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Combine harvester monitoring based on a single-board microcomputer

Olukayode Oje
Iowa State University

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Iowa State University

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Combine harvester monitoring based on a single-board microcomputer

by

Olukayode Oje

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of DOCTOR OF PHILOSOPHY

Major: Agricultural Engineering

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In Charge of Major Work

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DEFINITION OF SYMBOLS

Cl = Coefficient of lodging determined from 3-year lodging data at harvest for a particular variety of corn.

Cp = Man-machine performance coefficient (1.0 for 2-row, 40-inch header and 0.9 for 4-row, 40-inch header).

Cr = Row spacing coefficient (1.0 for 40-inch rows, 1.1 for 30-inch rows, and 1.4 for 20-inch rows).

D = Day of year (D=1 for March 1)

F = Fines passing through 12/64-inch screen (decimal fraction of gathered yield).

Lc = Cylinder loss (decimal fraction of gathered yield).

Le = Stubble length for soybean.

Lg = Gathering loss: decimal fraction of harvestable yield (yield at maturity minus preharvest loss).

Lp = Preharvest loss (decimal fraction of yield at maturity).

Ls = Separation loss (decimal fraction of gathered yield).

M = Grain moisture (decimal wet basis).

V = Harvester speed (miles per hour).
INTRODUCTION

Because harvesting is as old as farming itself, harvesting machinery have a long history of development. In ancient times, the process of combining (combination of cutting, threshing and winnowing) as we know it today was carried out in several processes. Sickles for cutting straw were made first of stone and then of metal with a wooden handle shaped to fit the hand and threshing was accomplished by beating with a stick or treading by animals (Quick and Buchele, 1978). A forking operation removed coarse straw and winnowing scoops were used in pairs to throw the grain with the wind from the threshing floor. Around the time of Christ, various machines began appearing for performing the different processes of harvesting.

Time taken to harvest a crop was long. It took about 47 hours to harvest one acre of land - 15 hours to reap (cut) the grain, 5 hours to bind, 13 hours to thresh, 10 hours to winnow, and four more hours to put the grains in sacks.

Harvesting technology passed from China through England to the new world. By 1776, the American farmer had fashioned their own form of reapers which reduced harvesting time by as much as 10 hours!

Inventors such as Patrick Bell in 1826, Cyrus McCormick in 1831, and others finally led to the combine revolution.
By 1945, the harvester was able to perform all the harvesting operations on the field.

The combine revolution marched on! Prior to World War I, over 160 companies manufactured grain harvesting equipment in North America alone. By 1977, the number had dropped drastically; the four top combine companies in North America are full-line multinational corporations that manufacture 90% of the combines sold in North America.

There are now over 3 million combines in the world and the combines are becoming bigger and more sophisticated. Figures 1 and 2 show the distribution and use of combines in the U.S., U.S.S.R., and Europe (Quick and Buchele, 1978).

FIGURE 1. Combine Distribution in North America
FIGURE 2. Combine Distribution in USSR and Europe

One of the areas of concern in combine harvesting is seed loss.

There is no place on earth where a kernel of grain looks as large and is of so much value as at the tail end of a combine. There is no time when a farmer is so careful of his property as right then. In a bushel of wheat weighing 60 pounds, there are about 950,000 kernels.

If we should happen to catch ten kernels of wheat in a half minute, it would be said that half the grain was going out with the straw. Let us see. Counting ten hours a day and 26 days for a month, it would take over three months to catch a bushel of wheat at this rate of loss.

In order to waste five bushels in a day of ten hours run, there would have to be 139 kernels escaping every second, or 8,240 every minute. It is very deceiving when a quantity of grain comes to be measured by the kernel. It takes 26 kernels on a square foot to make a bushel per acre.

-Anonymous
Coupled with seed loss is the economics of the combine. Although increasing forward speed leads to increased seed losses, it does decrease timeliness costs. The timeliness costs include those items that increase with delay of harvest and lowering of capacity of machine. These items include: preharvest shatter cost, labor cost, and fixed cost (if the owner intends to engage in custom harvesting). Fixed costs include depreciation, interest, taxes, insurance, and housing. With the exponential rise in timeliness and fixed costs in recent years, timeliness costs have become a force to be reckoned with in most industries. A balance must be struck between timeliness costs and seed losses.

Using space-age electronic technology, this research worker believes that a digital electronic device could be developed to achieve a balance between forward speed and grain losses. The result - the ideal speed -, when transmitted to the combine operator console, would aid the operator in adjusting the speed of the combine and minimizing the cost of harvesting grain. To do this, grain yield and loss measurements must be made where possible and mathematical relationships relating losses and speed must be developed where it is not possible to measure.
OBJECTIVES

The overall objective of the grain harvesting project at the Agricultural Engineering Department of Iowa State University was the development of a computer controlled combine.

It was anticipated that a computer in the business office of the farm would be programmed with a simulation model. This model would accept data concerning the relationships between weather, moisture content, traction, field conditions, etc. Using these data and such items as fixed and operating costs, preharvest losses, and acres of crops, the most economical size of combine can be determined if the farm is anticipating the purchase of a combine. If a combine is already on hand, then the ideal forward speed could be determined. An on-board computer developed during this project would accept the above ideal speed information and combine it with current operating data concerning losses, yield, and moisture content of grain to provide the best forward speed (proportional to throughput) for minimizing the cost of harvesting in dollars per bushel and increase the net income of the farmer by reducing grain losses.

The objective of this study which fell within the overall objective of the department was to develop monitoring instruments which would improve the operator's
ability to control the combine harvester and increase the efficiency and profitability of the machine.

Two approaches to the problem were considered:

A. Mathematical modelling and simulation of combine operations, and,
B. Development of measurement and control systems.

The specific objectives for these two approaches were:

A.

1. To develop a mathematical relationship between the various losses in a combine and forward speed.
2. To develop a simulation model for some combine operations.

B.

1. To select appropriate sensors for measuring combine shoe and walker losses.
2. To select an appropriate sensor for measuring forward speed.
3. To design and construct a sensor for measuring combine yield.
4. To design the hardware for the input signals of these sensors.
5. To design the software for accepting the signals, converting them, and displaying them in the form of yield in bushels per hour and losses in
7

bushels per hour.

6. To set up a laboratory model for testing the sensors, the hardware, and the software.
LITERATURE REVIEW

Soybean Losses

There are four categories of soybean losses (Byg, 1967a and Ayres, 1973).

1. Preharvest loss - loose beans in pods that are detached from the stalks and lying on the ground prior to harvesting.

2. Gathering unit loss which is the sum of the following specific losses:
   * shatter loss - beans free of pods and pods free of stalks chargeable to the machine.
   * stubble loss - beans in pods attached to the free-standing stubble left by the machine.
   * lodged loss - beans in pods attached to stalks or branches abnormally longer than the stubble which slipped under the cutterbar.
   * stalk loss - beans remaining in pods attached to stalk pieces which were cut but not collected (cutterbar loss).

3. Cylinder loss - unthreshed beans remaining in pods which passed through the harvester.

4. Separation loss - beans free of pods which were discharged from the combine separating mechanism.

Byg (1967a) recommended that forward speed should be 3
FIGURE 3. Gathering Losses for Soybean (Quick, 1973)
mph to prevent stripping of beans from stalk. He also recommended that forward speed should be reduced if stubble height is uneven or jagged. The combine is to be slowed down if separating losses are high.

Buchele (1967) presented the cost of harvesting relative to combine ground speed. He argued that slower speeds result in greater overhead costs per acre, but fast combining speeds also cost money. He used a figure as high as $12.50/hr to represent timeliness factor.

Byg and Johnson (1970) conducted tests on 22 farmer-operated machines. They found that the total losses averaged 10% of the yield and the gathering unit loss was 93% of total loss. A previous study had indicated 13% total loss and a gathering loss in the range of 84% of total loss.

Johnson (1967) thought that losses in soybean harvesting could be reduced by 5%. He calculated that 5% reduction in losses would save the farmer 125 million dollars per year which is equivalent to $8.50/hr. for each hour spent operating the combine.

Hoag (1972) constructed a machine which induced shatter in soybeans. Measurements were taken of the energy absorbed by a soybean pod as it was shattered by impact and of the impulse imparted by the impact. He found that there was a definite decrease in the amount of energy necessary to cause soybean shatter as the moisture of the soybeans decreased.
He also found that variations in the amount of energy necessary to cause the shatter of soybean pods due to different impact velocities was not clearly defined.

Quick (1972), Quick (1973), and Quick and Buchele (1974) conducted laboratory and field experiments to determine the effect of various harvesting parameters on soybean combine header loss. They showed that as the stubble length increased, total header loss increased. Increase in moisture content from 5% up to 22% decreased the total header loss while increase in ground speed increased total header loss exponentially.

Corn Losses

Johnson et al. (1963) reported two categories of corn losses - visible and invisible.

Invisible losses are primarily related to dry matter yield reduction. Possible causes of dry matter reduction include:

1. Imperfect shelling - kernels tips which remained in the cob and chips of kernels which were blown out of the combine and were not adequately measured as visible loss.

2. Maturity loss - interruption of dry matter accumulation within the kernel.

3. Scavenger loss - reduction in yield due to the
action of wild life.

Visible losses were characterized as follows:

1. Preharvest loss - detached ears prior to harvesting.
2. Ear loss - dropped ears during harvesting.
3. Snapping roll loss - kernels, shelled off the cob, which passed through the snapping roll.
4. Cylinder loss - kernels which remained on cobs after the cobs have passed through the machine.
5. Separation loss - kernels freed from the cob which passed over the separating mechanisms (straw racks).
6. Cleaning loss - kernels or parts of kernels freed from the cob but lost during cleaning (shoe losses).

It was the opinion of Johnson et al. that total yield should be the sum of machine yield, visible losses, and invisible losses.

Machine losses in harvesting ear and shelled corn was investigated by Agricultural Engineers from Ohio State University and the Ohio Agricultural Research and Development Center during the 1964, 1965, and 1966 seasons (Byg et al., 1964, Byg et al., 1966, Byg, 1967b, Byg and Hall, 1968, and Byg et al., 1970). The purpose of the study was to determine the following:
* Total machine losses
* Machine component losses
* Machine settings used by farmers
* Unusual operating practices used by farmers
* Certain specifics concerning the corn crop.

The study included corn pickers, picker shellers, and corn combines.

Byg et al. (1964) concluded that machine losses in harvesting corn were slightly higher with a field sheller than with a corn picker when invisible losses were included. The field shellers operated at less than 90% efficiency. They also found that the ear loss for field shellers was nearly twice that for pickers. Shelling and separation losses in the field shellers were relatively small compared to ear losses and total losses.

During the 1966 season, Byg et al. (1966) found that weather conditions influenced harvesting losses. Before November 2 when weather conditions were favorable, average loss for the combine was 6.8 bu/acre while that of the picker was 4.0 bu/acre. On November 2, there was a wet snow followed by generally heavy rains. Harvesting losses almost doubled to 11.9 bu/acre for the combine and 8.1 bu/acre for the corn picker during this time. They found that corn planted in 30 and 20 inch rows had a higher plant population than corn in 38 and 40 inch rows. Lodged plants were
greater in the high population plantings after the snow and rain in early November. There was no change in harvesting losses for corn pickers due to row width when the crop was standing well although losses increased as lodging increased. Losses were slightly higher for the 20 and 30-inch row combines as compared to the 38 and 40-inch row combines when the corn was standing well.

Byg (1967b) presented the average component harvest losses for fields that were 10% lodged with moisture content ranging from 20 to 30% (averaging 24%) and average yield of 105 bu/acre. He found that the greatest loss from corn pickers was the shelled corn coming from the snapping rolls while the greatest loss from corn combines was from the gathering unit.

Byg and Hall (1968) found that ears of corn left in the field by the combine-type corn head averaged nearly twice that from the conventional corn picker. Harvesting loss checks on combine corn heads in January 1967 revealed ear losses ranging from 2.25 to 48 bu/acre and averaged 22.4 bu/acre. Some of the problems that contributed to excessive ear losses were improper operation of combine, misadjustment, high plant population, and increased corn acreages which lead to an extended harvesting season.

Byg et al. (1970) discovered that machine ear loss was the largest single source of loss for most combine
operators. They found that ear losses varied from nil to 26 bu/acre and averaged 4 bu/acre during the normal harvest season. Total machine losses as high as 29.4 bu/acre were measured.

Woods and Rossman (1956) analyzed losses and yield at 6 locations in Michigan. They concluded that total picker losses (gleaned ear corn and shelled corn) averaged 6.0, 6.9, 10.3, and 13.4% of the total yield for average populations of 10,300, 14,900, 18,900, and 22,900 plants per acre. Within the recommended plant populations for Michigan (up to 16,000 plants per acre), there were no significant increases in either shelled or ear corn losses as population increased. Stalk lodging increased but there was no serious handicap to mechanical harvest. The percent of husk-free ears after picking was not affected by plant population.

Corn combine harvesting losses were divided into two groups by Ayres (1973). Preharvest losses were classified as ears that dropped from the stalk before harvesting began (delay of harvest losses). These losses were not caused by the combine although they could be reduced by harvesting early. Harvesting losses were subdivided into four types namely:

* Gathering losses - occurs at the front of the combine and consist of ears missed or dropped by machine.
Loose kernels shelled by the cylinder - kernels found on the ground behind the combine.

* Separating losses - kernels that were not shaken out of the cobs and husks and were lost over the back of the combine.

Ayres (1973), Ward (1966), and Swanson (1962) all gave methods of measuring losses in the field.

Ayres et al. (1972) conducted a survey of corn combines in North-Central Iowa in 1971. Their results indicated that loose kernel loss was reduced by a reduction in ground speed. They also found that visible losses were lower for combines checked in the afternoon than for combines checked in the morning. Visible field losses were found to increase as lodging increased and were higher in weedy fields.

Waelti et al. (1969) determined corn losses before and during the harvesting season. They found that for most varieties of corn, the losses increased rapidly as the grain moisture dropped below 25%. They also found that 85 to 95% of all losses were ear dropped losses before or during the harvesting operation.

**Man-Machine Relationships**

Several researchers have developed mathematical models for the various operations of the combine. Others have used the digital computer to simulate harvesting.
Holtman et al. (1970) developed a harvest performance model that calculated harvesting time and yield for a combine harvester on a particular day. Acres of corn suitable for harvesting on a given day was provided by the harvesting decision model.

Harvester losses equations were calculated from the data of Johnson et al. (1963), Byg et al. (1966), Johnson and Lamp (1966), and others. The equations are given below.

\[ L_g = 0.01 + Cr(1+0.17L) \]

where,

\[ L = C_1(D - 199) \]

also,

\[ L_s = 0.005 + 0.4F \]

and,

\[ V = 3.0C_p(1.0 - 0.5L) \]

where,

\( Cr \) is row spacing coefficient,
\( D \) is day of the year,
\( L_s \) is separation loss,
\( V \) is the forward speed,

and,

\( C_p \) is man-machine performance coefficient.

Von Bargen and Peart (1969) developed a general simulation model for row-crop planting, harvesting and other operations. A continuous field pattern was programmed for
the field machine with each pass of the machine through the field simulated as a discrete activity. Their input parameters included field geometry, field environment, and operating policy.

Parsons et al. (1971) used modified forms of equations from Holtman et al. (1970) to develop a Michigan State Model. They stated that:

\[
\begin{align*}
L_p &= 0.07L \\
L_c &= 0.14[\min(\max(M,0.22),0.35) - 0.22] \\
L_s &= 0.55M^2 - 0.23M + 0.038025
\end{align*}
\]

where,

- \(L_p\) is preharvest loss,
- \(L_c\) is cylinder loss,
- \(M\) is grain moisture.

Their input data included the state of the crop and soil, daily climatic records, individual operating preferences and certain combine characteristics. The output data were the combine speed.

Quick (1972) developed mathematical relationships between header losses, forward speed of combine, and stubble length for soybeans. The tests were performed on fields with net potential plot yields ranging between 37.7 and 59.7 bu/acre. Reel index was 1.2 and moisture content varied between 12 and 13%.
For total header loss, the prediction equation was:

\[ H_s = 10.8316 - 4.2301V + 1.1409V^2 - 1.2997Le + 0.289Le^2 \]

where,

- \( H_s \) is the header loss,
- \( Le \) is the stubble length.

He also performed laboratory tests and developed an equation that related speed to header loss.

\[ H_s = 4.1956/V + 2.4779 + 1.1275V \]

Microcomputers in Agriculture

An increasing number of Agricultural Engineers are becoming aware of the enormous potential of the use of microcomputers in Agriculture. This is reflected in the many attempts that have been made all over the world in instrumenting agricultural equipments.

Wendte and Rozeboom (1981) discussed the improved depth sensing device and draft transducer developed by International Harvester Company. It included a data center comprising of an Intel 8080 processor with a parallel I/O board, 4K bytes of Random Access Memory (RAM), 3K bytes of Programmable Read Only Memory (PROM), and various counters for counting pulses from the input signals. The source of the input signals going into the data center was two
magnetic pickups.

Wilhelm et al. (1981) discussed a software package for use with a DEC PDP11/03 based tractor instrumentation system. The program was written in modular form to readily permit program revision. Program modules were provided for calibration and testing of components, data acquisition, data examination, and general support. The program was user oriented, permitting considerable operator input during actual use.

Bedri et al. (1981) designed a tractor performance monitor based on a single-chip microcomputer to measure ground speed, slip, fuel consumption, total area, theoretical time, and total time. The microcomputer, an Intel 8035, monitored the input signals given by the front and rear wheel transducers, fuel flow transducer, and implement operating switch. It then calculated and displayed the fuel consumption and field performance parameters.

Tompkins and Wilhelm (1981) developed a tractor-mounted, microcomputer-based instrumentation system for monitoring the energy inputs to implements powered by a specially outfitted tractor. The system measured and recorded ground axle torque. From these data, axle power, drawbar power, drive wheel slip, and fuel consumption per unit area was analytically computed.
Morton et al. (1981) built and tested a complete system for tractor output measurements. The system consisted of a fuel consumption meter, an engine revolution counter, a timer, and two wheel revolution counters. The engine torque was correlated with fuel consumption per engine revolution, and the engine power was then calculated.

Hendrick et al. (1981) designed and constructed a computer-based field measurement system for recording field performance of tillage and traction machinery systems. The system included an 8-channel analog input capacity with a data acquisition rate of at least 100 scans/sec. of 8 channel per scan. It also included a printed data output of mean and standard deviation for each channel.

Smith et al. (1981) developed an instrumentation system for monitoring fuel consumption, engine speed, forward travel speed, rear axle torque and angular velocity, and implement load. Transducer outputs were recorded on magnetic tape using a 16-channel datalogger.

Beppler and Shaw (1980) instrumented gasoline and diesel tractors, as well as self-propelled harvesting machines for measuring rates of fuel consumption, travel speed and wheel slip. Activation of the measuring devices was integrated within one control box and remote control of the entire package was possible.

Herron et al. (1977) instrumented a farm tractor to
measure fuel consumption, travel reduction, draft, elapsed time, and speed. The system provided data for field performance calculations and was operable by the tractor driver.

Baskin et al. (1981) designed and tested the electronic circuitry for displaying moisture content and optimal combine cylinder speed for varying grain moistures. The unit could be operated from inside the operator's cab and used the combines electrical system for power. It had an accuracy of 1% moisture and was compatible with the adjustment capabilities of the combine.

Wihelm et al. (1982) developed and operated a system to obtain solar energy data and transmit the information to a "host" unit via telephone. Field units collected and stored the data in memory. A "host" computer polled the units daily, collected the stored data, and ran diagnostics to test the field units.

Schwartz et al. (1981) used a SYM-1 single board computer to build a datalogger for collecting data on solar collectors. The SYM-1 was used to control fan and water additions in an ice freezing project.

Upchurch et al. (1980) designed and developed a microprocessor-based steering controller to provide improved steering maneuverability for an over-the-row apple harvester. The controller allowed the machine operator to
select from five steering modes - front only, four way, crab, rear only, and automatic.

Leviticus (1980) discussed an electronic fuel weighing system which was developed for and tested at the Nebraska Tractor Test Laboratory. The most important characteristics of the microprocessor was that it gave a continuous history of the fuel consumption and it covered accurately a range of 15 HP to 400 HP tractors.

Kruse and Krutz (1982) developed a microprocessor-based ground speed controller for maintaining constant engine loading. The controller had four input and one output signals. The system could vary the combine speed between zero ground speed and the maximum forward ground speed set by the operator while harvesting a crop.

Schueller et al. (1982) accomplished a high speed data acquisition and control on a grain combine harvester using an on-board microprocessor. Collected data were stored on floppy diskettes, which facilitated later analysis. Yield and loss were estimated by measuring input to the combine.

Wood and Kerr (1980) described five types of grain loss monitors that were evaluated by the Prairie Agricultural Machinery Institute (PAMI). These were:

* Senstek Sens-Saver SS2 Grain Loss Monitor
* Smith-Roles GM30 Combine Grain Monitor
* BEE Model 7410 Combine Loss Monitor
* SED Model 912 Grain Loss monitor
* RDS Mark 3 Combine Monitor

Three of the loss monitors employed pad sensors. One or more of these sensors were mounted at the rear of the straw walkers and shoe. One loss monitor employed tube sensors. A single tube was mounted in a central straw walker while a multi-tube sensor was mounted at the rear of the shoe. The shoe sensor sampled the entire depth of effluent at spaced intervals across the width of the shoe.

They also evaluated the combine loss monitor manufactured by Dickey-john Corporation, Auburn, Illinois. Tests were performed both in the field and in the laboratory. They found that the loss monitors indicated the presence of combine grain loss but did not give an accurate reading of the actual loss rate. The monitor indicated the loss rate with low errors at low to moderate feed rates when calibrated at a normal loss level. As the combine capacity was exceeded, the meter readings were found to lag below the actual loss rates and large errors were encountered. The loss display was indicated by a needle with three loss zones - normal, above normal, and excessive.
MODELLING OF COMBINE OPERATIONS

Mathematical Modelling of Grain Loss

Grain loss is dependent on many factors including the forward speed of the combine, grain moisture, lodging, throughput, combine design parameters, and operating rpm. Forward speed is the only variable considered in this study.

Data obtained from Ayres (1973) and Quick (1973) were regressed in order to obtain relationships between these two variables. The speed studied by Ayres ranged from 1.5 to 4.4 mph. The losses were obtained for corn harvested in Iowa.

The following equations were obtained by regression of these data using the cadet programs on the Iowa State University computer systems. The data used can be found in Appendix I.

For harvest losses attributed to stalk roll shelling

\[ \text{Loss} = -5.3424 + 8.6327V - 3.5632V^2 + 0.4519V^3 \]

This is the main loss reported at the front apart from machine missed ears (figure 4).

The equation for gathering losses of ear dropped during harvest plus stalk roll shelling together is:

\[ \text{Loss} = 4.8189 - 1.9107V + 0.35V^2 \] (figure 5)
FIGURE 4. Stalk roll shelling losses for corn
and for cylinder loss is:

\[ \text{Loss} = 0.4857 - 0.2407V + 0.07857V^2 \text{ (figure 6)} \]

For soybeans, the data from Quick (1973) were used for both standard cutterbar and machete continuous belt impact cutterbar. The data can also be found in Appendix I.

For the machete cutterbar,

\[ \text{Loss}(% \text{ of yield}) = 8.964 + 3.8485V - 0.283V^2 \]

For the standard cutterbar (figure 7),

\[ \text{Loss}(% \text{ of yield}) = -4.4 + 15.69V - 2.809V^2 \]

Simulation of Corn Harvesting

During harvesting, efficiency depends on a variety of factors including weather conditions, speed of machinery, and other operating conditions.

Von Bargen and Peart (1969), Holtman et al. (1970), and Parsons et al. (1971) developed simulation models based on harvester losses calculated from the data of Johnson et al. (1963), Byg et al. (1966), Johnson and Lamp (1966), and others.

Simulation models can be of help in understanding physical processes. Although they do not always explain the process completely, they often serve as pointers to those
FIGURE 5. Machine missed ears and stalk roll shelling
FIGURE 6. Cylinder losses for corn
parts of the physical process that are not understood.

A simulation model was developed for the grain combine to help show the relationship between the factors that influence the operation and efficiency of the combine. The model developed here was limited in scope and dealt only with the relationship between field operating speed, weather data, moisture content, and probability of operating on any given day.

The model

The model is a combination of a stochastic and deterministic model. It consists of a main program and three subroutines - the probability generator, the speed generator, and the loss calculator. Smaller subroutines are nested within some of these three subroutines (figure 8).

The program starts by generating the probability of good, fair, or bad day in a particular location based on the rainfall data for this area in the previous years. On the basis of this probability, it generates appropriate forward speed and moisture content for each day. If the end of the day signifies the end of the harvesting period, the model outputs the total losses and yield. Otherwise, the date is incremented by one and new speed and moisture contents are generated.
FIGURE 7. Soybean combine losses vs forward speed
FIGURE 8. Block diagram of model
Input data

The input data are basically rainfall data. Average daily precipitation data for Ames, Iowa for 1979 and 1980 were used. Only the data for 60 days of harvesting — October 15 to December 15 were used in this model.

The probability generator

This generator (figure 9) assumes that each day within the harvest period has the same probability of good, fair, or bad weather. It then counts the number of good, fair, and bad days during the season using the following criteria:

For any given day,

- day is good if precipitation $\leq 0.2''$
- day is fair if $0.2'' <$ precipitation $\leq 1.0''$
- day is bad if precipitation $> 1.0''$

These three points are then taken as points in a discrete probability distribution and

$\text{probg} = \frac{\text{no of good days}}{\text{total no of days}}$

$\text{probf} = \frac{\text{no of fair days}}{\text{total no of days}}$

$\text{probb} = \frac{\text{no of bad days}}{\text{total no of days}},$ where, probg is the probability of good days during the season probf is the probability of fair days during the season and probb is the probability of bad days during the season.

Speed generator

The speed generator is a subroutine that generates the day's speed and moisture content (figure 10). Randu is a
FIGURE 9. The Probability Generator

system subroutine on the Iowa State University VAX system. It generates a number \( R \) between 0 and 1 using two integers \( I_1 \) and \( I_2 \) given by the user. The speed and moisture content of grain for this day is then set depending on the value of \( R \) generated.

For \( R > \text{probg} \), Speed = 3.5mph, and,
moisture content = 20%. This is a good day with respect to weather.

For \( \text{probf} < R < \text{probg} \), Speed = 2.5mph, and,
moisture content = 25%. This is a fairly
good day.

For $\text{probb} < R < \text{progf}$, $\text{Speed} = 2.0\text{mph}$, and, moisture content = 30%. This day is just fair.

For $R < \text{probb}$, $\text{Speed} = 0.0\text{mph}$. This is a bad day and there is no harvesting.

FIGURE 10. The Speed Generator
The speed and moisture content are then varied by calling subroutine Normal which must be given the standard deviation of speed (0.1 for this particular run) and moisture content (2%). For example, the new speed for the day becomes:

\[ \text{Speed} = \text{Speed} + \sigma N \text{ where } N \text{ is randomly generated by Randu and } E(N) = 0 \]

\( E(N) \) is the expectation of \( N \). This same operation is carried out for the moisture content of grain for the day.

Loss calculator

This subroutine calculates the various losses and yield at the end of the day given the speed and moisture content (figure 11). The model of Holtman et al. (1970) as modified by Parsons et al. (1971) was used to calculate preharvest, gathering, cylinder, and separation losses. This model was also used to calculate the yield given the estimated yield for the farm.

The main program adds the losses and yield and outputs these totals at the end of the harvesting season. The program listing is shown in Appendix II.

Results

The program was run for a field of 1,000 acres, a 6-row combine and an 8 hr harvesting day. The estimated yield per acre was assumed to be 100 bushels.
FIGURE 11. The Loss Calculator

The maximum preharvest loss was less than 1% of estimated yield. The maximum cylinder loss was also less than 1%. Maximum separation and gathering losses were between 1 and 2%. The actual yield was more than 96% of estimated yield and it took 31 days to harvest the field of 1,000 acres. A plot of the ground speed for the run is shown in figure 12.
FIGURE 12. Variation in ground speed for 1,000 acres
MEASUREMENT DEVICES

Apart from mathematical modelling, another area of interest in this study is measurement and control. For the combine to be effectively controlled in the field, it will be necessary to measure the variables of interest during the time of operation. This will help not only in controlling the machine, but also in providing more data information and aiding further research into how the combine operates.

Three measurements were of interest in this research - yield, walker and shoe losses, and forward speed.

Speed Sensor

Various ways have been used to measure velocity or forward speed (Doebling, 1976). These include:

* Electrical differentiation of displacement voltage signals - the output voltage of a displacement transducer is applied to the input of a suitable differentiating circuit to obtain a voltage proportional to velocity.

* Photoelectric pulse counting - using photocells and light sources with slotted wheels or black and white targets.

* Stroboscopic methods - using electronic stroboscopic lamps which flash at known and adjustable rate.
* Moving-coil and moving magnet pickups - output voltage linearly follows the input velocity (especially used to measure vibratory velocities).
* D.C tachometer generators for rotary velocity measurements - a permanent magnet or an excited field produces an output voltage roughly proportional to speed.
* Seismic displacement pickups - used especially where a fixed reference is not available.
* Magnetic pulse counting - magnetic pickups.

Because of availability and cost, the last device - magnetic pulse counting has been used for this design. The magnetic pickup unit consists of two sections: a permanent magnet with wire leads and a rotating section consisting of strips of magnetic material. The rotating section is attached to the wheel while the other section is fixed. When magnetic material passes close in front of the pickup, the reluctance of the magnetic path changes with time, generating a voltage in the coil (figure 13). The output voltage increases with velocity and air space between the external moving iron and the pickup.

Loss sensors

The loss transducers are basically pressure transducers which respond electrically to the pressure on a diaphragm.
Traditional methods of pressure measurement include dead weight gages, manometers, and elastic transducers (using Bourdon type diaphragms or belows). In this case, an electrical pressure pickup is desired. Electrical pressure transducers are basically spring-mass systems with intentional or unintentional damping and their dynamic behavior is of standard second-order form. Helical Bourdon tubes, potentiometer type pickups, or unbonded strain gages could be used. Others include variable-inductance, piezoelectric, and capacitance pickups.

The device used in this research (manufactured by Dickey-John Inc.) is a flat diaphragm and senses the...
deflection with bonded strain gages underneath the surface of the diaphragm.

The pressure-deflection formula for a flat diaphragm with edges clamped is:

\[
p = \frac{16Et^4}{3R^4(1 - \mu^2)} \left[ \frac{y_p}{l} + 0.488 \left( \frac{y_p}{l} \right)^4 \right]
\]

where \( p \) = pressure difference across diaphragm
\( E \) = modulus of elasticity
\( t \) = diaphragm thickness
\( \mu \) = Poisson's ratio
\( R \) = diaphragm radius
\( y_c \) = center deflection.

For small deflections, \((y_c/t)^3\) is negligible compared with \((y_c/t)\) and linear behavior may be expected since bending stresses predominate. At larger deflections, a stretching action is added to the bending, stiffening the diaphragm and contributing the \((y_c/t)^3\) term.

The diaphragm has, at any point on the low-pressure surface, a radial stress \( S_r \) and a tangential stress \( S_t \) given by the following formulas:

\[
s_r = \frac{3\mu R^2 \varepsilon^t}{8t^5} \left[ \left( \frac{1}{\mu} + 1 \right) - \left( \frac{3}{\mu} + 1 \right) \left( \frac{R}{d} \right)^2 \right]
\]
\[
s_t = \frac{3\mu R^2 \varepsilon^t}{8t^5} \left[ \left( \frac{1}{\mu} + 1 \right) - \left( \frac{1}{\mu} + 3 \right) \left( \frac{L}{d} \right)^2 \right]
\]
The deflection at any point is given by:

\[ y = \frac{3p(1 - \mu^2)(R^2 - r^2)^2}{16E\ell^2} \]

The stress situation on the diaphragm is such that both tension and compression stresses exist simultaneously. This allows the use of a four-active-arm bridge in which all effects are additive and also gives temperature compensation. Gages 2 and 4 (figure 14) are placed as close to the center as possible and oriented to read tangential strain since it is maximum. Gages 1 and 3 are oriented to read radial strain and placed as close to the edge as possible since radial strain has its maximum negative value at that point.

The stress equations cannot be used directly to determine the strains "seen" by the gages since the diaphragm surface is in a state of biaxial stress and both the radial (\( \epsilon_r \)) and tangential (\( \epsilon_\theta \)) stress contribute to the radial or tangential strain at any point. The general biaxial stress-strain relation gives

\[ \epsilon_r = \frac{\sigma_r - \mu \sigma_\theta}{E} \]
\[ \epsilon_\theta = \frac{\sigma_\theta - \mu \sigma_r}{E} \]
FIGURE 14. Diaphragm-type strain gage pressure pickup
Individual change in resistance $\Delta R$'s for both strains can be obtained from

$$R = \text{gage factor} \times \text{strain} \times \text{resistance of gage}$$

where gage factor $= 1 + 2\mu$.

Output voltage is then obtained as

$$e_o = \frac{(e_{in} \times \Delta R)}{4R}$$

where $e_o = \text{output voltage}$

$e_{in} = \text{input voltage}$

$\Delta R = \text{change in resistance}$

$R = \text{original resistance of gages}$.

The device has an input voltage of 12 volts D.C and an initial output voltage of 5 volts D.C. The output generated by changes in strain is then a decaying a.c. voltage which rides on top of the +5 volts D.C.

Yieldmeter

The yieldmeter was designed and constructed at the Agricultural Engineering Research Laboratory. It consists of a receiving chamber, a dividing chamber, the sensor, and two exit pipes. The schematic diagram of the yieldmeter is shown in figure 15 and the actual yieldmeter is shown in figure 16. The receiving chamber was designed to receive
the grains from the auger and transfer them to the dividing chamber. The dividing chamber was necessary because the sensor cannot cope with the volume of grain coming from the auger. Grain entering the receiving chamber was immediately divided into five parts before flowing into the dividing chamber. At the dividing chamber, the incoming flow was divided into two parts each to make a total of ten parts.

The sensor for yield was the same as the loss sensors. It gives a decaying sinusoidal signal whose magnitude is dependent on the amount of grain falling on it. The sensor is placed so that it collects grains from only one of the ten exits. The exit pipes allow for the passage of the flow from the other exits.

The yieldmeter box was made entirely of wood but was attached to the auger with metallic rings. It was designed small enough so as not to impede the flow of grain into the grain tank or reduce the capacity of the grain tank.

Sensor Connections and Placement

The loss and yield sensors have a driving input voltage of +12VDC and a null output voltage of +5VDC. Since this was a laboratory setup, the situation on the field had to be simulated. To simulate the losses, a box was constructed and the sensors were mounted on it (figure 17). The four loss sensors (two for the walker and two for the shoe) were
FIGURE 15. Schematic diagram of the yieldmeter
FIGURE 16. The yieldmeter
attached on the back cover approximately 7 inches from the top with bolts and nuts. Grain, under the motivation of the vibrometer flowed on top of the sensors. The box was covered with plexiglass in order to view the action and to prevent grain spillage on the side. An exit was made for grains at the front of the glass.

Since the height and velocity of impact of the falling grain could differ from one another, a device was made for slowing the velocity of the grain and reducing the height of fall on the sensors. The device was 7 inches long and 3.5 inches in depth. The width was 2.5 inches. It has two slanting edges at 60 degrees to allow the grains to slide into the sensors. The device was made for each sensor and attached with screws to the plywood box so that their relative position to the sensors can be changed slightly in order to allow for maneuverability during calibration (figure 17).

Inside the box are the speed transducers and the 12VDC. and 5VDC. power supply. The magnetic pickup was attached to the wooden box by means of two long bolts and four nuts so that the position could be adjusted. In order to simulate the variations in speed of a combine, the wheel of the pickup system was attached to a variable speed drill which was mounted on a clamp so that the relative position to the pickup can be varied (figure 18). The drill was connected
FIGURE 17. Arrangement of the loss transducers
to a variable transformer which is a means of changing the speed.

The power supply has its inputs connected to 120VAC supply and gives an output of +12VDC and +5VDC. Wires were passed out of the box from the 12VDC supply for connection to the loss and yield sensors. Wires were also passed out of the box from the +5VDC supply for connection to the input/output board by means of extension cords. Wires were passed out from the output pins of the magnetic pickup for connection to the amplifier board. The schematic diagram for the model is shown in figure 19.
FIGURE 18. The speed transducer and drill
FIGURE 19. Schematic diagram for the combine model
The electrical signal produced by the magnetic pickup and the strain gages were very small - about 0.1 mv. The deflection of the diaphragm is maximum when it is first hit by a grain and subsequently decreases. This is understandable in view of the fact that the diaphragm strain gage is a second order system with damping. Because the system is overdamped, the signal, like the characteristic transient signal of an overdamped system, is maximum at the beginning and gradually dies out. Moreover, there is a no-load reading of +5VDC and the subsequent transient signal rides on this DC voltage. The maximum voltage output of this system is also of the order of 0.2mv.

**Signal Conditioning and Conversion Board**

The signal conditioning and conversion board consists of the amplifiers, the voltage comparators and their resistances, capacitors, and potentiometers.

**Amplification**

In order to increase the magnitude of the transducer signals, it was necessary to amplify the signals. For this purpose, operational amplifiers were used. For the type of signal received from the sensors, non-inverting arrangement was desirable (figure 20).
\[ V_{out} = \frac{R_1 + R_2}{R_1} \cdot V_{in} \]
\[ R_3 = \frac{R_1}{R_2} \]

**FIGURE 20. Non-inverting AC amplifier**

For all sensors,

- \( R_1 = R_3 = 1K \), and,
- \( C_1 = 1 \mu F \)
- \( R_2 = 18K \) for the lossmeters,
- \( 10K \) for the yieldmeter, and,
- \( 10K \) for the speed sensor

The capacitor was necessary to filter out the undesirable +5VDC present in the output of the sensors when there was no load.

National Semiconductor operational amplifier model LM 358 was used for amplifying the signals.

The LM 358 consists of two independent, high gain, internally frequency compensated operational amplifiers.
which were designed specifically for operating from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply drain is independent of the magnitude of the power supply voltage. The main advantages over conventional operational amplifiers is that it can be more easily implemented in single power supply systems. For example, it is used in this system with the standard +5VDC power supply and does not require an additional +15VDC power supply. The ratings and connection diagrams are shown in Appendix III.

Voltage comparators

Since the output signal of the loss and yield meters are decaying ac signals, it is desirable to pick voltages above a certain limit and generate pulses that would be sent to counters and subsequently to the input/output device of the microcomputer. It is also advantageous to have a device that would accept an analog input and produce a digital output. For these reasons, a voltage comparator was used.

Voltage comparators are devices that compare a given voltage with a reference voltage. The output of the comparator is +5VDC or 0VDC depending on whether or not the input voltage is higher than the preset reference voltage.

The National Semiconductor voltage comparator model LM 319 was chosen for this design.
FIGURE 21. Voltage Comparator Circuit

The LM 319 is a precision high speed dual comparators fabricated on a single monolithic chip. It is designed to operate over a wide range of supply voltages down to a single 5V logic supply and ground. The two comparators on a chip are independent, operate from a single 5V supply and have a typical response time of 80 nanoseconds at +15V. The pin diagram is shown in Appendix III.

The reference voltage was supplied by a potentiometer which has a maximum resistance of 20K ohms and an input voltage of 5VDC. The output of the potentiometer was the reference voltage that goes into the voltage comparator.

The reference voltage was raised or lowered with a screw located at one end of the potentiometer. The output
of the comparator goes into the input/output board.

The output from the voltage comparator depended on the impact of the grain hitting the surface of the sensor. The harder the impact, the more the number of pulses generated by the comparator. The number of pulses generated was directly proportional to the kinetic energy of the grain impacting on the surface which was itself proportional to the weight of grain, assuming that all the grains hit the surface with the same velocity.

**Plugboard connections**

The amplifiers and comparators were connected by means of wrapping wires on a 6.5" by 4.5" dip plugboard according to figures 20 and 21. The schematic diagram for two channels of the amplifier/comparator arrangement can be seen in figure 22. Six channels were needed for this study - 4 for lossmeters, 1 for yieldmeter, and 1 for speedmeter - but eight channels were constructed in order to allow for future expansion.

The amplifiers, comparators, and their accompanying resistors, capacitors, and potentiometers were arranged on the plugboard in the following order: potentiometers, comparators, potentiometers, resistors and capacitors, and amplifiers. The plugboard, together with the I/O plugboard, was placed inside a 12" by 10" by 3" covered aluminum box so as to protect the chips from dust and also to protect the
FIGURE 22. 2 channels of amplifier/comparator
electrical connections. The board was fitted with connectors which were connected to the plugboards on the inside and to the sensors on the outside.

Input/Output Board

The input/output board consisted of counters, line drivers, and decoders.

Counters

The output of the comparators were passed on to the counters. Each signal is either +5V or 0V (logical 1 or 0). The counter is an electronic device for recording the number of logical 1s coming into it. The concept of counters is explained in Carlson and Gisser (1980).

The counter used was Texas Instruments model 74LS393 series which is a dual 4bit counter. Figure 23 shows the pin arrangement of this counter. In order to make an 8bit counter, the most significant bit of the first 4 bits of the counter was tied to the input pin of the other 4 bits. The most significant bit of this new 8bit counter was then connected to the input of another 8bit counter (constructed as above) so as form a 16bit counter. The 8 most significant bits of this 16bit counter is then connected and read through the line drivers.

The line driver is a device that allows each counter to be read when given the signal to do so and subsequently
FIGURE 23. Pin assignment for counters

prevents it from being read. This was necessary because the 8 bits of the counters for all the sensors were tied to a single reading port on the microcomputer. These line drivers prevent the data on one counter from interfering with the data on other counters.

For the line drivers, Texas Instrument line driver model 74LS244 series were used. These line drivers require an active-low output control. The LM 244 series has 8 input pins which were connected to the counters and 8 output pins which were connected to port B on the microcomputer (see section on microcomputers). Each line driver was chosen by using a 3 to 8 decoder (see section on decoders).
Decoders

There are 6 input signals in the design - 4 loss sensors, the yieldmeter, and the speed sensor. Since the microcomputer used can only read one 8-bit input at a time, it became necessary to multiplex. Port B of the microcomputer was used to multiplex. Also, the counters have to be cleared each time they are read and port B was also used for this purpose. Port B has 8 input pins, so, 4 pins were used for clearing the counters and the other 4 used for choosing the line drivers.

Two 3 to 8 decoders were used - one for choosing the line drivers and the other for clearing the counters. The 3 to 8 decoder used was the Texas Instrument decoder model LM138. The pin connections of this decoder are shown in figure 24. For choosing the line drivers, pins G2A and B were tied to ground while pin G1A was tied to pin 4 on port B. Pins 5-7 on port B were then used as the input signal for selecting the counters in the following order:

- $80 selects the signal from one walker lossmeter
- $90 selects the signal from one shoe lossmeter
- $A0 selects the signal from the other shoe lossmeter
- $B0 selects the signal from the other walker lossmeter

---

1 $ signifies hexadecimal.
$C0$ selects the signal from the yieldmeter
$D0$ selects the signal from the speed transducer.

FIGURE 24. The 3 to 8 Decoders

Each of these will send a low signal to the line driver and allow the counters to be read by the microcomputers.

In order to clear the counters, another 3 to 8 decoder was used. Pins G2A and B were also tied to ground but pin G1A was tied to pin 0 of port B. Pins 1–3 on port B serve as input signals for selecting counters.

The counters required +5V to clear and since the 3 to 8 decoders gave low signals, a line driver/inverter was needed between the decoder and the pins that were to be cleared. Texas Instrument line driver/inverter model LM 240 was used
for this purpose. Its pin assignment is shown in figure 25. Input signals for clearing the counters are as shown.

- $08$ for one walker lossmeter
- $09$ for one shoe lossmeter
- $0A$ for the other shoe lossmeter
- $0B$ for the other walker lossmeter
- $0C$ for the yieldmeter
- $0D$ for the speed transducer.

FIGURE 25. Pin arrangement for the Line driver/Inverter

Input/Output plugboard connections

The counters, line drivers, and decoders were connected with wrapping wires on a 6.5" by 4.5" dip plugboard and kept in the same aluminum box with the signal conditioning and
conversion plugboard. The layout of 2 channels in the Input/output plugboard are shown in figure 26. Figure 27 shows the aluminum box containing the two plugboards.

The Microcomputer

The microcomputer is the device that reads the already processed signals, calculates where necessary and displays the output. For a microcomputer to read the signals, the signals must be processed as had been described in the previous sections. The microcomputer must also be programmed.

The microcomputer chosen was the AIM 65 microcomputer systems manufactured by Rockwell International Inc.

AIM 65 consists of two modules - the master module and the keyboard module - interconnected by a short plug-in ribbon cable. The master module holds a printer, a display, and the microcomputer components.

The R6502 is the Central Processing Unit (CPU) of the AIM. It is an 8bit MOS technology microprocessor which operates at 1MHz on AIM 65 to provide a minimum instruction execution time of two microseconds. It has 56 instruction and 13 addressing modes (Rockwell International, 1979). The R6502 can address 4K bytes of Random Access Memory (RAM) and 20K bytes of Read Only Memory (ROM) on the master module plus an additional 40K bytes of user produced external RAM,
FIGURE 26. 2 channels of the Input/Output board
FIGURE 27. Box containing I/O and counter boards
ROM, or Input/Output (I/O).

Other R6500 devices on the AIM include the R6522 Versatile Interface Adapter (VIA), the R6532 RAM - Input/Output Timer (RIOT), the R6520 Peripheral Interface Adapter (PIA), the R2332 ROM, and the R2114 RAM. The R6522 has two bidirectional ports (ports A and B). Port B was used for multiplexing as described in the sections above while port A was used for reading the incoming 8-bit signal from the counters through the line drivers. The schematic of the whole system is shown in figure 28.
FIGURE 28. Schematic of the complete system
SOFTWARE DEVELOPMENT

The software for the system was written to read the signals from the sensors, convert them where necessary, and display them upon request. Displayed were: total time since the beginning of operation, yield per hour, walker loss per hour, and shoe loss per hour. The AIM 65 system was used for software development.

The AIM 65 Development System

As described in the last chapter, the AIM 65 system was manufactured by Rockwell International Inc. It has a 4K RAM memory and 20K bytes of ROM used primarily by the monitor. The 4K RAM is available to the user.

The AIM can be programmed in three ways:

* by using hexadecimal machine codes
* by entering the program in machine language
* by using the editor and assembler.

The first method is tedious and prone to error. The second method, although less tedious than the first one is also prone to errors and errors so committed are difficult to find. The editor is the most convenient method to use. It allows for explanatory notes within the program so as to facilitate debugging.
How to Operate the Program

The program allows the user to start and stop at any time. When started, the program requests the user to indicate the crop being harvested - corn or soybean (It is presently built to work with soybeans). After the "Return" key is depressed, the program asks for the combine tire radius and then starts to display time in hours, minutes, and seconds. Upon request, the display gives the yield or losses in bushels per hour.

Seven keys were used as function keys from the keyboard. The F1 key was used for "START", the reset key for "STOP", the S key for "SOYBEAN", the C key for "CORN", the L key for "SHOE LOSSES", and the W key for "WALKER LOSSES". The functions of the keys are as follows:

START (F1 key)
Directs the program to begin. Program requests for the kind of crop and the tire diameter. Displays time in the format HH:MM:SS. For example, 1 hour, 10 minutes, and 15 seconds after the beginning of harvesting will indicate 01:10:15.

STOP (Reset)
Stops the program at the command of the user. The program counter jumps into the monitor. Program can be restarted by pressing the start key.
**YIELD (Y key)**

This key has to be depressed for approximately 3 to 10 seconds for response. The display then shows the current yield in bushels per hour until the key is released. After this, display returns to the time mode.

**WALKER LOSS (W key)**

This key has to be depressed for 3 to 8 seconds to generate response. The display gives the walker loss in bushels per hour until the key is released. Display then returns to time mode.

**SHOE LOSS (L key)**

This key also has to be depressed for 3 to 8 seconds. The display gives the shoe loss in bushels per hour until the key is released. Display returns to time mode.

The program is designed to work for 10 hours at which point it resets itself back to zero.

**Composition of the Program**

The combine program has three elements -

* the request section which is responsible for asking for information from the user and accepting the response
* the main part which initiates the counters, displays the time, and gives the yield and losses
on request (flowchart for the request and main programs is shown in figure 29)

* the interrupt service subroutine that updates the time values, reads the counters, and also clears the counters once every ten seconds (see flowchart in figure 30).

Calibration of System

The yieldmeter was attached to the auger of a wagon at the Agricultural Engineering Research Laboratory and connected to the computer and input/output box (see figure 31). The auger was run by a hydraulic motor. Different weights of soybeans were run through the yieldmeter and the number displayed by the last 8 bits of the 16bit counter was noted. The auger output was then converted to bushels per hour and calibrated against the number given by the counters. The result is shown in figure 32.

Known weights of soybean seeds were run through the lossmeters and the last 8 bits of the 16bit counters were recorded. These weights were then converted to bushels per hour and calibrated against the numbers given by the counters (figure 33).
FIGURE 29. Flowchart for the request and main sections
FIGURE 30. Flowchart for the interrupt service routine
FIGURE 31. AIM 65 and Input/Output box
FIGURE 32. Calibration curve for the yieldmeter
FIGURE 33. Calibration curve for the Lossmeters
Assembling the Program

The assembly listing of the program is shown in Appendix IV. The memory of the AIM was too small for loading and assembling the program, so it was loaded from tape into the editor twice. The request program was loaded into location $250^2$ to $6FF$ and assembled in $A00$ to $B00$ with the last instruction as JMP $B00$. Locations $200$ to $250$ were reserved for the variables used in the program. The main program and the interrupt service routine were loaded into location $250$ to $955$ with the first instruction assembled at address $B00$ so that the program counter jumps from the request to the main program.

Limitations of the Program

The program was designed to display time in hours, minutes, and seconds up to a maximum of 9 hours, 59 minutes, and 50 seconds. It can also display yield from 0 bushels per hour to a maximum of 99 bushels per hour, shoe losses from 0 to 9.8 bushels per hour and walker losses from 0 to 9.8 bushels per hour. This is because it is unlikely for any operator to operate the combine for more than 10 hours at a stretch, harvest soybean at more than 99 bushels per hour, or loose seeds at more than a total of 19 bushels per

---

$^2$ S designates hexadecimal.
hour. However, the program can be changed to any limit desired within the capability of the AIM 65.

Evaluation of Program

After some initial debugging, the program started working very well. Even without the combine in use, the program could be used as a timer or clock. The following display were shown by the microcomputer for each of the variables measured:

- TIME
  TIME = __:__:__

- YIELD
  YIELD (BU/HR) = __

- WALKER LOSS
  WALKER (BU/HR) = __

- SHOE LOSS
  SHOE (BU/HR) = __

The program could be loaded from tape and assembled at any time.

Program Listing

The program listing as written for the AIM 65 microcomputer is shown below.
81

; THIS PROGRAM REQUESTS FOR CROP TYPE AND TIRE RADIUS
; BEGINNING OF HARVEST
; INITIALIZE
RCHECK=$E907
OUTPUT=$E97A
RDRUB=$E95F
CLR=$EB44
READ=$E92C
NUMA=$EA46
RADIUS=$200
CROP=$201
; 1ST QUESTION
*C=$18C
JMP START
*C=$A00
START NOP
; CLEAR D/P
ASK1 JSR CLR
LDX #$00
QUES1 LDA QUESN1,X
JSR OUTPUT
INK
CPX #13
BNE QUES1
; RECEIVE ANSWER
; <ESC>?
JSR RCHECK
; INPUT KEY?
JSR RDRUB
STA CROP
RPT1 JSR READ
CMP #$0D
BNE RPT1
LDA CROP
CMP #$C
BNE SQYTST
JSR CLR
JMP ASK2
SQYTST CMP #$S
BNE ASK1
; CLEAR D/P
JSR CLR
JMP ASK2

; 2ND QUESTION
ASK2 LDX #$00
QUES2 LDA QUESN2,X
JSR OUTPUT
INK
CPX #13
BNE QUES2
; RECEIVE ANSWER
JSR RCHECK
; INPUT KEY?
JSR RDRUB
ASL A
ASL A
ASL A
ASL A
AND #$F0
STA RADIUS
JSR RCHECK
JSR RDRUB
AND #$0F
CLC
ADC RADIUS
STA RADIUS
RPT2 JSR READ
CMP #$0D
BNE RPT2
JSR CLR
JMP $B00
QUESN1 BYT 'ENTER C OR S=
QUESN2 BYT 'WHEEL RADIUS=
. END
JSR NUMA
JMP DISLP
SHOE JSR CLR
LDX #0
DISP1 SH LDA LOSH,X
JSR OUTPUT
INX
CPX #12
BNE DISP1 SH
LDX $20F
CLC
LDA $400,X
LDX $212
SED
ADC $400,X
STA TEMP
CLD
JMP DECI
WALKER JSR CLR
LDX #0
DISWAK LDA LOWAK,X
JSR OUTPUT
INX
CPX #14
BNE DISWAK
LDX $210
CLC
LDA $400,X
LDX $211
SED
ADC $400,X
STA TEMP
CLD
JMP DECI
DECI LDA TEMP
LSR A
LSR A
LSR A
LSR A
AND #$0F
JSR NOUT
LDA #'
JSR OUTPUT
LDA TEMP
AND #$0F
JSR NOUT
JMP DISLP

DISP LDA MESG,X
JSR OUTPUT
INX
CPX #5
BNE DISP
LDA HOUR
JSR NUMA
LDA #$3A
JSR OUTPUT
LDA SECS
JSR NUMA
RTS
INTERRUPT ROUTINE
INT PHA
TXA
PHA
DEC COUNT
BNE RETURN
LDA #$200
STA COUNT
LDX #$30
LDY #$08
LOAD TXA
STA DRB
LDA DRA
STA DEVICE,Y
TYA
STA DRB
INY
LDA #0
STA DRB
TXA
CLC
ADC #$10
TAX
CMP #$E0
BNE LOAD
LDA #$10
CLC
ADC SECS
STA SECS
LDA SECS
CMP $50
BNE RETURN
LDA $0
STA SEC
INC MIN
LDA MIN
AND #$FF
CMP #$0A
BNE RETURN
CLC
LDA MIN
ADC #$06
STA MIN
CMP #$60
BNE RETURN
INC HOUR
LDA $0
STA MIN
LDA HOUR
CMP #$0A
BNE RETURN
LDA $0
STA HOUR
CLC
BCC RETURN
RETURN LDA T1LL
PLA
PLA
RTI
MESG .BYT 'TIME='
YILD .BYT 'YIELD(BU/HR)='
LOSE .BYT 'SHOES(BU/HR)='
LOWAK .BYT 'WALKER(BU/HR)='
END
RESULTS AND DISCUSSION

The solution to the problems of the combine harvester is not a very easy one. The operator of the machine seeks to obtain the optimum conditions for operation in order to minimize grain loss and damage and to maximize profit.

Mathematical Modelling of Combine Losses

Combine losses are caused by many interrelated factors but only forward speed was considered here.

Three components of losses were considered for corn - stalk roll shelling, cylinder loss, and machine missed ears. The effects of speed on these loss components differ one from another. In stalk roll shelling, losses ranged from a minimum of approximately 0.6 bushels per acre to 1.6 bushels per acre. Losses decreased as speed increased from 1.5 miles per hour, the minimum occurring between 3 and 3.5 miles per hour. Loss then increased as speed increased to 4.5 mph.

Cylinder loss was minimum at a very low speed of 1.5 miles per hour (0.3 bu/acre) and increased to 0.85 bu/acre as speed increased to 4 mph.

Machine missed ears and shelling losses behaved somewhat like stalk roll shelling in that it was minimum at an intermediate speed and increased as speed decreased or increased from this point. The minimum loss of 2.2 bushels
per acre occurred between 2.5 and 3 miles per hour. This increased to 2.6 bushels per acre as speed decreased to 1.5 mph and also increased to 3.2 bushels per acre as speed increased to 4 mph.

For soybean, header loss was modelled against forward speed. For the standard reciprocating cutterbar, total header loss increased from 10% of losses at 1 mph to 17% at 3.5 mph. Machete impact cutterbar losses were higher than the standard reciprocating cutterbar at speeds below 2.5 mph. The total header loss for the machete impact cutterbar varied from 15% at 1 mph to 23% at 9.5 mph.

The lack of uniformity of forward speeds at which losses are minimized underscore the complexity of the combine harvester. This shows that an attempt to change the speed of the combine in order to minimize cylinder losses for example, may result in dramatic increases in the other loss components. The combine operator soon learn that the ideal forward speed, height of cut and cylinder speed is a compromise of the best operating speed.

Simulation of Combine Operations

This simulation model was written in Fortran language. Outputs included the required daily forward speed if harvesting is to be done that day, preharvest loss estimates in bushels per acre, cylinder loss, separation loss, daily
yield, and total area covered per day. The program was run for a farm of 1,000 acres.

Thirty-one days were spent for harvesting 1,000 acres of corn. Of these, there was no harvesting for three days. Forward speed varied from 0 mph during days of no harvest to a maximum of 3.5 mph. Preharvest losses increased as the harvest season progressed from less than 0.2 bushels per acre at the beginning of harvest to 1.2 bushels per acre on the last day of harvest.

Gathering losses varied from 1.38 bushels per acre to 1.94 bushels per acre and had an average of 1.49. Cylinder losses averaged less than 1 bushel per acre and varied from 0.2 to 1.2. Separation losses were the highest and varied from 1.4 to 1.6 bushels per acre, averaging 1.57. The highest yield of 98.12 bushels per acre was recorded on the twelfth day and the highest average harvested acreage for any single day was 49.8 acres. The results are shown in Appendix II.

Design of Combine Monitor

The Dickey-John loss sensors that were used worked very well. Grains were not counted individually but the impact of grain passing on the sensor at a given time was calibrated against the voltage given by the sensor and hence against the count supplied by the counter. The calibration
plot was linear which shows that the weight of grain that fell on the sensor was directly related to the output voltage of the sensor.

The yieldmeter constructed from a Dickey-john loss sensor and divider boards worked very well. It took up a small fraction of the space in the grain wagon. It also has the additional feature of continuous output. The calibration for the yieldmeter was also linear. The weight of the grains passing on the yieldmeter is directly proportional to the sensor's output voltage.

The speed sensor generated a lot of electrical noise. Its output voltage was measured but not displayed. Further modifications on this design could utilize better speed measuring devices like radar.

The microcomputer used was not exactly designed for operating on a combine harvester but was good enough for this stage of the study. It was portable and the presence of an editor and assembler allowed for efficient software development. Although a cassette tape recorder was used for loading the program in two segments because of inadequacy of the memory unit, the AIM 65 worked well enough for the development of the software.

The software program developed for the system worked correctly. The request section of the program accepted the letter for the harvested crop (C or S) but did not use them
at this point because the system was operated on soybeans. It also accepted the tire radius but did not use it since the forward speed was not displayed.

Total harvesting time was displayed and changed every 10 seconds for a total of 9 hours, 59 minutes and 50 seconds after which it was reset to zero. The microcomputer display showed yield upon request from 0 to 99 bushels per hour, walker loss, and shoe loss from 0 to 9.6 bushels per hour.
Two approaches were used in this dissertation to solve the problem of reducing the cost of harvesting grain ($ per bushel), and increasing the net income of the farmer.

An analysis of the data permitted the discovery of the following conclusions:

* Equations relating forward speed to cylinder, machine missed ear, and stalk roll shelling losses on the combine harvester were developed.

* A simulation model that calculated ground speed, preharvest loss, gathering loss, cylinder loss, separation loss, daily yield, and area harvested per day during the harvest season was written in Fortran language.

* Sensors for measuring walker loss, shoe loss, and yield in bushels per hour from a combine harvester were developed.

* The hardware necessary for receiving and converting signals coming from the various sensors and feeding them to a single board microcomputer was developed.

* The software for calibration and display of walker loss, shoe loss, and yield was written.
SUGGESTIONS FOR FURTHER WORK

The following suggestions are offered for further work on combine monitoring and control.

1. Develop relationships between grain loss and other factors like grain moisture, cylinder speed, cylinder clearance, walker shake speed, shoe shake speed, and throughput.

2. Develop relationships between grain damage and other factors like grain moisture, cylinder clearance, and cylinder speed.

3. Develop simulation models that will include the effects of these factors and that can be used on a personal computer.

4. Develop or select transducers for measuring all the variables on the combine.

5. Design the hardware necessary to accept these signals.

6. Develop the software for calibrating and displaying the data.

7. Develop a system for automatic control of the combine using the variables measured.
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To all my friends and acquaintances for the encouragement and support given during the research period.
### TABLE 1: INFLUENCE OF COMBINE FORWARD SPEED ON STALK ROLL SHELLING IN IOWA (Ayres et al., 1972)

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Average speed (mph)</th>
<th>Loss (bu/a)</th>
<th>Estimated loss (bu/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5-1.9</td>
<td>1.7</td>
<td>1.3</td>
<td>1.2556</td>
</tr>
<tr>
<td>2.0-2.4</td>
<td>2.2</td>
<td>1.1</td>
<td>1.2151</td>
</tr>
<tr>
<td>2.5-2.9</td>
<td>2.7</td>
<td>0.9</td>
<td>0.8841</td>
</tr>
<tr>
<td>3.0-3.4</td>
<td>3.2</td>
<td>0.8</td>
<td>0.6016</td>
</tr>
<tr>
<td>3.5-3.9</td>
<td>3.7</td>
<td>0.5</td>
<td>0.7063</td>
</tr>
<tr>
<td>4.0-4.4</td>
<td>4.2</td>
<td>1.6</td>
<td>1.5373</td>
</tr>
</tbody>
</table>
### TABLE 2: INFLUENCE OF COMBINE FORWARD SPEED ON LOOSE KERNELS FOR CORN IN IOWA (Ayres et al., 1972)

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Average speed (mph)</th>
<th>Loss (bu/a)</th>
<th>Estimated loss (bu/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5-1.9</td>
<td>1.7</td>
<td>0.4</td>
<td>0.504</td>
</tr>
<tr>
<td>2.0-2.4</td>
<td>2.2</td>
<td>0.5</td>
<td>0.3707</td>
</tr>
<tr>
<td>2.5-2.9</td>
<td>2.7</td>
<td>0.5</td>
<td>0.3914</td>
</tr>
<tr>
<td>3.0-3.4</td>
<td>3.2</td>
<td>0.5</td>
<td>0.5657</td>
</tr>
<tr>
<td>3.5-3.9</td>
<td>3.7</td>
<td>0.7</td>
<td>0.8936</td>
</tr>
<tr>
<td>4.0-4.4</td>
<td>4.2</td>
<td>1.5</td>
<td>1.375</td>
</tr>
</tbody>
</table>

### TABLE 3: INFLUENCE OF COMBINE FORWARD SPEED ON STALK ROLL SHELLING AND MACHINE AND MACHINE MISSED EARS IN IOWA (Ayres et al., 1972)

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Average speed (mph)</th>
<th>Loss (bu/a)</th>
<th>Estimated loss (bu/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5-1.9</td>
<td>1.7</td>
<td>2.5</td>
<td>2.582</td>
</tr>
<tr>
<td>2.0-2.4</td>
<td>2.2</td>
<td>2.4</td>
<td>2.310</td>
</tr>
<tr>
<td>2.5-2.9</td>
<td>2.7</td>
<td>2.3</td>
<td>2.210</td>
</tr>
<tr>
<td>3.0-3.4</td>
<td>3.2</td>
<td>2.3</td>
<td>2.289</td>
</tr>
<tr>
<td>3.5-3.9</td>
<td>3.7</td>
<td>2.3</td>
<td>2.541</td>
</tr>
<tr>
<td>4.0-4.4</td>
<td>4.2</td>
<td>3.1</td>
<td>2.968</td>
</tr>
</tbody>
</table>
TABLE 4: INFLUENCE OF COMBINE FORWARD SPEED ON UNSHELLED KERNELS IN IOWA
(Ayres et al., 1972)

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Average speed (mph)</th>
<th>Loss (bu/a)</th>
<th>Estimated loss (bu/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5-1.9</td>
<td>1.7</td>
<td>0.3</td>
<td>0.3036</td>
</tr>
<tr>
<td>2.0-2.4</td>
<td>2.2</td>
<td>0.3</td>
<td>0.3364</td>
</tr>
<tr>
<td>2.5-2.9</td>
<td>2.7</td>
<td>0.5</td>
<td>0.4086</td>
</tr>
<tr>
<td>3.0-3.4</td>
<td>3.2</td>
<td>0.5</td>
<td>0.5200</td>
</tr>
<tr>
<td>3.5-3.9</td>
<td>3.7</td>
<td>0.6</td>
<td>0.6700</td>
</tr>
<tr>
<td>4.0-4.4</td>
<td>4.2</td>
<td>0.9</td>
<td>0.8610</td>
</tr>
</tbody>
</table>
APPENDIX II MODELLING PROGRAM LISTING

100 C WHAT THE PROGRAM DOES
200 C -----------------------
300
400 C This program uses the rainfall
500 C data for a location for the previous
600 C year or years to calculate the length
700 C of the harvesting season for a field.
800 C It also calculates the losses and
900 C yield associated with this field.
1000 C Input data is average daily rainfall
1100 C data for Ames, Iowa for 1979 and 1980
1200 C for the days between October 15 and
1300 C December 15 which is assumed to
1400 C be the harvesting season for this
1500 C area of the country.
1600
1700
1800
1900
2000 C DEFINITION OF SYMBOLS.
2100 C =========================
2200
2300 C ACRES = Number of acres in field.
2400
2500 C AREA = Area covered by machine at the
2600 C end of a day
2700
2800 C C1 = Corn variety lodging coefficient
2900 C used in loss subroutine
3000 C = Parsons et al. (1971)
3100 C
3200 C DAREA = Dummy variable used to check
3300 C when field has been completely
3400 C harvested
3500 C
3600 C I1 = Large random integer for use by
3700 C the random number generator
3800 C
3900 C I2 = Large random integer for use by
4000 C the random number generator
4100 C
4200 C ID = Variable indicating the number of
4300 C days that harvesting has taken place
4400 C
Lc = Combine cylinder losses
Lg = Combine gathering losses
Lp = Preharvest losses
Ls = Combine separation losses
Lx = Losses due to lodging
m = constant used in loss subroutine
- Parsons et al. (1971)
MC = Final moisture content for the day
generated by subroutine Gauss
MCO = Initial moisture content of the grain
given to subroutine Gauss
N = Number of days in harvesting season
PRECIP = Subroutine for calculating the
probabilities of good, fair, and
bad days
PROBG = Probability of good days in the
season
PROBF = Probability of fair days in the
season
PROBB = Probability of bad days in the
season
R = Random number between 0 and 1
generated by Randu
RANDU = The random number generator on
VAX system in ISU.
Rs = Initial speed given to subroutine
Gauss
RYIELD = Final average yield at the
end of the day
SIGMAM = Standard deviation of grain
SIGMAV = Standard deviation of ground speed
moisture
Smin = Speed at minimum combine loss
- Parsons et al.
Sp = Final speed for the day given by Gauss
SPEED = Subroutine for calculating initial speed for the day
t = Constant for use by subroutine loss
- Parsons et al.
TAREA = Total area covered at the end of the season
Tlc = Average cylinder losses at the end of season
Tlg = Average gathering losses at the end of the season
Tls = Average separation losses at the end of the season
TRYIELD = Average yield at the end of season
YIELD = Estimate of yield in bu/acre

C$\cdash\cdash\cdash$ MAIN PROGRAM C$\cdash\cdash\cdash$
The main program reads in data, calls the various subroutines and prints out results

EXTERNAL PRECIP, SPEED, LOSS
REAL PREC, PPP, PROG, PROBF, PROBB
+ L, Lg, Lx, Lc, Ls, Lp, m, MC

WRITE (6, 55)
55 FORMAT ('ENTER THE TOTAL NUMBER OF

ACCEPT*, ACRE

WRITE (6, 56)
56 FORMAT ('ENTER THE NUMBER OF DAYS

ACCEPT*, N

WRITE (6, 57)
57 FORMAT ('ENTER STIMATED YIELD IN

ACCEPT*, YIELD

WRITE (6, 58)
58 FORMAT ('ENTER ANY TWO BIG INTEGERS')

ACCEPT*, I1, I2

Smin = 2.5

t = 0.0055

m = 0.0005

Cl = 0.0005

ID = 1

ATarea = 0.0 ! initialization of totals

ATlp = 0.0

ATlg = 0.0

ATIc = 0.0

ATIs = 0.0

ATyield = 0.0

20 FORMAT (100(1H=))

22 FORMAT (/, 3X, 'DAY', 5X, 'GROUND', 3X,

+ 'PREHARVEST', 3X, 'GATHERING', 3X, 'CYLINDER',

+ 3X, 'SEPARATION', 3X, 'DAILY', 7X, 'AREA', /,

+ 16X, 'SPEED', 7X, 'LOSS', 9X, 'LOSS', 7X,
103

17700 + 'LOSS',9X,'LOSS',5X,'YIELD',6X,'(ACRES)',/,  
17800 + 16X,'(MPH)',4X,'(BU/ACRE)')  
17900  
18000  
18100 28 FORMAT ( 7X,I3.5(3X,F9.5),1X,F8.2,3X,F9.2)  
18200 30 FORMAT (1X,'TOTAL',1X,I3,12X,4(3X,F9.5),  
18300 + 1X,F8.2,3X,F9.2)  
18400  
18500  
18600  
18700  
18800  
18900  
19000  
19100  
19200  
19300 CALL PRECIP(N,PROBG,PROBF,PROBB) !  
19400 + GENERATES PROBABILITIES FOR SPEED AND  
19500 + MOISTURE IN GRAIN  
19600  
19700  
19800  
19900  
20000  
20100 100 CALL RANDU(I1,I2,R)  
20200  
20300  
20400 CALL SPEED(I1,I2,R,PROBG,PROBF,PROBB,Sp,MC)  
20500  
20600  
20700 IF (Sp.EQ.0.0) THEN  
20800 Lp=0.0  
20900 Lg=0.0  
21000 Lc=0.0  
21100 Ls=0.0  
21200 ryield=0.0  
21300 GOTO 50  
21400 ENDIF  
21500  
21600  
21700  
21800 CALL LOSS(Smin,t,m,yield,CI,ID,MC,Sp,Lp,  
21900 + Lg,Lc,Ls,ryield)  
22000  
22100  
22200
Area = Sp*14.545455 ! CONVERSION OF AREA TO ACRES
Darea = Acre - Tarea

IF (Darea.LE.Area) THEN
    Area = Darea
ENDIF

Print 28, ID, Sp, Lp, Lg, Lc, Ls, ryield, Area

Tarea = Tarea + Area ! UPDATING AREAS
ATlg = ATlg + Lg*Area
ATlc = ATlc + Lc*Area
ATlp = ATlp + Lp*Area
ATls = ATls + Ls*Area
ATtryield = ATtryield + ryield*Area

IF (Tarea.GE.Acre) GO TO 400

ID = ID + 1
GO TO 100

Tlg = ATlg/Tarea
Tlc = ATlc/Tarea
Tlp = ATlp/Tarea
Tls = ATls/Tarea
Tryield = ATtryield/Tarea

Print20,
Print30, ID, Tlp, Tlg, Tlc, Tls, Tryield, Tarea

Print20,
STOP
END
This subroutine reads the precipitation data for the past year or the average for the past years and returns the probability values for good, fair, and bad days.

SUBROUTINE PRECIP(N,PROBG,PROBF,PROBB)

INTEGER N
REAL PREC,PPP,PROBG,PROBF,PROBB,MC
LOGICAL COUNT
DIMENSION PREC(1000)

MAIN SUBROUTINE
COUNT = .TRUE
GOOD = 0.0
FAIR = 0.0
BAD = 0.0

DO 100 I=1,62
READ*, PREC(I) ! COUNTING GOOD, BAD AND FAIR DAYS

DO WHILE (COUNT)

IF (PREC(I).LE.0.2) GOOD=GOOD+1.0
IF (PREC(I).GT.0.2.AND.PREC(I).LE.1.0) FAIR=FAIR+1.0
IF (PREC(I).GT.1.0) BAD=BAD+1.0
COUNT = .FALSE
END DO

IF (I.GE.2) THEN
PPP = PREC(I) + PREC(I-1)
IF (PPP .LE. 0.2) GOOD = GOOD + 1.0
IF (PPP .GT. 0.2 .AND. PPP .LE. 1.0) FAIR = FAIR + 1.0
IF (PPP .GT. 1.0) BAD = BAD + 1.0
END IF
CONTINUE

PROBG = GOOD / 60.0 ! CALCULATING PROBABILITIES
PROBF = FAIR / 60.0
PROBB = BAD / 60.0
RETURN

C SUBROUTINE SPEED
C This subroutine accepts the probabilities of good and bad days and returns the final speed and grain for today
SUBROUTINE SPEED(I1, I2, R, PROBG, PROBF, PROBB, SpfMC)
REAL MC, MCO
SIGMAS = 0.1
SIGMAM = 0.02
C******* GOOD DAY CALCULATIONS ***********
37000 IF (R.GE.PROBG) THEN
37100  Rs = 3.5
37200  MCO = 0.2
37300  CALL GAUSS (I1,i2,Rs,Sigmas,Sp)
37400  CALL GAUSS (I1,i2,MCO,Sigmam,MC)
37500  return
37600  ENDIF
37700
37800
37900  C******* FAIR DAY CALCULATIONS ***********
38000  IF (R.LT.PROBG.AND.R.GE.PROBF) THEN
38200  Rs = 2.5
38300  MCO = 0.25
38400  CALL GAUSS (I1,i2,Rs,Sigmas,Sp)
38500  CALL GAUSS (I1,i2,MCO,Sigmam,MC)
38600  return
38700  ENDIF
38800
38900
39000  C****** NOT TOO FAIR DAY CALCULATIONS ***********
39100  IF (R.LT.PROBF.AND.R.GE.PROBB) THEN
39300  Rs = 2.0
39400  MCO = 0.30
39500  CALL GAUSS (I1,i2,Rs,Sigmas,Sp)
39600  CALL GAUSS (I1,i2,MCO,Sigmam,MC)
39700  return
39800  ENDIF
39900
40000
40100  C****** BAD DAY CALCULATIONS ***************
40200
40300
40400  Sp = 0.0
40500  return
40600
40700  END
40800
40900
41000
41100
41200  C............. SUBROUTINE GAUSS.............
41300
41400  C This subroutine accepts the mean and
standard deviation of any variable and
returns the random value of that
variable that is to be used

SUBROUTINE GAUSS(I1,I2,V,SIGV,VF)

REAL NORMAL

SUM = 0.0

DO 115 L=1,12
CALL RANDU(I1,I2,Rv)

115 SUM = SUM + Rv

NORMAL = SUM - 6.0

VF = NORMAL*SIGV + V

RETURN

END

SUBROUTINE LOSS(Smin,t,m,yield,C1,ID,MC,
+ Sp,Lp,Lc,Ls,ryield)

This subroutine accepts Smin, t, m,
estimated yield, moisture content, and
the current speed, and returns the
preharvest and gathering losses and total
yield for the combine harvester.

EXTERNAL L
REAL L, Lg, Lx, Lc, Ls, Lp, m, MC

Lx = L(C1, ID)

rmax = amax1(Lx, 0.05)
rmin = amin1(rmax, 0.50)
r = s*rmin + t

C******* CALCULATION OF GATHERING LOSSES *********

ALgmax1 = amax1(Smin, Sp)
ALgmax2 = amax1(Smin-Sp, 0.0)
ALgp = r*ALgmax1 + m*ALgmax2
Lg = yield * ALgp

C***** CALCULATION OF PREHARVEST LOSS ***********

ALpp = 0.07*Lx
Lp = yield * ALpp

C****** CALCULATION OF CYLINDER LOSS

ALcmax = amax1(MC, 0.22)
ALcmin = amin1(ALcmax, 0.35)
ALcp = 0.14*(ALcmin-0.22)
Lc = yield*ALcp

C******* CALCULATION OF SEPARATION LOSSES ******

ALsp = 0.55*(MC**2)-0.23*MC+0.038025
Ls = ALsp*yield

C***** CALCULATION OF ACTUAL YIELD

RYIELD = yield -Lp -Lc -Ls

END

C....... FUNCTION SUBPROGRAM .....................
This function calculates the loss due to lodging.

REAL FUNCTION L(C1, ID)
L = amin1(1.0, C1 * ID**1.7)
RETURN
END
<table>
<thead>
<tr>
<th>DAY</th>
<th>GROUND SPEED (MPH)</th>
<th>PREHARVEST GAIN (BU/ACRE)</th>
<th>GATHERING LOSS (BU/ACRE)</th>
<th>CYLINDER LOSS (BU/ACRE)</th>
<th>SEPARATION LOSS (BU/ACRE)</th>
<th>DAILY YIELD (BU/ACRE)</th>
<th>AREA (ACRES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
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<td>2</td>
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<td>0.112727</td>
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<td>1.804542</td>
<td>0.000000</td>
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<tr>
<td>3</td>
<td>2.000000</td>
<td>0.225533</td>
<td>1.300241</td>
<td>0.714055</td>
<td>1.608701</td>
<td>97.65</td>
<td>32.71</td>
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<td>0.669572</td>
<td>1.378630</td>
<td>0.4354556</td>
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<td>35.32</td>
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<td>5</td>
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<td>0.663392</td>
<td>1.490502</td>
<td>1.337147</td>
<td>2.021402</td>
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<td>1.378356</td>
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<td>1.482221</td>
<td>98.05</td>
<td>35.32</td>
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<td>1.466544</td>
<td>1.882800</td>
<td>0.795643</td>
<td>1.650341</td>
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<td>0.175420</td>
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<td>29.15</td>
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<td>97.62</td>
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<td>21</td>
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<td>0.000000</td>
<td>0.000000</td>
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<tr>
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<td>1.583850</td>
<td>97.08</td>
<td>48.43</td>
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<td>23</td>
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<td>0.394632</td>
<td>1.482037</td>
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<td>34.18</td>
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<td>24</td>
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<td>0.777010</td>
<td>1.412040</td>
<td>0.194880</td>
<td>1.431860</td>
<td>97.60</td>
<td>37.34</td>
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<td>25</td>
<td>1.407420</td>
<td>0.805047</td>
<td>1.405260</td>
<td>0.899669</td>
<td>1.708170</td>
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<td>3.135974</td>
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<td>49.00</td>
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<td>0.900000</td>
<td>1.402700</td>
<td>97.65</td>
<td>35.59</td>
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<td>0.297170</td>
<td>1.454725</td>
<td>97.24</td>
<td>35.69</td>
</tr>
<tr>
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<td>97.53</td>
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<tr>
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<td>1.200586</td>
<td>1.491913</td>
<td>0.669548</td>
<td>1.587878</td>
<td>96.54</td>
<td>37.15</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>0.457274</strong></td>
<td><strong>1.492440</strong></td>
<td><strong>0.55192</strong></td>
<td><strong>1.571700</strong></td>
<td><strong>97.44</strong></td>
<td><strong>1000.00</strong></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX III RATINGS FOR HARDWARE COMPONENTS

TABLE 1: ABSOLUTE MAXIMUM RATINGS FOR LM 358

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage V</td>
<td>32VDC or ±16VDC</td>
</tr>
<tr>
<td>Differential Input voltage</td>
<td>32VDC</td>
</tr>
<tr>
<td>Input voltage</td>
<td>-0.3VDC to +32VDC</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>570mw</td>
</tr>
<tr>
<td>Output short circuit to GND</td>
<td>Continuous</td>
</tr>
<tr>
<td>(one amplifier at V 15VDC and Temperature=25 )</td>
<td></td>
</tr>
<tr>
<td>Input current (Vin, -0.3VDC)</td>
<td>50ma</td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>0 C to +70 C</td>
</tr>
<tr>
<td>Storage temperature range</td>
<td>-65 to +150 C</td>
</tr>
<tr>
<td>Lead temperature (soldering, 10 seconds)</td>
<td>300 C</td>
</tr>
</tbody>
</table>
### TABLE 2: ABSOLUTE MAXIMUM RATINGS FOR LM 319

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total supply voltage</td>
<td>36V</td>
</tr>
<tr>
<td>Output to negative supply voltage</td>
<td>36V</td>
</tr>
<tr>
<td>Ground to negative supply voltage</td>
<td>25V</td>
</tr>
<tr>
<td>Ground to positive supply voltage</td>
<td>±18V</td>
</tr>
<tr>
<td>Differential input voltage</td>
<td>+5V</td>
</tr>
<tr>
<td>Input voltage</td>
<td>+15V</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>500mW</td>
</tr>
<tr>
<td>Output short circuit duration</td>
<td>10 sec</td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>0°C to 70°C</td>
</tr>
<tr>
<td>Storage temperature range</td>
<td>-65°C to +15°C</td>
</tr>
<tr>
<td>Lead temperature (soldering, 10 seconds)</td>
<td>300°C</td>
</tr>
</tbody>
</table>
; THIS PROGRAM REQUESTS FOR CROP TYPE AND TIRE RADIUS
; BEGINNING OF HARVEST
; INITIALIZE
==0000 RCHECK=$E907
==0000 OUTPUT=$E97A
==0000 RDRUB=$E95F
==0000 CLR=$EB44
==0000 READ=$E93C
==0000 NUMA=$EA46
==0000 RADIUS=$200
==0000 CROP=$201

; 1ST QUESTION
==0000
==010C *=$10C
4C000A JMP START
==010F *=$A00
==0A00 START
EA NOP
; CLEAR D/P
==0A01 ASK1
2044EB JSR CLR
A200 LDX #00
==0A06 QUES1
BD700A LDA QUESN1.X
207AE9 JSR OUTPUT
E8 INX
E00D CPX #13
D0F5 BNE QUES1

; RECEIVE ANSWER
; <ESC>?
207E9 JSR RCHECK
; INPUT KEY?
205FE9 JSR RDRUB
==0A17
8D0102 STA CROP
==0A1A RPT1
203E9 JSR READ
C90D CMP #$0D
D0F9 BNE RPT1
AD8102 LDA CROP
C943 CMP '#C
D006 BNE SQYTST
2044EB JSR CLR
==0A2B
4C380A JMP ASK2
==0A2E SQYTST
C953 CMP '#S
D0CF BNE ASK1
; CLEAR D/P
2044EB JSR CLR
4C380A JMP ASK2

; 2ND QUESTION
==0A38 ASK2
A200 LDX #00
==0A3A QUES2
BD700A LDA QUESN2.X
207AE9 JSR OUTPUT
E8 INX
E00D CPX #13
D0F5 BNE QUES2
; RECEIVE ANSWER
207E9 JSR RCHECK
; INPUT KEY?
205FE9 JSR RDRUB
==0A4B
0A ASL A
0A ASL A
0A ASL A
0A ASL A

RCHECK=$E907
OUTPUT=$E97A
RDRUB=$E95F
CLR=$EB44
READ=$E93C
NUMA=$EA46
RADIUS=$200
CROP=$201

A200 LDX #00
==0A06 QUES1
BD700A LDA QUESN1.X
207AE9 JSR OUTPUT
E8 INX
E00D CPX #13
D0F5 BNE QUES1

0A ASL A
0A ASL A
0A ASL A
0A ASL A
29F0 AND #$F0
3D0002 STA RADIUS
2067E9 JSR RCHECK
205FE9 JSR RDRUB
230F AND #$0F
==0A5C
18 CLC
6D0002 ADC RADIUS
6D0002 STA RADIUS
==0A63 RPT2
203CE9 JSR READ
C90D CMP #$0D
D0F9 BNE RPT2
2044EB JSR CLR
4C000B JMP $B00
==0A70 QUESN1
454E .BYT 'ENTER C
OR S=
==0A7D QUESN2
5748 .BYT 'WHEEL RADIUS=
.END
ERRORS= 0000

; THIS PART OF THE PROGRAM INITIALISES THE COUNTER;
; IT ALSO DISPLAYS TIME CONSTANTLY;
; YIELD, WALKER, AND SHOE LOSSES ARE DISPLAYED ON REQUEST;
; INITIALISE ADDRESSES

==0000 RCHECK=$E907
==0000 OUTPUT=$E97A
==0000 CLR=$EB44
==0000 NUMA=$EA46
==0000 T1LL=$A004
==0000 NOUT=$EA51
==0000 T1CH=$A005
==0000 ACR=$A008
==0000 IER=$A00E
==0000 COUNT=$202
==0000 HOUR=$203
==0000 MIN=$204
==0000 SECS=$205
==0000 TSECS=$206
==0000 DDRA=$A003
==0000 DDRB=$A002
==0000 DRA=$A001
==0000 RCHECK=#E397
==0000 OUTPUT=#E97A
==0000 CLR=#EB44
==0000 NUMA=#EA46
==0000 TILL=#A004
==0000 NOUT=#EA51
==0000 TICH=#A005
==0000 ACR=#A00B
==0000 IER=#A00E
==0000 COUNT=#202
==0000 HOUR=#203
==0000 MIN=#204
==0000 SECS=#205
==0000 TSECS=#206
==0000 DDRA=#A003
==0000 DDRB=#A002
==0000 DRA=#A001
==0000 DRB=#A000
==0000 DEVICE=#207
==0000 TEMP=#208
==0000 **=#A400
==A400 . WOP INT

==A402
117

```
2067E3 JSR RCHECK
C353 CMP #"V
F35B BEQ YIELD
C34C CMP #"L
==8859
F323 BEQ SHOE
C357 CMP #"W
F344 BEQ WALKER
4C3A0B JMP REPEAT
==8862 YIELD
2044EB JSR CLR
A200 LDX #0
==8867 DISPYD
BD3B0C LDA YIELD, X
207AE9 JSR OUTPUT
E8 INX
E03D CPX #13
D0F5 BNE DISPYD
AE1302 LDX $213
BD0004 LDA $400, X
==8878
2046EA JSR NUMA
4C480B JMP DISLP
==887E SHOE
2044EB JSR CLR
A200 LDX #0
==8881 DISPSH
BD3B0C LDA LOSSH, X
207AE9 JSR OUTPUT
E8 INX
E03C CPX #12
D0F5 BNE DISPSH
AE8F02 LDX $20F
18 CLC
BD0004 LDA $400, X
==8895
AE1202 LDX $212
F3 SED
7D0004 ADC $400, X
3D0802 STA TEMP
D8 CLD
4C380B JMP DECI
==88A3 WALKER
2044EB JSR CLR
A200 LDX #0
==88A8 DISWAK
BDA48C LDA LOWAK, X
207AE9 JSR OUTPUT
E8 INX
E00E CPX #14
D0F5 BNE DISWAK
AE1002 LDX $210
18 CLC
BD0004 LDA $400, X
==88BA
AE1102 LDX $211
F3 SED
7D0004 ADC $400, X
3D0802 STA TEMP
D8 CLD
4C380B JMP DECI
==88C8 DECI
AE0802 LDA TEMP
4A LSR A
4A LSR A
4A LSR A
4A LSR A
290F AND #$0F
2051EA JSR NOUT
A92E LDA #7
207AE9 JSR OUTPUT
==88D9
AD0802 LDA TEMP
290F AND #$0F
2051EA JSR NOUT
4C480B JMP DISLP
==88E4 DISP
BD860C LDA ME5G, X
207AE9 JSR OUTPUT
E8 INX
```
E085 CPX #5
D085 BNE DISP
AD086 LDA HOUR
2046EA JSR NUMA
==0BF5
A93A LDA #3A
207AE9 JSR OUTPUT
AD0462 LDA MIN
2046EA JSR NUMA
A93A LDA #3A
; LDA WITH :
207AE9 JSR OUTPUT
==0C05
AD0502 LDA SECS
2046EA JSR NUMA
0A RTS
; INTERRUPT ROUTINE
==0C0C INT
43 PHA
3A TXA
43 PHA
CE0202 DEC COUNT
D06B BNE RETURN
AD0C8 LDA #200
3D0202 STA COUNT
A280 LDX #80
A088 LDY #88
==0C1D LOAD
3A TXA
3D06A0 STA DRB
AD04A0 LDA DRA
390702 STA DEVICE: Y
39 TYA
3D00A0 STA DRB
C6 INY
A908 LDA #0
==0C2E
3D06A0 STA DRB
3A TXA
18 CLC
6910 ADC #10
AA TAX
C9E0 CMP #6E
D0E3 BNE LOAD
A910 LDA #10
18 CLC
3D0502 ADC SECS
==0C40
3D0502 STA SECS
AD0502 LDA SECS
C960 CMP #60
D035 BNE RETURN
A900 LDA #0
8D0502 STA SECS
EE8402 INC MIN
==0C52
AD0402 LDA MIN
298F AND #$0F
C90A CMP #$0A
D024 BNE RETURN
18 CLC
AD0402 LDA MIN
6366 ADC #$06
3D0402 STA MIN
==0C64
C960 CMP #$60
D017 BNE RETURN
EE8302 INC HOUR
A900 LDA #0
3D0402 STA MIN
AD0302 LDA HOUR
C90A CMP #$0A
==0C75
D086 BNE RETURN
A900 LDA #0
3D0302 STA HOUR
18 CLC
3000 BCC RETURN
==0C79 RETURN
AD04A0 LDA TILL
83 PLA
AA TAX
83 PLA
40 RTI
==0C36 MESS
5449 .BYT 'TIME='
==0C3B YIELD(U)
5349 .BYT 'YIELD(BU)
==0C38 LOSS
5349 .BYT 'SHOE(BU
.HR)='
==6CA4 LOWAK
5741 .BYT 'WALKER( BU/H)='
END
ERRORS= 0000