returning to the elevator........	9.00	
T10-arrives at the elevator (reenters as truckload 63 in T3)..		676.95

[1] Truckload 51 waits 1.74 minutes until truckload 50 leaves the receiving unit. The time the combine waits in the field for the truck to return is shown in T12 (fig. 45); the time the truck spends at the elevator is shown in T13.

[2] Truckload 51 arrives in the middle of the day, 600 minutes after the first truck arrives at the elevator.

TIME BETWEEN ARRIVALS OR DEPARTURES	TIME TRUCK ENTERS OR LEAVES THE SYSTEM	TRUCK NUMBER	TIME TRUCK ARRIVES AT RECEIVING UNIT	MOVES ON SCALE	WEIGHING LOADED	LEAVES SCALE	ARRIVES AT DUMP PIT	MOVES TO DUMP PIT	UNLOADING AT DUMP PIT	MOVES FROM DUMP PIT	ARRIVE AT SCALE	MOVES ON SCALE	WEIGHING EMPTY
T1	T2	TRK	T3	T4	T5A	T5B	T5C	T5D	T5E	T5F	T5G	T5H	T5I X* 1.4
0.	0.	184	647.99	651.23	0.86	652.09	652.37	685.85	2.44	688.29	688.89	689.89	0.41
0.	0.	185	648.39	652.87	0.98	653.85	654.13	686.29	1.82	690.11	690.71	690.71	2.59
0.	0.	186	652.95	653.85	0.49	654.34	654.62	690.11	1.96	692.07	692.67	693.30	2.11
0.	0.	187	655.52	655.62	1.17	656.79	657.07	692.07	3.65	695.72	696.32	696.32	0.59
0.	0.	188	660.48	660.60	0.56	661.16	661.44	695.72	2.07	697.79	698.39	698.39	1.05
0.	0.	189	660.56	662.71	1.40	664.11	664.39	697.79	2.60	700.39	700.99	700.99	2.11
0.	0.	190	661.13	664.11	0.70	664.81	665.09	700.39	5.25	705.64	706.24	706.24	1.48
0.	0.	191	666.43	666.48	0.91	667.39	667.67	705.64	4.37	710.01	710.61	710.61	0.70
0.	0.	192	671.35	671.35	0.73	672.08	672.36	710.01	2.74	712.75	713.35	713.35	1.13
0.	0.	193	671.46	672.08	1.40	673.48	673.76	712.75	1.68	714.43	715.03	715.03	2.11
0.	0.	194	671.79	675.01	0.45	675.46	675.74	714.43	5.25	719.68	720.28	720.28	1.21
0.	0.	195	675.90	675.90	0.73	676.63	676.91	719.68	1.82	721.50	722.10	722.10	1.81
0.	0.	196	680.69	680.69	0.86	681.55	681.83	721.50	2.07	723.57	724.17	724.17	1.21
0.	0.	197	685.02	685.51	0.70	686.21	686.49	723.57	2.60	726.17	726.77	726.77	2.59
0.	0.	198	686.91	688.76	0.56	689.32	689.60	726.17	2.74	728.91	729.51	729.51	0.70
0.	0.	199	690.98	693.30	0.56	693.86	694.14	726.91	2.33	731.24	731.84	731.84	1.28
0.	0.	200	706.49	707.72	0.77	708.49	708.77	731.24	1.50	732.74	733.34	733.34	1.29
0.	0.	201	706.81	708.49	0.27	708.76	709.04	732.74	3.05	735.79	736.39	736.39	1.58
0.	0.	202	707.32	708.76	0.91	709.67	709.95	735.79	5.25	741.04	741.64	741.64	2.59
0.	0.	203	715.49	717.14	0.49	717.63	717.91	741.04	1.68	742.72	743.32	744.23	2.11
0.	0.	204	716.32	717.63	1.06	718.69	718.97	742.72	2.33	745.05	745.65	746.34	2.11
0.	0.	205	716.92	718.69	0.70	719.39	719.67	745.05	2.44	747.49	748.09	748.45	1.31
0.	0.	206	721.82	723.91	0.27	724.18	724.46	747.49	1.82	749.31	749.91	750.26	0.70
0.	0.	207	725.09-	725.38	0.81	726.19	726.47	749.31	1.82	751.13	751.73	751.73	0.97

VALUES SHOWN ARE IN MINUTES

Figure 46.--A portion of the simulation data for receiving

elevator (T3 to T10) as shown in table 15 and reenter the elevator later in T3. T3 is a chronological listing of new trucks (T2) and trucks already in the system (T10). Use of this method resulted in less deviation from figure 11 for the higher daily arrival rates than was anticipated.

Another problem for receiving units 2 and 3 was in programing T5H--the time trucks enter the scale to weigh empty (figs. 46 and 47). This value should be the latest of the following times:

1. The time the truck arrives at the scale to weigh empty (T5G).

2. The time the previous truck weighing empty leaves the scale. (T6).

3. The time a truck weighing loaded leaves the scale when the truck in question arrives to weigh empty (T5B).

This last check was the problem because it was impossible to program these later trucks ahead in T3 because of limitation of the memory positions available in the computer. The impossibility of making this last check presented a situation where trucks were weighing loaded and empty on the scale at the same time. This problem was partially solved by not letting trucks enter the scale to weigh loaded (T4) if there were any trucks on the scale weighing or within 0.3 minute of arriving at the scale to weigh empty. This approach worked fairly well.

In receiving unit 3 (fig. 47) where there are three dump driveways the setup was that trucks always entered dump (1) (T5D1) if it was empty; if dump (1) was not empty a truck entered dump (2) (T5D2); if neither of these were empty a truck entered dump (3) (T5D3). If all dumps were in use when a truck arrived, it waited and entered the first dump that was empty.

TIME BETWEEN ARRIVALS OR DEPARTURES T1	TIME TRUCK ENTERS OR LEAVES THE SYSTEM T2	TRUCK NUMBER TRK	MOVES FROM SCALE T6	RETURNING TO FIELD T7	LOADING UP IN FIELD T8	RETURNING TO ELEVATOR T9	ARRIVES AT ELEVATOR T10	TIME TRUCK IS AWAY FROM FIELD T11	TIME COMBINE WAITS FOR TRUCK T12	TIME TRUCK SPENDS AT ELEVATOR T13	X= 1.4
0.	0.	184	689.30	9.00	114.59	11.00	823.89	61.31	31.31	41.31	
0.	0.	185	693.30	10.00	83.07	12.00	798.37	66.91	36.91	44.91	
0.	0.	186	695.41	14.00	32.98	16.00	758.39	72.46	42.46	42.46	
0.	0.	187	696.91	10.00	41.25	12.00	760.16	63.29	33.29	41.29	
0.	0.	188	699.44	4.00	53.58	6.00	763.02	48.96	18.96	38.96	
0.	0.	189	703.10	10.00	37.59	12.00	762.69	64.54	34.54	42.54	
0.	0.	190	707.72	1/						46.59	
0.	0.	191	711.31	10.00	6.51	12.00	739.82	66.88	36.88	44.88	
0.	0.	192	714.48	11.00	152.30	13.00	890.78	67.13	37.13	43.13	
0.	0.	193	717.14	10.00	80.81	12.00	819.95	67.68	37.68	45.68	
0.	0.	194	721.49	12.00	174.28	14.00	921.77	75.70	45.70	49.70	
0.	0.	195	723.91	9.00	152.30	11.00	896.21	68.01	38.01	48.01	
0.	0.	196	725.38	11.00	12.03	13.00	761.41	68.69	38.69	44.69	
0.	0.	197	729.36	10.00	41.25	12.00	792.61	66.34	36.34	44.34	
0.	0.	198	730.21	10.00	43.81	12.00	796.02	65.30	35.30	43.30	
0.	0.	199	733.12	9.00	95.65	11.00	848.77	62.14	32.14	42.14	
0.	0.	200	734.62	5.00	206.71	7.00	953.33	40.13	10.13	29.13	
0.	0.	201	737.97	14.00	18.94	16.00	786.91	61.16	31.16	31.16	
0.	0.	202	744.23	7.00	14.54	9.00	774.77	52.91	22.91	36.91	
0.	0.	203	746.34	10.00	6.51	12.00	774.85	52.85	22.85	30.85	
0.	0.	204	748.45	10.00	70.49	12.00	840.94	54.13	24.13	32.13	
0.	0.	205	750.26	15.00	10.41	17.00	792.67	65.34	35.34	33.34	
0.	0.	206	750.96	8.00	140.78	10.00	909.74	47.14	17.14	29.14	
0.	0.	207	752.70	16.00	18.03	18.00	804.73	61.61	31.61	27.61	

VALUES SHOWN ARE IN MINUTES

1/ BLANK SPACES INDICATE THE TRUCK LEFT THE SYSTEM. (DETERMINED FROM COLUMN T2)

unit 2 indicating the movement of trucks in minutes.

T1	T2	TRK	T3	T4	T5A	T5B	T5C	T5D1	T5C2	T5C3	T5E	T5F	T5G X# 1.0
TIME BETWEEN ARRIVALS AND DEPARTURES	TIME TRUCK ENTERS OR LEAVES THE SYSTEM	TRUCK NUMBER	TIME TRUCK ARRIVES AT RECEIVING UNIT	MOVES ON SCALE	WEIGHING LOADED	LEAVES SCALE	ARRIVES AT DUMP PIT	MOVES TO DUMP PIT NO. 1	MOVES TO DUMP PIT NO. 2	MOVES TO DUMP PIT NO. 3	UNLOADING AT DUMP PIT	MOVES FROM DUMP PIT	ARRIVES AT SCALE
0.	0.	121	334.07	336.22	0.42	336.64	336.92	0.00	0.00	336.92	1.29	338.21	338.81
0.	0.	122	335.55	336.64	0.76	337.40	337.68	0.00	337.89	0.00	5.25	343.14	343.74
0.	0.	123	335.67	337.40	0.65	338.05	338.33	0.00	0.00	338.33	1.82	340.15	340.75
2.	336.	124	336.00	338.05	0.71	338.76	339.04	339.04	0.00	0.00	2.20	341.24	341.84
0.	0.	125	336.11	339.50	0.33	339.83	340.11	0.00	0.00	340.15	2.07	342.22	342.82
2.	338.	126	338.00	340.73	0.68	341.41	341.69	341.69	0.00	0.00	1.29	342.98	343.58
2.	340.	127	340.00	341.41	0.57	341.98	342.26	0.00	0.00	342.26	2.90	345.16	345.76
0.	0.	128	341.15	341.98	0.27	342.25	342.53	342.98	0.00	0.00	2.33	345.31	345.91
2.	342.	129	342.00	342.25	0.51	342.76	343.04	0.00	343.14	0.00	2.74	345.88	346.48
0.	0.	130	342.43	342.76	0.27	343.03	343.31	0.00	0.00	345.16	1.50	346.66	347.26
2.	344.	131	344.00	345.64	0.45	346.09	346.37	346.37	0.00	0.00	3.65	350.02	350.62
0.	0.	132	344.03	346.81	0.57	347.38	347.66	0.00	347.66	0.00	5.25	352.91	353.51
0.	0.	133	344.61	348.25	0.49	348.74	349.02	0.00	0.00	349.02	3.65	352.67	353.27
2.	346.	134	346.00	348.74	0.76	349.50	349.78	350.02	0.00	0.00	2.20	352.22	352.82
0.	0.	135	347.29	349.50	0.27	349.77	350.05	352.22	0.00	0.00	3.05	355.27	355.87
2.	348.	136	348.00	349.77	0.83	350.60	350.88	0.00	0.00	352.67	2.60	355.27	355.87
0.	0.	137	348.10	351.09	0.71	351.80	352.08	0.00	352.91	0.00	1.50	354.41	355.01
0.	0.	138	349.89	351.80	0.33	352.13	352.41	0.00	354.41	0.00	2.33	356.74	357.34
2.	350.	139	350.00	352.13	0.46	352.59	352.87	355.27	0.00	0.00	5.25	360.52	361.12
2.	352.	140	352.00	352.59	0.71	353.30	353.58	0.00	0.00	355.27	2.74	358.01	358.61
0.	0.	141	352.02	355.06	0.57	355.63	355.91	0.00	356.74	0.00	2.44	359.18	359.78
0.	0.	142	353.05	357.44	0.37	357.81	358.09	0.00	0.00	358.09	2.33	360.42	361.02
0.	0.	143	354.90	357.82	0.49	358.31	358.59	0.00	359.18	0.00	2.07	361.25	361.85
0.	0.	144	357.08	358.31	0.71	359.02	359.30	0.00	0.00	360.42	2.60	363.02	363.62

VALUES SHOWN ARE IN MINUTES

Figure 47.--A portion of the simulation data for receiving

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TIME BETWEEN ARRIVALS OR DEPARTURES	TIME TRUCK ENTERS OR LEAVES THE SYSTEM	TRUCK NUMBER	MOVES ON SCALE	WEIGHING EMPTY	MOVES FROM SCALE	RETURNING TO FIELD	LOADING UP IN FIELD	RETURNING TO ELEVATOR	ARRIVES AT ELEVATOR	TIME TRUCK IS AWAY FROM FIELD	TIME COMBINE WAITS FOR TRUCK	TIME TRUCK SPENDS AT ELEVATOR	
T1	T2	TRK	T5F	T5I	T6	T7	T8	T9	T10	T11	T12	T13	X# 1.C
0.	C.	121	34C.00	C.73	34C.73	11.CO	183.49	13.CC	548.22	30.66	C.66	6.66	
0.	C.	122	343.74	C.25	343.99	8.CC	46.46	1C.CO	4C8.45	26.44	C.00	8.44	
0.	C.	123	343.99	C.33	344.32	9.CC	1.39	11.CC	365.72	28.66	C.00	8.66	
2.	336.	124	344.32	C.58	344.9C	5.CC	36.41	7.CO	393.31	20.90	C.00	8.90	
0.	C.	125	344.9C	C.41	345.31	1C.CC	43.81	12.CO	411.12	31.20	1.20	9.20	
2.	338.	126	345.31	C.33	345.64	7.CC	95.65	9.CO	457.30	23.64	C.00	7.64	
2.	34C.	127	345.76	C.47	346.23	8.CO	15.4C	1C.CO	379.63	24.23	C.CO	6.23	
C.	C.	128	346.23	0.58	346.81	8.CC	2C6.71	1C.CC	571.52	23.66	C.00	5.66	
2.	342.	129	346.81	C.82	347.63	16.CC	4.27	18.CC	385.90	39.63	9.63	5.63	
C.	0.	13C	347.63	C.62	348.25	6.CO	126.45	8.CC	488.7C	19.82	C.00	5.82	
2.	344.	131	350.62	C.47	351.C9	14.CC	66.76	16.CC	447.86	37.09	7.09	7.09	
C.	C.	132	353.51	C.54	354.C5	14.CO	63.22	16.CO	447.28	4C.02	1C.02	1C.02	
0.	0.	133	354.C5	C.54	354.59	6.CO	25.6C	8.CO	394.20	23.98	C.00	9.98	
2.	346.	134	354.59	C.47	355.C6	8.CO	45.12	1C.CC	418.18	27.06	C.00	9.06	
0.	0.	135	355.87	C.67	356.54	7.CC	18.C3	9.CO	39C.58	25.26	C.00	9.26	
2.	348.	136	356.54	C.54	357.C8	12.CC	22.67	14.CC	4C5.75	35.08	5.C8	9.08	
0.	C.	137	357.08	C.36	357.44	5.CC	1C4.47	7.CC	473.92	21.34	C.00	9.34	
C.	C.	138	357.44	C.38	357.82	1/						7.93	
2.	350.	139	361.12	C.44	361.56	4.CO	55.1C	6.CC	426.66	21.56	C.00	11.56	
2.	352.	140	361.56	C.38	361.94	10.CC	241.95	12.CO	625.89	31.94	1.94	9.94	
C.	C.	141	361.94	C.25	362.19	8.CO	183.49	1C.CC	563.68	28.17	C.00	10.17	
0.	C.	142	362.19	C.2C	362.39	1C.CC	59.86	12.CO	444.25	31.34	1.34	9.34	
C.	C.	143	362.39	C.73	363.12	4.CC	14.54	6.CC	387.66	18.22	C.00	8.22	
0.	C.	144	363.62	C.54	364.16	13.CC	241.95	15.CO	634.11	35.09	5.09	7.09	

VALUES SHOWN ARE IN MINUTES

1/ BLANK SPACES INDICATE THE TRUCKS LEFT THE SYSTEM (DETERMINED FROM COLUMN T2).

unit 3 indicating movement of trucks in minutes.

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