A SYSTEMS ANALYSIS OF SILAGE CORN HARVESTING METHODS AND ECONOMICS FOR SOUTHWESTERN QUEBEC

Suggested Short Title:

SYSTEMS ANALYSIS OF SILAGE CORN HARVESTING FOR QUEBEC

A SYSTEMS ANALYSIS OF SILAGE CORN HARVESTING METHODS AND ECONOMICS IN SOUTHWESTERN QUEBEC

by

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ABSTRACT

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A SYSTEMS ANALYSIS OF SILAGE CORN HARVESTING METHODS AND ECONOMICS FOR SOUTHWESTERN QUEBEC

A computer program utilizing CPM (Critical Path Management) was developed to calculate costs and capacities for 24 silage corn harvesting machine systems. A brief work study was done to provide data on individual machines. Network diagrams were used to represent tactical combinations of machines. The economics of the 24 systems were calculated, using the program, for several enterprize sizes.

The sensitivity of the 24 systems to changes in hauling distance, load weight and forage chopper field efficiency was studied. Based on variations found in the work study, both hauling distance and load weight were found to be relatively important to system costs. Differences between individual machine systems were explained by a 'criticality report'.

Possibilities for optimization, taking into account weather and crop factors, were examined. Lack of adequate data on crop value seasonal variation and lack of confidence in the model of weather interference prevented the completion of a proposed computerized optimization.

ACKNOWLEDGEMENTS

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I INTRODUCTION

Forage chopping done on the farm is becoming a major source of stored feed on Quebec dairy farms. Corn silage is one of the major constituents. Over the three year period 1966 to 1968, the acreage of silage corn grown in Quebec increased over 14 percent; from 73,854 acres in 1966, to 86,000 acres in 1968 (1, 11).

There are problems of an economic and management nature associated with Quebec dairy farm operations. Several government studies have recognized this and comment that the dairy farm is a low return enterprise (59, 61). This fact coupled with the "cost-price squeeze" documented by the Royal Commission on Farm Machinery (51) make it imperative that the farmer select the best field machine complement for his farm. He must also operate his machines to get the most out of the machine system he has chosen.

To analyse the effect of various machinery management input parameters on silage-corn harvesting, a mathematical model incorporating machinery costs and capacities is required in order to state the problem as precisely as possible. When this has been done, a knowledge of individual machine capacities can be used to determine the rate at which a machinery combination or system can do a particular job. The rate or capacity of the system determines the time and the cost to do a job of a specified size; in this instance, harvest a silage corn crop of a particular acreage and yield. The time taken to harvest the crop may or may not be critical to the economics of harvesting. This depends on the crop value versus time function and weather interference as well as cost factors.

Through computer modelling, industry has been able to answer many questions surrounding complex operations (64, 18). It is possible to develop a similar computer model to determine theoretical performance of a number of harvesting systems and to select those systems which are economically desirable. A computer model is necessary because of the large number of different systems available to do the job and because a sensitivity analysis of system performance requires that calculations be repeated several times with incremental changes in only one variable. Because the machines in a silage-corn harvesting system are involved in a complexity of operations, the system cannot be represented using ordinary mathematics. The operations research techniques of network diagramming and critical path methods (CPM) can be used to model the harvesting systems (13). The resulting networks and the CPM algorithm can easily be incorporated into the computer model.

Poor weather can delay silage-corn harvesting, possibly to an even greater degree than the delay due to poor weather experienced by hay harvesting. The problem is primarily one of poor traction due to muddy field conditions during and after a rain (39). An analysis of weather and how it determines soil moisture for a common southwestern Quebec soil type can give an indication of the length of delay, due to poor field conditions, that would be incurred with a particular silage-corn harvesting system. It is also possible that there might be significant differences in the duration of the delay experienced in several different locations in Quebec due to differing weather patterns.

The costs and harvest times of the economically feasible systems may be affected significantly by incremental variations of selected input parameters. This could be studied by running the harvest-systems computer model several times, each time with an incremental change in the parameter being studied. It may then be possible to determine the importance of particular types of farm and machinery factors to the productivity of the various harvesting systems. Some of the more obvious factors include: hauling distance from field to storage, field machine index (50), and observed machine operating capacity which may be treated as a function of operator ability (62) or as a function of field size and shape.

The value of the systems approach to the study of field machinery operations has been recognized by Donaldson and others (14, 63). One of the major benefits of the systems approach is that it forces quantification of certain problems that were previously only subjectively understood, if they were understood at all. The intent here is to examine the benefits of taking just such an approach to the problem of silage-corn harvesting as it confronts the Quebec dairy farmer.

II OBJECTIVES

A. To develop a computer model, incorporating critical path and network analysis techniques, of observed and synthesized field-machine combinations and methods for harvesting silage-corn.

B. To use the computer model to study the sensitivity of the costs and capacities of the harvesting systems to variations of several selected input parameters.

C. To outline a possible method, using the cost information developed by the model in conjunction with crop value information and weather pattern information, for selecting the economic optimum machinery combination.

III REVIEW OF LITERATURE

In the last twenty-five years, the amount of research done on farm machinery management has increased radically. Seferovich (55) in 1962 presented a review of the development and growth of farm machinery management research to that year. He stated that early research efforts just after the second world war were of the budgetary or analytical type. He showed how, in the late fifties, the econometric synthesis approach had been developed by Barnes (6) and later by Hunt (21). The next approach taken was the use of system analysis and in this connection Seferovich mentioned the work by MacHardy (31).

In the years from 1960 to 1968, the advent of low cost, high-speed computing has allowed a considerable number of computerized systems studies of farm machinery management. These computerized studies incorporated a great number of factors that could not previously be handled. The resulting complexity of the problem necessitated the systems approach. The systems approach as defined here involves the use of one or more of the tools of operations research to analyse the operation or enterprise under study.

Among the first of these computerized systems studies were the studies by Peart et al (44) and MacHardy (32).

Later work was done by Link (28), Hunt (22), Fuller (17), Preston (46) and Stapleton (57).

Peart et al (44) used linear programming and network techniques to study farmstead materials handling equipment. MacHardy (32) studied a wide range of techniques applied to the total farm management problem. His later work (33) used queing theory and Monte Carlo simulated sampling of weather data to select machinery for weather dependent operations.

Link (23) took the commendable approach of trying to account for the total farm operation in selecting machinery for a specific task. That is, he tried to account for other farm operations competing for the same equipment and labor. The techniques he used were primarily network techniques.

Hunt (22) developed a general computer program for harvesting machinery selection. The econometric basis for it was explained in his previous paper (21). An important highlight of this paper was Hunt's development and use of a timeliness factor to account for the variation in crop value with the passage of the harvest season. It assumed that crop value decreases linearly after the start of harvest.

Fuller (17) developed a FORTRAN simulator for forage harvesting. He accounted for weather on a probabilistic basis. Preston (46) used a very interesting network technique, referred to as SPNA or shortest-path-network-algorithm, to find optimum irrigation methods. This same technique was used very effectively by Fluck (16) to optimize sweet potato harvesting and handling.

Stapleton (57) used techniques similar to those of Hunt (22) to select cotton harvesting equipment. During this period, a great number of readily usable computer programs, utilizing one or more of the techniques mentioned above, were developed for management use by extension workers or professional farm managers. A fairly complete list of these programs was made by Nelson and Bowers (43).

Since 1968, the number of papers presented dealing with farm machinery management has mushroomed. Among them are papers by economists such as Hogland (19), Scott (53) and an excellent multidisciplinary study by Holtman et al (20) and by engineers such as Morey (39, 40, 41), Carpenter and Brooker (10), Von Bargen and Peart (63) and Millier and Rehkugler (36). At least one paper was written by an extension worker (Moggach (37)).

There are only a few operations research techniques that have been used with any degree of success to model forage harvesting machinery. Fuller (17) used simulation techniques to model all types of forage harvesting except silage corn. In this way he was able to account for the effect of weather and the variation of yield and crop value while studying the performance of a specific machine system. Coupland (13) used critical path networks to determine the performance of hay-baling systems. This allowed any type of hay-baling machine system to be studied, whether its performance in the field had been observed or not, as long as the operation times of individual machines were known. An explanation of all the various network techniques and how they could apply to agricultural machinery management was made by Peart et al (45); however, he did not recognize its usefulness in studying the performance of a tactical combination of machinery. A tactical combination of machinery is defined here as a specific operating combination of machinery which can be changed into another tactical combination simply by altering the way in which one or more of the machines are used. A strategic combination of machinery is defined here as one which can only be changed by changing one or more of the machines, (e.g. buying a new and bigger forage harvester).

While most of the machinery systems studies have included some sensitivity analysis, they were primarily concerned with the change in system performance resulting from a change in one or more of the cost inputs. A typical example is the study of forage harvesting, storing, and feeding systems done by Taylor and Barr (60). They considered 80 alternative machinery systems to harvest all types of forage crops, including silage corn, for a representative dairy farm at 30 and 70 cow herd sizes. Each system was compared on a profits-earned basis. They studied the sensitivity of the machine systems profit to changes in the cost of labor. Similarly, Morey et al (41) studied the sensitivity of the optimum policy for corn harvesting to changes in custom harvesting charges.

Only a few studies have been done to determine the sensitivity of machine system performance to factors characteristic of a farm's physical layout or an operator's tactical management ability. Von Bargen (62) studied the individual performance of hay harvesting systems to differences in operator ability. Von Bargen (63) in a later simulation study, examined in detail variations in tactical operating policies for corn planting systems.

Machinery selection is only one aspect of machinery management. Selection, however, implies the use of an optimizing method. Previous machinery selection studies have been of two basic types. The first type used a general cost versus capacity function and then selected, via some optimization technique, the optimum capacity for a particular size and type of operation or enterprise. The second type started with a finite number of machine systems with known costs and capacities, applied them to a particular size and type of enterprise and then found the optimum system. An example of the first type of optimization study is that by MacHardy (34). He developed cost information on a general basis, using a linear relationship between size and price of machines. He found the minimum cost combination using calculus and Lagrange multipliers. Hunt's (21) early work is also an example of this kind of machinery selection study. The study by Taylor and Barr (60), previously outlined, is a good example of the second type of machinery selection study as is the work by Fluck (16). The difficulty with the first type of study is that of finding a real machine system with the optimum capacity and having costs equal to or lower than those assumed. The second type of study also has a difficulty. Once the optimum system is found, unless the researcher has been very thorough, he cannot be sure that a better system does not exist.

IV INPUT FOR HARVEST SYSTEM MODEL

The model of silage-corn harvesting developed herein requires three kinds of input information. This input would include data on the types and material processing and handling capabilities of the machinery used. It would include data on both the capital and operating costs of this machinery and a method of accounting for these costs. It would also include information on how these machines interact with one-another on a time scheduling basis. To represent this latter information the special tool of the activity network is introduced.

A. Machinery and Capacities

Machinery capacity is expressed generally as a rate,- a rate of doing work. It is thus a dynamic time oriented characteristic, as opposed to a static capacity such as the volume of a grain tank on a combine. Two of the commonest measures of agricultural field machinery capacity are expressed as acres per hour and tons of crop handled per hour.

Donaldson (14) recognized that the capacity of farm machinery should be conditioned by an adjective. He mentioned the use of maximum capacity, expected capacity and excess capacity. Other capacities are maximum theoretical capacity, optimum capacity and observed capacity. Maximum theoretical capacity is the capacity of the machine calculated on a theoretical basis, taking into account only the physical dimensions and limitations on material strength. Optimum capacity is that capacity which results in the optimum economic operation of the machine. Expected capacity is that capacity which is the mean of a sufficiently large statistical sample of observed capacities. Observed capacity is the capacity of the machine determined in a single observation.

The A.S.A.E. has also defined two other measures of capacity (4). These are 'Effective Field Capacity' which is defined as the actual rate of performance in terms of land or crop processed in a given time, based upon total field time, and 'Theoretical Field Capacity' which is defined as the rate of performance obtained if a machine performs its function 100 percent of the time at the rated operating speed using 100 percent of its rated width.

The observed capacity of a machine is dependent on three factors. These are; physical design of the machine (that is the maximum theoretical capacity), the efficiency of control of the machine's operation, and the operating environment (which would include variations in the properties of the product being processed). For most industrial and commercial machinery the possible adverse effects of the latter two factors are minimized to a great extent. The machine is controlled automatically, sometimes by a computer. The machine's operating environment may also be brought to an optimum by housing it.

The expected operating capacity of an agricultural field machine, the capacity realized by most farmers, may differ by a significant amount from the optimum and maximum theoretical capacity of the machine. In turn, the observed capacity on a particular farm at a particular time may also differ significantly from the expected capacity. This is due to large variations in the efficiency of control and variations of the operating environment, which are not usually found in the case of industrial machinery. Most present-day farm field machinery is man-operated. The effects of variations in operator ability have been described by Von Bargen for hay balers (62). Environmental variations and their effects on field machine observed capacity have similarly been reported (13, 49, 47). Here, such factors as soil trafficability, field size and shape and crop variations have been studied.

In order to gain an understanding of some of the problems involved in silage-corn harvesting and to obtain an indication of the range of capacities of the machinery being used, a work study of silage-corn harvesting was conducted on a randomly chosen group of farms in southwestern Quebec. As it was not the purpose of this study to make an accurate determination of expected capacity, only five farms were visited for a total of ten days of observations. Weights of material handled by the machinery were studied in sequences. Each sequence consisted of the operations of chopping enough to fill one wagon, hauling that wagon to the silo, unloading the wagon into the silo and returning it to the field. The three kinds of machinery observed were forage choppers, self-unloading wagons and forage blowers. Further discussion in this chapter is confined to each of the above mentioned machines in turn.

The partially reduced data taken in the work study are listed in tabular form in Appendix A.

Forage Choppers

The forage chopper is the central machine in the harvesting system. It is usually towed by a tractor and is usually powered from the tractor's power-take-off shaft. It can cut and chop simultaneously one or two and on some machines three rows of corn, depending on the header unit attached to it. Most manufacturers have four header unit options; one-row corn head, two-row corn head, windrow header and a sickle-bar direct cut header. The chopping unit may have a reel (cylindrical) type cutterhead or a flywheel type cutterhead. The theoretical length of chop is usually varied by varying the ratio between the cutterhead speed and the feed mechanism speed. The cutterhead also acts as a blower-impeller, although some units have a separate blower-impeller, which conveys the chopped material into a wagon which is usually towed by the chopper.

According to calculations made using data on power requirements from ASAE D 230.2 (3), between 32.8 and 82.0 pto hp would be required for the largest of the observed forage choppers. These figures are obtained by multiplying the unit power requirement limits of 1.0 and 2.5 hp-hr per ton, taken from Table 1, page 292 of (3), by the highest observed capacity of 32.8 tons per hour, taken from Appendix A Farm Number 8. These figures do not include an allowance for drawbar horsepower required to tow both harvester and wagon. While most of the farms visited were using tractors of over 50 pto horsepower, a few were not. Unfortunately this aspect of the effects of available power on forage chopper capacity was not investigated during the work study. However, as a limiting factor, available power was not subjectively apparent.

Two different sized forage choppers of the same manufacture were used in the development of the model of harvesting. The capacity at which they were used in the model was one-half that of the manufacturer's rating as it was apparent from the work study that the farmers were getting about one-half of the manufacturer's rating. These two machines and their associated data are presented in Table 1.

Table 1. Summary of Machine Capacities used in Development of Harvest Model.

Forage Choppers

Machine Number	Capacity in Wet Tons per hour	Revised FMI	Type
1	20	0.85	International Harvester 350 1-row
2	40	0.92	International Harvester 550 2-row

Forage Blowers

4	20	1.00	New Holland 23 Hopper type
5	35	1.00	New Holland 26 Hopper type

Self-Unloading Wagon - John Deere 214

Capacity: 5.00 wet tons at 3.00 mph for average hauling distance of 0.25 miles (one way).

Assumed Conditions:
36 inch row spacing
75% moisture content (wet basis) of crop when harvested.

Forage Blowers

Difficulties in determining the relationship between rated capacity and observed capacity are encountered when considering forage blowers as well as forage choppers. From direct observation in the work study, it was seen that low rates of unloading forage resulted from poor feeding of silage into the blower hopper by the self-unloading wagon and sometimes from insufficient available power for the blower. Most of the wagons were loaded too full and during the unloading operation, large masses of silage would tumble over the top beater of the wagon into the stream of silage going into the hopper. The operator then had to be quick in holding back the flow so as to prevent the blower from clogging. This would usually happen six or seven times during unloading and as a result depressed the observed blower capacity considerably.

There were exceptions. One of the observed machines (blower C, Appendix A) was of the feed-table type. It had a feed roll just in front of the blower fan. This roll smoothed out any uneveness of feed. The result was a higher capacity than most of the other machines observed in the work study. Another blower (blower E, Appendix A) had a high capacity for slightly different reasons. Due to soft soil conditions the wagons were not loaded full. As a result uneven unloading did not occur because the level of silage in the full wagon was below the top beater.

Two different sized blowers of similar manufacture were used in the analysis. They are presented in Table 1 with appropriate data.

Self-Unloading Wagons

The load capacity for self-unloading wagons observed in the work study was around 3.50 tons for haylage and 5.00 tons for silage-corn (due to the difference in moisture content of the two crops). It was previously mentioned, however, that in one case the capacity of the wagons was limited by soft soil conditions while they were hitched behind the forage chopper. Clark and Norris (12) recognized this as a problem and designed an automatic draft control for a self-powered forage wagon, and in this way increased the mobility of the tractor-chopper-wagon unit. No attempt, however, was made to correlate soil conditions with hauling capacity of wagons in the work study done for this thesis.

The travel rate of wagons being towed back to the silo averaged at 3.00 mph. Variation was great with travel rates ranging between 1.75 and 5.50 mph.

In the analysis, only one model of wagon, a John Deere Model 214, was used. It had a capacity of 5.00 tons (wet) of corn silage. The hauling rate used was 3.00 mph. Increases in hauling capacity in the model were gained by using one, two, or three wagons in sequence with one or two towing tractors.

Table 1 summarizes the capacity data for the machinery considered in the analysis. Also noted, is the average observed field-machine-index or FMI (originally defined by Renoll (49)). According to Renoll's (49) definition, the FMI is the ratio of operating time to the sum of operating time, waiting time, breakdown time, and turning time at the end of the rows. As waiting time was accounted for by the activity networks in the model developed here, a revised definition of field machine index was used. The revised FMI is the ratio of operating time to the sum of operating time, turning time at the end of the rows, and breakdown time. In the work study the revised FMI is recalculated for the chopper for each wagon load.

The revised FMI on the farms visited in the work study varied between 0.75 and 0.94 for forage choppers. The observed revised FMI was higher for two row choppers than for single row choppers. It was also higher where the field was sufficiently long so as to require fewer rows to fill a wagon.

B. Machinery Cost Analysis

It is desirable from the standpoint of readily usable input for the computer model to use a costing method which will result in a total cost per hour of operation of an individual machine. It is also desirable that the costing method be relatively simple and yet conform to generally accepted practice in agricultural machinery management.

To satisfy these requirements it was decided to use the costing method suggested by ASAE D 230.2 (3). Some variations on this method such as straight line depreciation and addition of tractor fixed costs were also used in the analysis.

Depreciation

Straight line depreciation over a ten year economic life was used in order to simplify the model. At least two other studies have used straight line depreciation over ten years for harvesting equipment (10, 16). A calculation using the smallest set of machines at the largest acreage studied (140 acres) also revealed that a machine would not wear out (see Table 2, p. 294 (3)) before the end of the ten year period.

The formula for depreciation using 10 percent of initial list price as the salvage value is:

$$D_p = (C_i - 0.1P_1)/10 \qquad \ldots 1$$

where

D_p = depreciation cost per year

C_i = list price less 8% (usual dealer discount (48))

P_1 = list price

Use of the actual price paid by the farmer in calculating depreciation has been suggested by Morris (42) and more recently by the ASAE D 230.2 (3).

Interest, Housing and Insurance

These items are all expressed as an annual charge based on a percentage of remaining value. The percentage values used are those suggested by the ASAE D 230.2 (3). They are:

Interest	8.0%
Housing	1.5%
Insurance	0.5%
TOTAL	10.0%

The formula for the annual charge is:

$$IHI = 0.10\ (C_i - nD_p) \qquad \ldots 2$$

where

IHI = annual charge for interest, housing and insurance

n = age of machine in years

Formula 2 is not to be taken as a functional relationship since it is more likely that depreciation is actually inversely proportional to housing costs; the more money spent on housing, the lower the depreciation charges.

Repairs and Maintenance

Several formulae are suggested by ASAE D 230.2 for calculating total accumulated repairs. They are:

$$TAR = 0.127(x)^{1.4} \text{ for forage choppers and blowers} \quad ...3$$

$$TAR = 0.159(x)^{1.4} \text{ for self-unloading wagons} \quad ...4$$

where

TAR = total accumulated repairs as a percentage of list price

x = total accumulated hours as a percentage of lifetime hours

x is found from:

$$x = 100 \left(\frac{10Y}{life}\right) \quad ...5$$

where

Y = yearly use in hours

life = wear out life in hours (see Table 2, p. 294 (3))

and Y is found from:

$$Y = \frac{A_t Y_d}{C_p} \quad ...6$$

where

A_t = total acres harvested per year

Y_d = yield in tons/acre

C_p = capacity of machine in tons per hour (see Table 1)

Repairs costs are then:

$$R_p = \frac{TAR\%(P_1)}{10} \qquad \ldots 7$$

where

R_p = average yearly repair cost

Power Cost

From a random selection of several of the recent Nebraska tests for varying load, diesel tractors averaged 12.0 hp-hr per US gallon. When converted to Imperial measure, this figure becomes approximately 14.5 hp-hr per Imperial gallon. Fuel cost in Quebec is 22.0¢ per Imperial gallon. Power costs are then found from $\frac{22.0¢/\text{gallon}}{14.5 \text{ hp-hr/gallon}}$ = 1.52¢ per hp-hr. Annual power costs are then 1.52¢ per hp-hr + 8.5% of that for crankcase oil = 1.65¢ per hp-hr.

so that

$$P_c = \frac{1.65}{100} \times P_r \times Y \qquad \ldots 8$$

where

P_c = annual power cost in dollars

P_r = average power requirement in hp

In addition to calculating annual costs for each machine for each level of usage, a portion of the fixed costs and repairs and maintenance costs of the tractor must be added to the cost of the machine it is powering. In this study the tractor by itself is presumed not to perform any useful function and therefore must appear as an expense related to machine useage.

Each of the machines considered are independent of one another, that is, the cost of using a particular chopper is not changed when a larger blower is used. This is not the case for the self-unloading wagon. Its cost of use can change if it is used with a different forage chopper. This is because the number of hours of use per year of the wagon will depend on the other machines in the system it is used with. It would make more sense, then, to charge the cost of the wagon on an hourly basis. In this case a forage wagon costing $2,075. and having a life of 2500 hours would have a depreciation cost of $0.83 per hour. It is assumed for convenience that forage wagons have no salvage value. ASAE D 230.2 (3) suggests that total life costs of interest, housing and insurance may be estimated as five percent of the list price. Total fixed costs per hour for the wagon are then $0.87. Repairs and maintenance would be 100 percent of the list price of the wagon over its lifetime, so their cost per hour would be $0.83. Repairs and maintenance can, of course, only be charged while the wagon is operating.

Labor Cost

The average wage without board to male laborers on farms was $1.46 an hour in May 1971 (15) and in January 1972 it was $1.51. Labor cost was then rounded to $1.50 an hour.

Rather than charging this cost to each activity within the harvesting system, the labor cost was charged to the system as a whole. If one combination of tractors, forage choppers, forage blowers and wagons used three men, then the unit labor cost was multiplied by three, multiplied by the number of working hours in a day and multiplied by the number of days to complete the harvest.

C. Machinery Systems

A combination of machinery operated in an ordered or logical sequence to produce or harvest a particular crop has been defined by the ASAE (4) as a Crop Production Subsystem. Corn silage harvesting and the required machinery is such a subsystem. It will be referred to here, generally, as the Machine System. The actual capacity of a machine system such as this is not necessarily the same as the capacity of the primary machine unit (in this case, the forage chopper). In fact, the machine system capacity is nearly always less than the capacity of the primary machine unit. This is because individual operations in the subsystem are carried on both in parallel and in series with one another (4). Consequently some operations may be delayed as they depend on previous operations not yet completed.

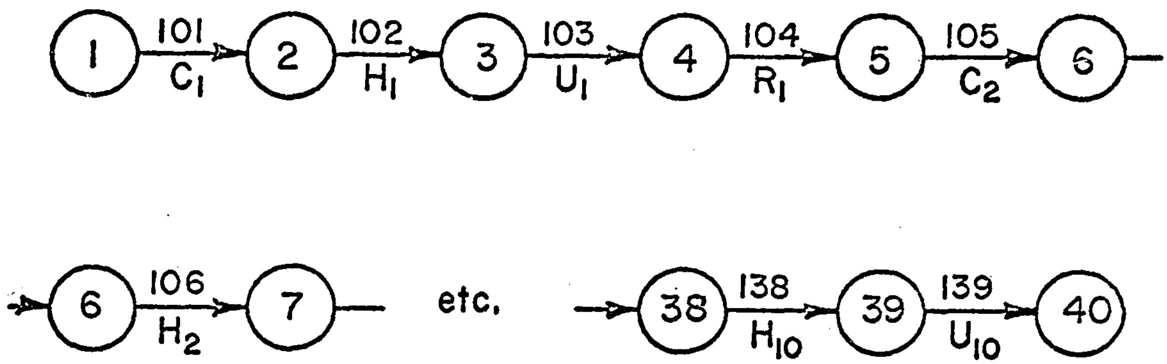
Using the methods of classical mathematics, it is not generally possible to model a system such as has been described.

To model the time interdependencies of such a system, the special tool of the activity network and its associated method CPM (Critical Path Management) are introduced herein. There are a large number of books available which describe the use of the activity network and CPM. The one used extensively in the development of the model is by Law and Lach (26). Another excellent book on the subject is by Wiest and Levy (65).

One of the requirements in drawing an activity network is that it and the project it represents must have a clear beginning and end. To draw a network with a clear beginning and end for silage corn harvesting would be tedious as the beginning would come when the harvest is started and the end would come when the entire crop was in storage. Instead of doing this, the networks were drawn to represent the harvesting of ten loads of corn silage. Coupland (13), in drawing similar networks for hay baling, used seven loads. However, it was felt that a ten-load network enabled easier computing and attenuated additional time effects at the beginning and the end of the networks to a greater degree than seven would have. It would have been somewhat more realistic to base the networks on a day length of say eight hours of operation. However this is not feasible since the objective using CPM is to find the completion time given the number of activities; it is not the objective to find the number of jobs that can be done given a completion time.

The actual amount of silage harvested would depend on the size of the individual load. The size of the load in tons multiplied by ten, the number of loads, and divided by the time in hours to harvest the ten loads (calculated by the Critical Path Management algorithm) results in the machine system capacity in tons per hour.

A single network can only be used to represent the machinery system if the number and types of machines and the way they work together on a time scheduling basis remains constant. The introduction of another machine, such as having two self-unloading wagons instead of one, or the changing of the network logic, requires that another network be drawn. Six networks were needed to represent all the machine systems used in the model developed in the next chapter. The activity networks themselves are shown in Figures 1, 2, 3, 4, 5 and 6. Table 2 lists the requirements of men and machinery for each network.



Notes:

1. Each circle is an event or node, the number is the node number. For the computer program all node numbering must start from 1. The arrows connecting each node are activities. The number is the activity number. All activity numbering must start from 101. The numbers do not have to be sequential, but the node number of the finish event of an activity must be greater than the node number of the start event of that activity.

2. The key for activity descriptions is as follows:

   C Chopping activity
   H Hauling activity
   U Unloading activity
   R Returning activity

   The dummy activity (required to maintain network logic) is a dashed arrow.
   The subscripts on the activity letter codes denote the sequence or load number.

Figures 1 and 2. Activity Networks 1 and 2.

(Reference to Fig. 1 means Activity Network 1 while reference to Fig. 2 means Activity Network 2. The two Figures were drawn as one since logically they are the same.)

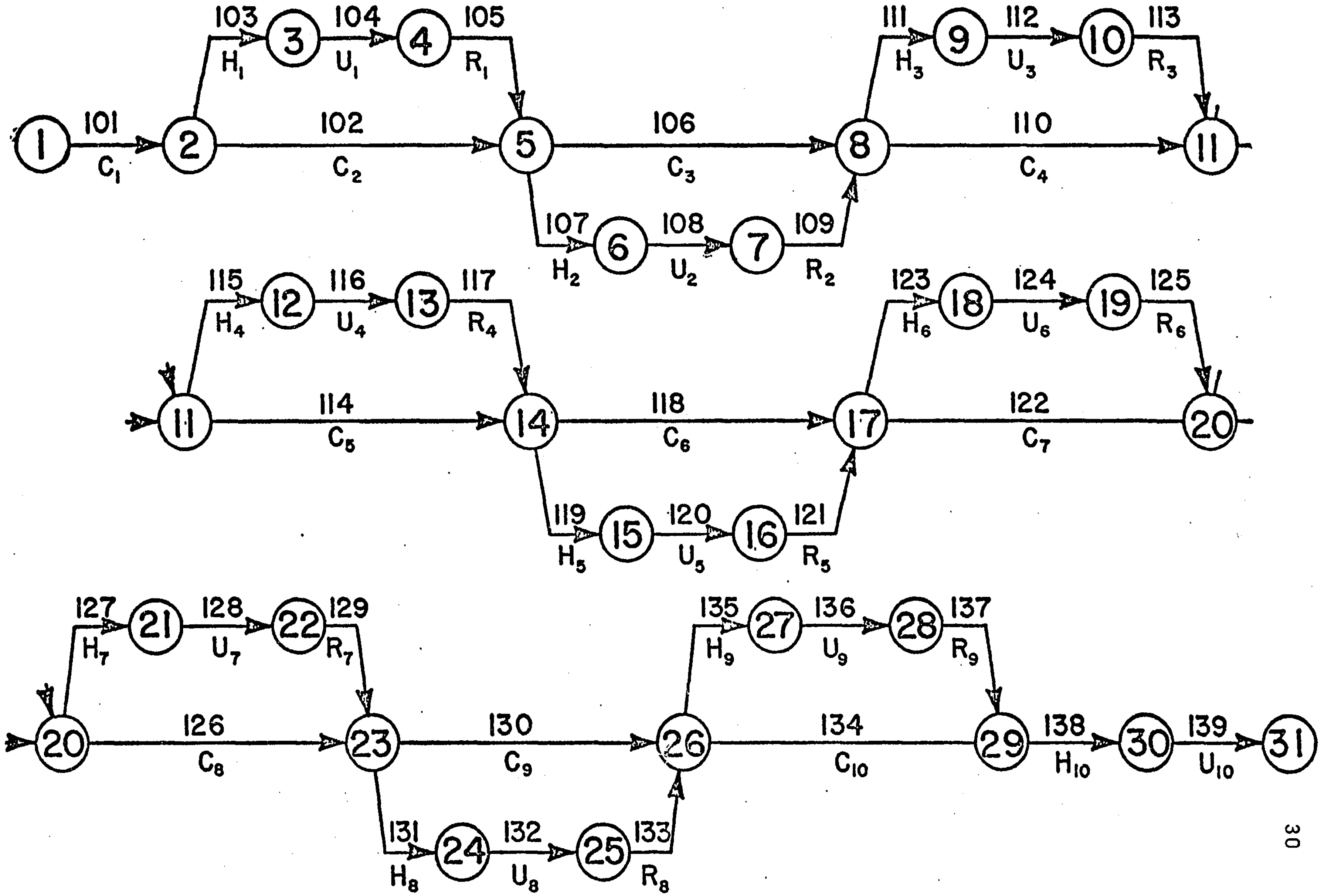


Figure 3. Activity Network 3. Notes 1 and 2 of Figures 1 and 2 apply.

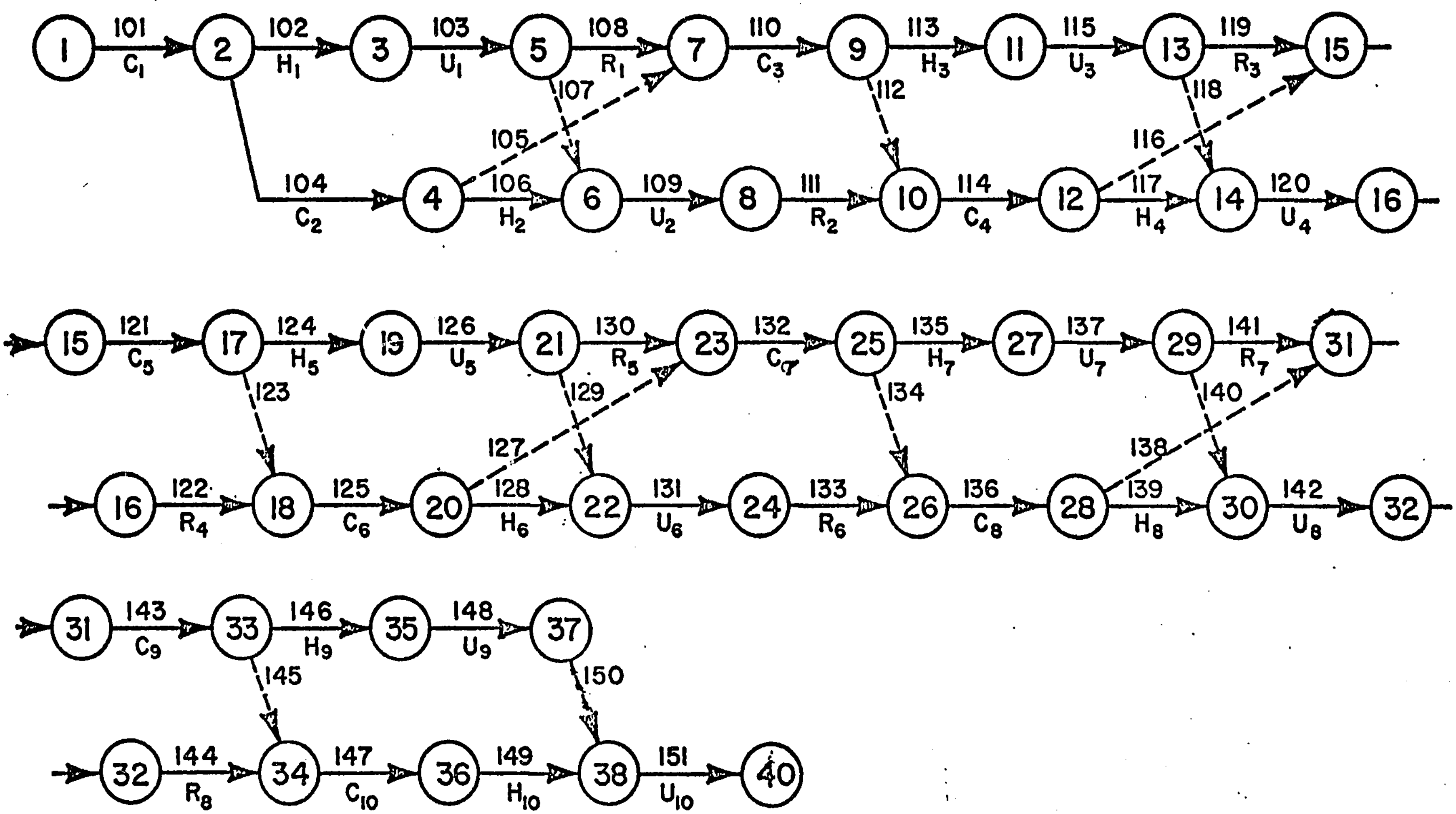


Figure 4. Activity Network 4. Notes 1 and 2 of Figures 1 and 2 apply.

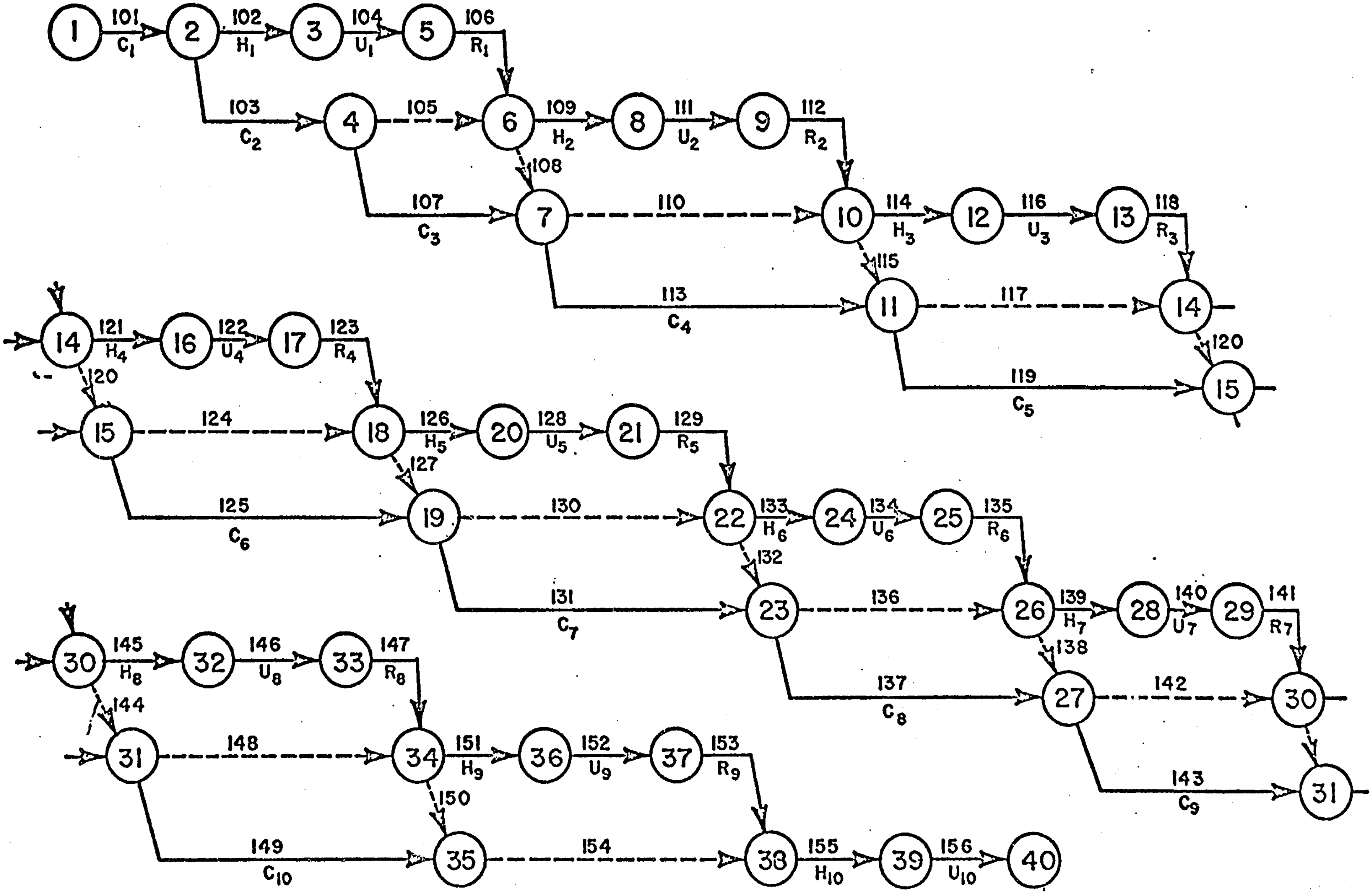


Figure 5. Activity Network 5. Notes 1 and 2 of Figures 1 and 2 apply.

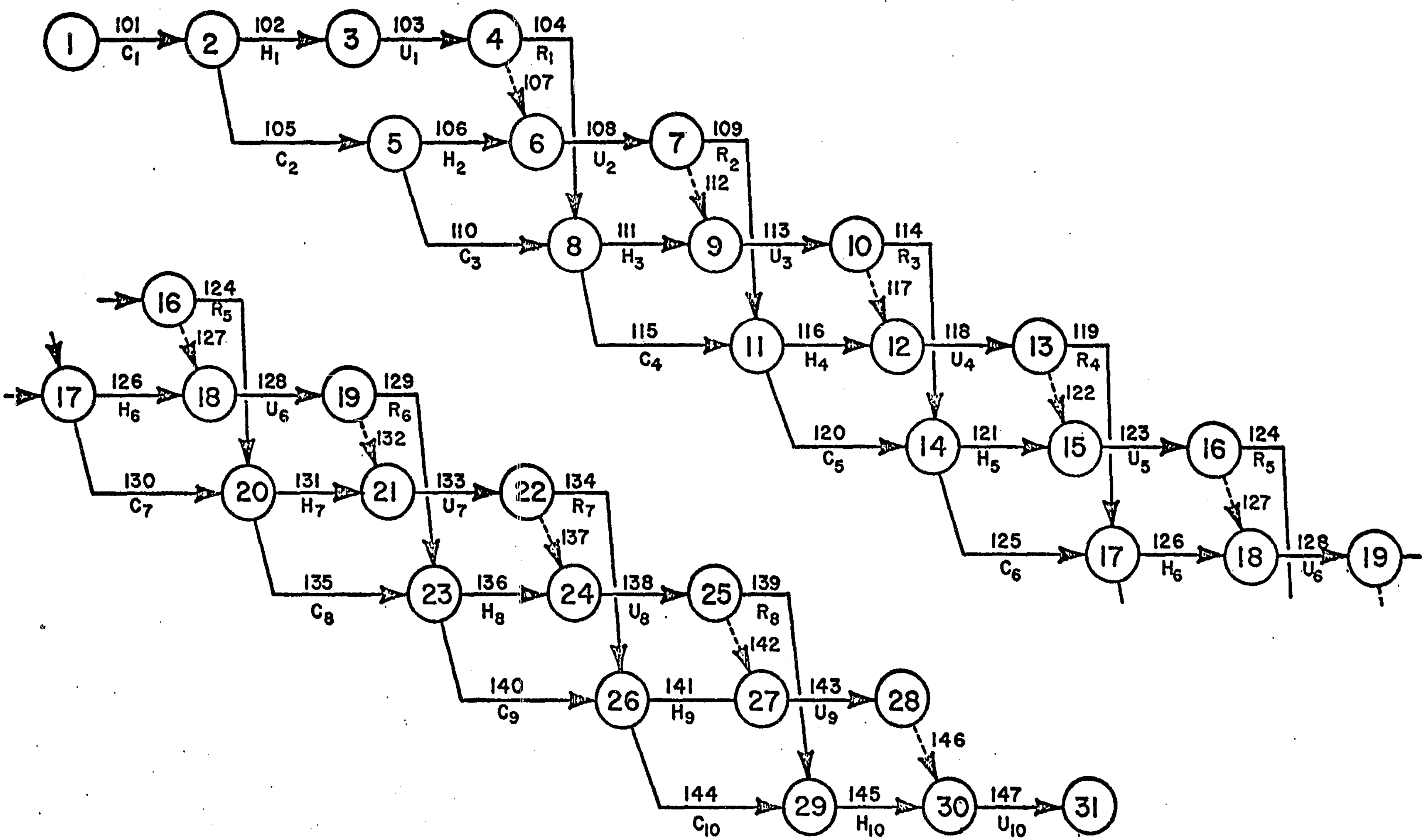


Figure 6. Activity Network 6. Notes 1 and 2 of Figures 1 and 2 apply.

Table 2. Network Machinery and Labor Requirements.

Network Number	Number of Men and Machines Required: Tractors	Wagons	Forage Harvesters	Forage Blowers	Men	Comments
1	2	1	1	1	1	One tractor remains on blower. One tractor shared by wagon and forage chopper.
2	3	1	1	1	1	
3	3	2	1	1	2	
4	4	2	1	1	3	
5	3	3	1	1	2	
6	4	3	1	1	3	

V HARVEST SYSTEM COMPUTER MODEL DEVELOPMENT

A computerized model was developed to calculate the total harvest cost and time for each of 24 machine systems to harvest an increasing series of acreages and yields of silage corn. The number of machine systems was arrived at by multiplying the two forage chopper sizes available by the two forage blower sizes available to give four machine combinations. Four machine combinations multiplied by six activity networks give 24 machine systems. The program was written to allow easy expansion to any number of machine systems.

The model first calculated the fixed costs, which included depreciation, interest, housing and insurance charges for each machine including tractors but excluding self-unloading wagons. Then, starting with the first acreage and yield, all the variable costs, except labor, associated with the activity of chopping a wagon load of silage, as well as the time required, were calculated. Following this, all similar costs and times were calculated for the hauling activity, the unloading activity and the returning-of-the-wagon-to-the-field activity. These costs and times were calculated for each size of machine that could be involved.

Starting with the first machine system, a CPM algorithm FORTRAN subroutine calculated the duration of the network and the critical path (the critical path may be described as that path or sequence of activities through the network which takes the longest time). It recorded the number of times a particular type of activity (chopping, hauling, unloading, returning or dummy activity) fell on the critical path. The time required to harvest the entire crop (based on an eight hour day), the daily fixed costs, the network or 10 load cost, the daily variable costs and the total harvest cost were then calculated.

A flow chart of the resulting FORTRAN main program is given in Figure 7. A complete program listing with a key to all the input variables and a list of the computer software and hardware required are given in Appendix B. A complete description of the program output follows in the next chapter on the results of the initial run of the model's computer program.

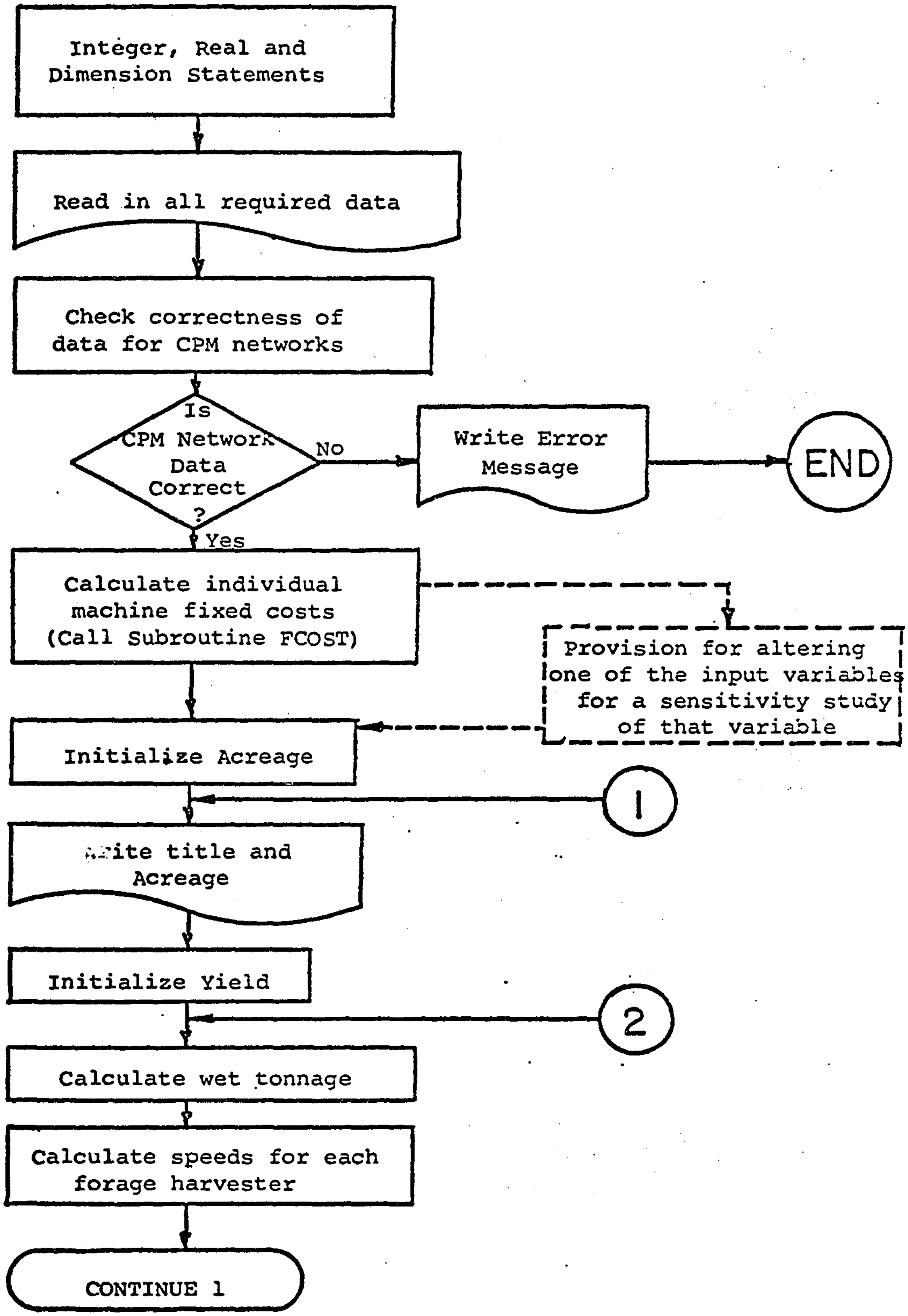


Figure 7. Flow chart of computer Model of Silage-Corn Harvesting.

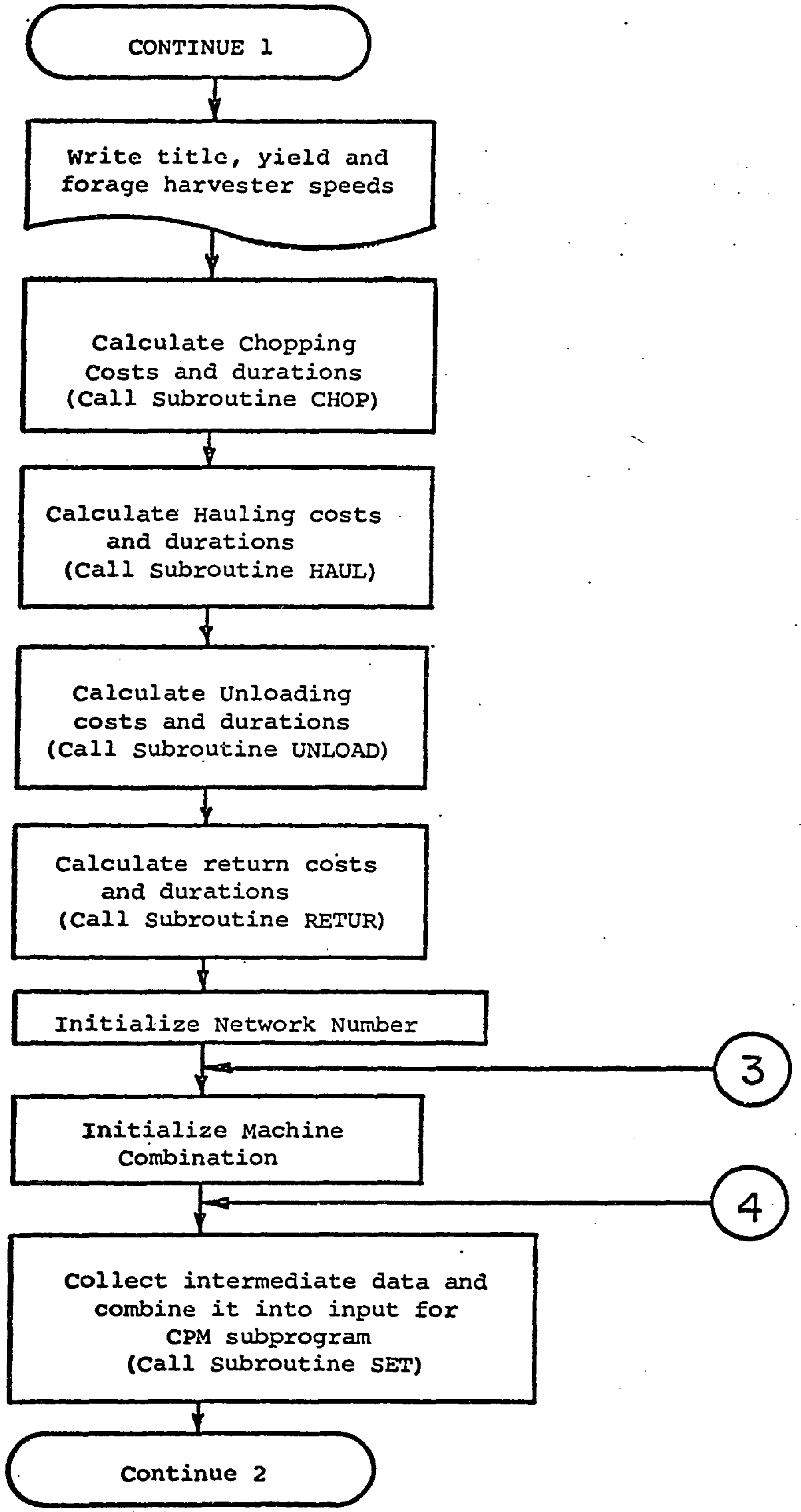


Figure 7. ...continued

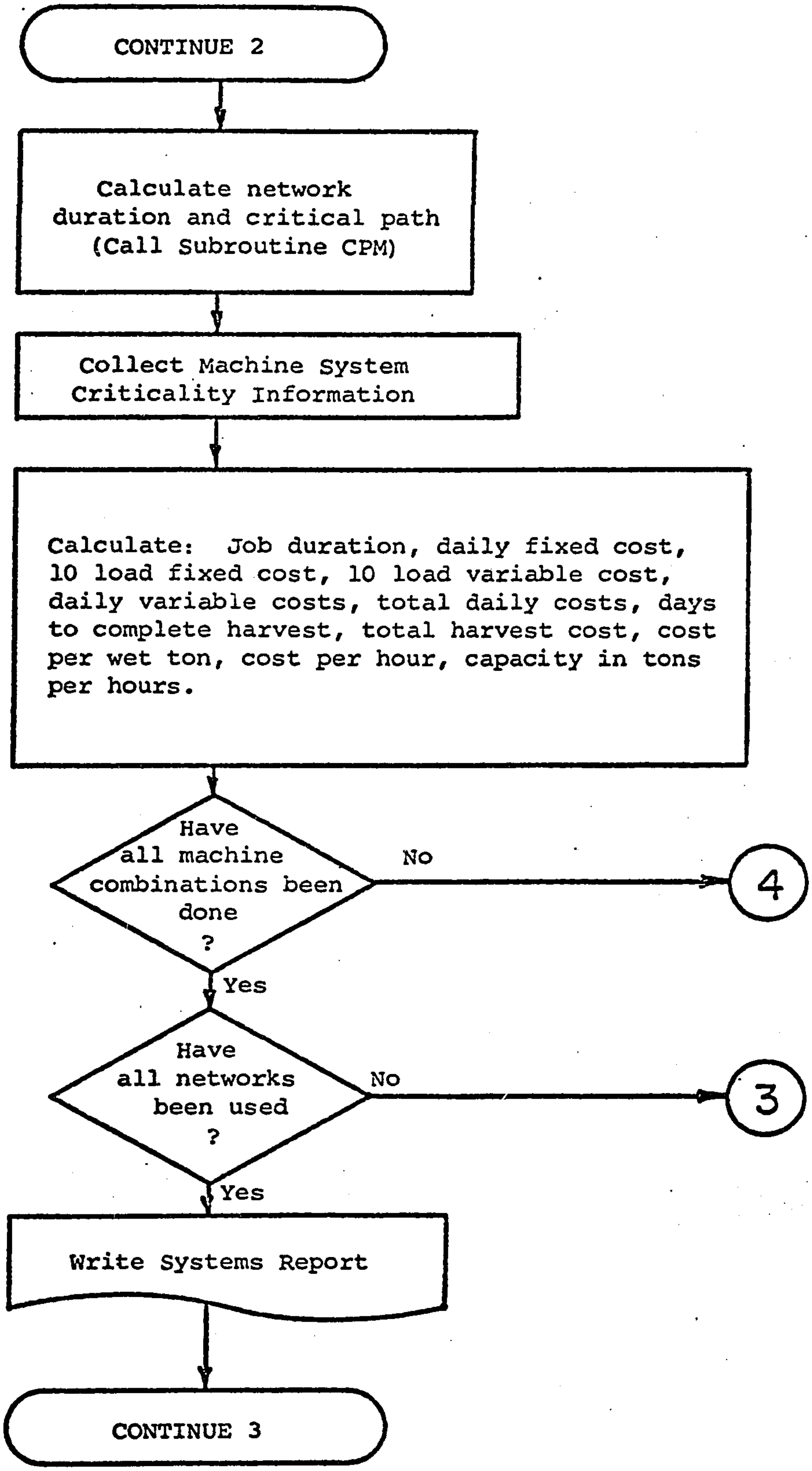


Figure 7. ...continued

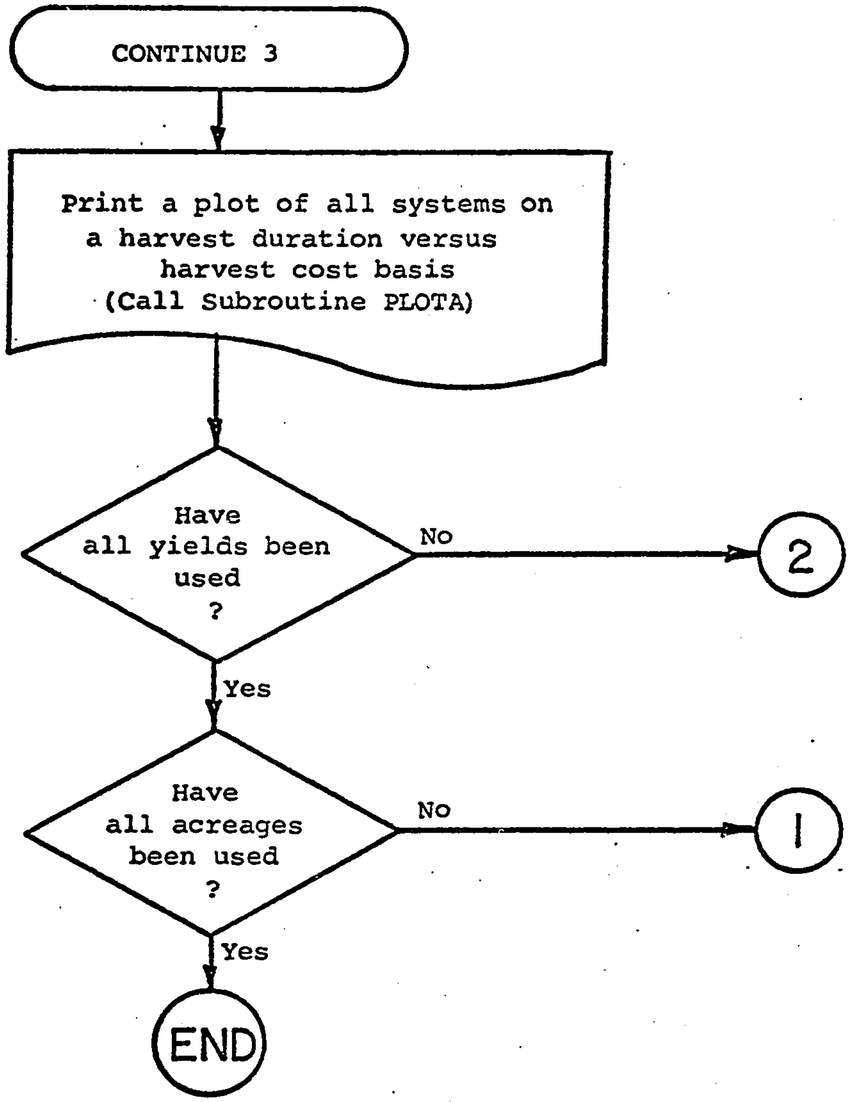


Figure 7. ...continued

VI RESULTS OF INITIAL COMPUTER MODEL RUN

Before entering the discussion of results, an explanation of the output format of the computer program of the model must be given. Three types of results are reported by the program for each acreage and yield combination. The costs and activity durations are first reported by each of the four subroutines which calculate these values. A systems report which lists important parameters for each of the 24 machine systems is then printed. A graph showing the position of each machine system on a plot of system annual harvest cost versus harvest duration is also printed. Examples of each type of output or result are shown in Table 3 and Figure 8.

In examining Table 3, several points should be noted. For each activity the total cost reported is the variable cost excluding labor. The difference between duration and actual-duration is the time required for hitching and unhitching. For the activities of chopping and unloading, the parameters are calculated for each of the two machines involved. In the case of the chopping activity, two actual durations are reported. This is because of the extra unhitching time required when using network 1. For the hauling and returning activities, parameters are calculated for each of the three possible hauling vehicles. The wagon power cost as reported for these

CORN SILAGE AT 80. ACRES/YEAR

AT A YIELD OF 24. TONS(WET)/ACRE. CHOPPER A AT 2.29MPH CHOPPER B AT 2.29MPH

CHOP	TOTAL COST	DURATION	ACT/DUR 1	ACT/DUR 2	CHOPPER	COST/HOUR
	0.88	0.294	0.377	0.327	1	3.01
	0.51	0.136	0.219	0.169	2	3.74

HAUL	TOTAL COST	DURATION	ACT/DUR	COST/HOUR	WAGON POWER COST
	0.13	0.083	0.117	1.60	0.01
	0.11	0.083	0.117	1.33	0.01
	0.10	0.083	0.117	1.15	0.01

UNLOAD	TOTAL COST	DURATION	ACT/DUR	COST/HOUR	BLOWER
	0.54	0.250	0.283	2.16	4
	0.35	0.143	0.176	2.45	5

RETURN	TOTAL COST	DURATION	ACT/DUR	COST/HOUR	WAGON POWER COST
	0.10	0.063	0.096	1.54	0.00
	0.09	0.063	0.096	1.27	0.00
	0.07	0.063	0.096	1.10	0.00

SYSTEM	10 LD TIME	10 LD COST	DAILY VARY COSTS	DAILY FIXED COSTS	TOTAL DAILY COSTS	DAYS FOR THIS TONNAGE	COST FOR THIS TONNAGE	COST PER TON	COST PER HOUR	TONS PER HOUR
A	8.73	67.04	14.67	46.74	61.41	41.9	2574.40	1.341	7.68	5.73
B	7.73	65.47	14.61	53.12	67.72	37.1	2513.90	1.349	8.47	6.47
C	7.07	66.73	14.38	61.17	75.54	33.9	2562.43	1.335	9.44	7.08
D	6.07	63.47	14.24	69.45	83.69	29.1	2437.15	1.269	10.46	8.24
E	8.23	65.43	15.38	48.19	63.57	39.5	2512.42	1.309	7.95	6.07
F	7.23	63.59	15.41	54.82	70.23	34.7	2438.33	1.270	8.78	6.91
G	6.57	64.17	14.78	63.40	78.18	31.5	2464.21	1.283	9.77	7.61
H	5.57	60.56	14.70	72.32	87.03	26.7	2325.33	1.211	10.88	8.98
I	5.23	64.41	24.20	74.26	98.46	25.1	2473.30	1.288	12.31	9.55
J	4.23	58.54	26.32	84.31	110.64	20.3	2248.11	1.171	13.83	11.81
K	5.07	68.24	19.15	88.60	107.75	24.3	2620.52	1.365	13.47	9.87
L	4.07	61.47	20.12	100.81	120.93	19.5	2360.59	1.229	15.12	12.30
M	4.40	65.65	29.65	90.70	119.35	21.1	2520.77	1.313	14.92	11.36
N	3.95	62.68	28.07	98.88	126.95	19.0	2406.92	1.254	15.87	12.66
O	3.52	61.91	27.44	113.38	140.81	16.9	2376.94	1.239	17.60	14.22
P	2.92	56.64	27.87	127.49	155.35	14.0	2174.96	1.133	19.42	17.14
Q	5.23	63.96	24.20	81.22	105.42	25.1	2648.14	1.379	13.18	9.55
R	4.23	62.23	26.32	91.27	117.60	20.3	2389.54	1.245	14.70	11.81
S	5.07	72.65	19.15	95.56	114.71	24.3	2789.78	1.453	14.34	9.87
T	4.07	65.01	20.12	107.77	127.89	19.5	2496.45	1.300	15.99	12.30
U	3.73	63.27	33.77	101.80	135.58	17.9	2429.51	1.265	16.95	13.39
V	3.63	63.03	30.52	108.21	138.73	17.4	2419.37	1.260	17.34	13.76
W	3.12	60.91	30.96	125.39	156.34	15.0	2338.91	1.218	19.54	16.04
X	2.25	52.08	36.12	149.05	185.17	10.8	1999.85	1.042	23.15	22.22

CRITICALITY REPORT - ACTIVITIES

SYSTEM	CHOP	HAUL	UNLOAD	RETURN	DUMMY
A	10	10	10	9	0
B	10	10	10	9	0
C	10	10	10	9	0
D	10	10	10	9	0
E	10	10	10	9	0
F	10	10	10	9	0
G	10	10	10	9	0
H	10	10	10	9	0
I	1	10	10	9	0
J	1	10	10	9	0
K	1	10	10	9	0
L	1	10	10	9	0
M	6	6	6	5	0
N	8	7	7	6	4
O	5	5	6	5	1
P	5	5	6	5	1
Q	1	10	10	9	0
R	1	10	10	9	0
S	1	10	10	9	0
T	1	10	10	9	0
U	10	1	1	0	0
V	10	1	1	0	0
W	1	1	10	0	9
X	1	9	10	8	5

Table 3. Example of Harvest Model Program Output.

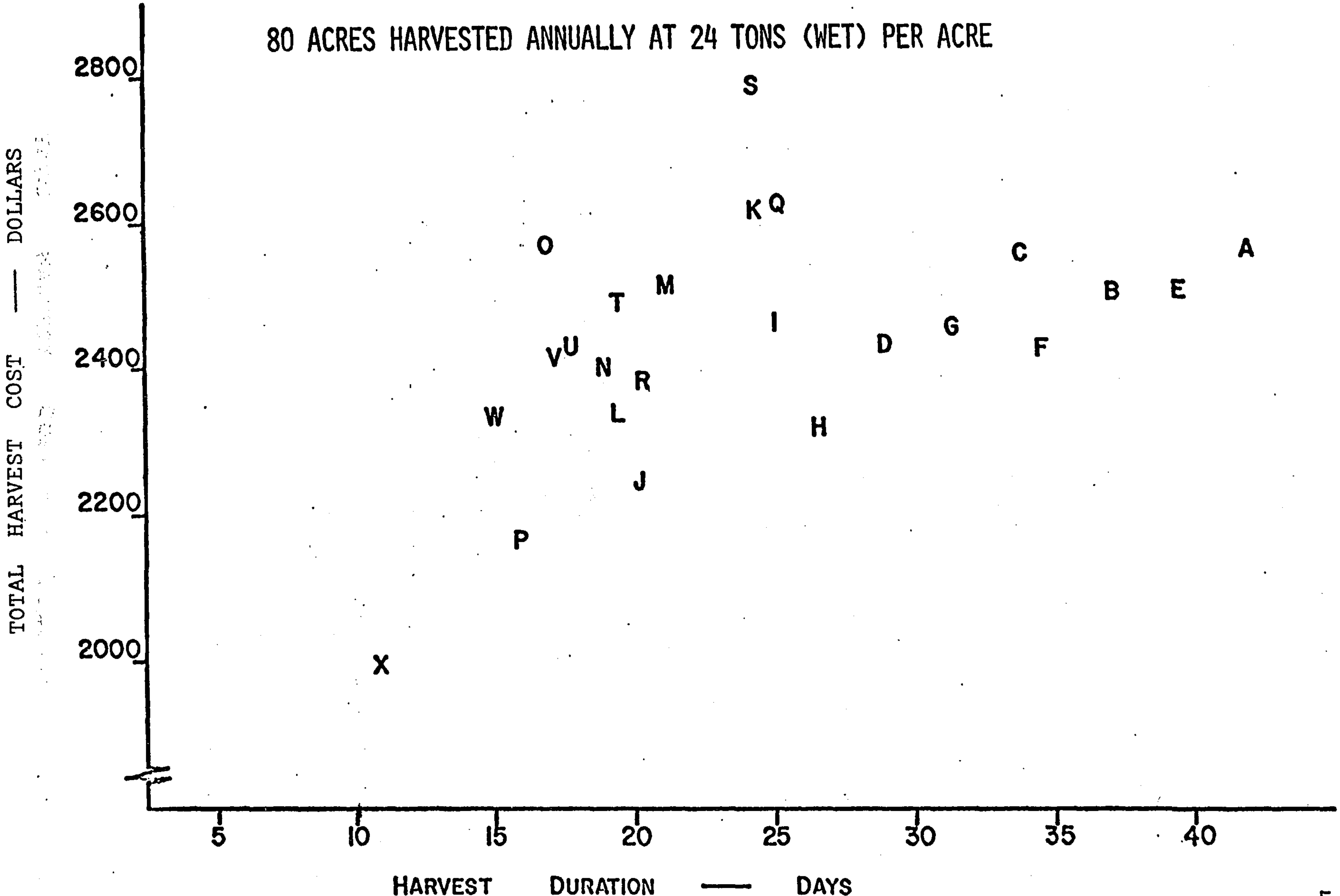


Figure 8. Example of Subroutine PLOTA Output.
Machine systems shown by letter code.

activities is the cost of fuel and lubrication for hauling the loaded and empty wagon. The fuel cost for returning an empty wagon, in the example, is some amount less than one-half a cent; the program reports it as zero, although in further calculations, it uses the actual cost, not zero. All the individual activity costs and durations reported in the activity report are used by the program in calculating the parameters in the systems report.

Several other points should be noted in examining the systems report in Table 3. The 10-load time is the duration of the critical path for the activity network used with that machine system (refer to Table 4 which lists the labor and machine complement of each system). It is the time to harvest 10 loads of corn silage. The 10-load cost is the total cost, both variable and fixed, for the project represented by that particular network. All other costs and times are based on these two values.

The criticality report lists, for each system, the number of times that a particular type of activity appeared on the critical path of the 10-load network. To be more precise, it lists the number of times a particular activity had zero float or waiting time. Machine systems A through H using networks 1 and 2 have all their activities taking place sequentially, so that all the activities are on the critical path. A difficulty with the criticality report for machine systems M through P was encountered in the initial run. These machine systems use activity network 4, and after close examination it was discovered

Table 4. Machine and Labor Complement of Each Machine System

System Letter Code	Forage Chopper Code Number	Tractor on Chopper Code Number	Type of Hauling Tractor	Number of Hauling Tractors	Wagon Type Number of Wagons	Forage Blower Code Number	Tractor on Blower Code Number	Number of Men	Network Used
A	1 IH350	7 IH724	IH724*	0	1 JD414	4 NH23	7 IH724	1	1
B	1 IH350	7 IH724	IH724*	0	1 "	5 NH26	7 "	1	1
C	2 IH550	6 JD4000	JD4000*	0	1 "	4 NH23	7 "	1	1
D	2 IH550	6 JD4000	JD4000*	0	1 "	5 NH26	7 "	1	1
E	1 IH350	7 IH724	IH434	1	1 "	4 NH23	7 "	1	2
F	1 IH350	7 IH724	"	1	1 "	5 NH26	7 "	1	2
G	2 IH550	6 JD4000	"	1	1 "	4 NH23	7 "	1	2
H	2 IH550	6 JD4000	"	1	1 "	5 NH26	7 "	1	2
I	1 IH350	7 IH724	"	1	2 "	4 NH23	7 "	2	3
J	1 IH350	7 IN724	"	1	2 "	5 NH26	7 "	2	3
K	2 IH550	6 JD4000	"	1	2 "	4 NH23	7 "	2	3
L	2 IH550	6 JD4000	"	1	2 "	5 NH26	7 "	2	3
M	1 IH350	7 IH724	"	2	2 "	4 NH23	7 "	3	4
N	1 IH350	7 IH724	"	2	2 "	5 NH26	7 "	3	4
O	2 IH550	6 JD4000	"	2	2 "	4 NH23	7 "	3	4
P	2 IH550	6 JD4000	"	2	2 "	5 NH26	7 "	3	4
Q	1 IH350	7 IH724	"	1	3 "	4 NH23	7 "	2	5
R	1 IH350	7 IH724	"	1	3 "	5 NH26	7 "	2	5
S	2 IH550	6 JD4000	"	1	3 "	4 NH23	7 "	2	5
T	2 IH550	6 JD4000	"	1	3 "	5 NH26	7 "	2	5
U	1 IH350	7 IH724	"	2	3 "	4 NH23	7 "	3	6
V	1 IH350	7 IH724	"	2	3 "	5 NH26	7 "	3	6
W	2 IH550	6 JD4000	"	2	3 "	4 NH23	7 "	3	6
X	2 IH550	6 JD4000	"	2	3 "	5 NH26	7 "	3	6

* Tractor used on forage chopper is also used for hauling the wagon.

that this network, using some of the activity durations developed in this study, had at least two critical paths. The manner in which this affects the interpretation of the criticality report is taken up in the following discussion of the results.

Discussion

The initial run of the harvest system model computer program was done to study the effect of increasing annual acreage and increasing yield on each of the machine systems. It was also done to provide results which were used to illustrate the significance of the criticality report. All the computer output for each of the runs including the sensitivity studies are on file in the Agricultural Engineering Department, McGill University.

Increasing the yield had the same effect on the cost per ton for harvesting, for each machine system, as increasing annual acreage. This is shown in Figure 9 which is a plot in graphical form of the cost per ton harvested versus the total tonnage harvested for each combination of yield and annual acreage. This is perhaps obvious since the logic of the model converts both yield and annual acreage to annual tonnage before any further processing takes place. The model has also assumed that machine system capacity is independent of yield. This was mentioned in the chapter on machinery and capacities. It that this network, using some of the activity durations developed in this study, had at least two critical paths. The manner in which this affects the interpretation of the criticality report is taken up in the following discussion of the results.

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The type of curve shown in Figure 9 is a characteristic type; to be found in almost any study of machinery management which examines costs in relation to scale of operations. Good examples of similar curves are found in the study on machinery capacity by Donaldson (14). If the cost per hour for each machine system were plotted with annual tonnage harvested it would result in the same type of curve as in Figure 9. This is because, in this model, the cost per hour, cost per ton and capacity have the following relationship:

Cost per hour = (cost per ton) x (capacity in tons per hour).

In the study of varying acreage and yield the capacity of each machine system remains constant. The capacities of each machine system are listed in Table 5, and the important input parameters are listed in Table 6.

Besides showing the variation of cost with scale of operation, Figure 9 also shows the differences between individual machine systems. The differences in cost per ton between systems at a specific annual tonnage can amount to as much as 30 percent. Machine system X was definitely the lowest cost system of those presented in Table 9 and was in fact the lowest cost system of all 24 above a certain annual tonnage. Table 5 shows that system X also has the highest capacity and Table 4, which gives the machinery and labor complement of each machine system, shows that system X has the largest machinery investment. A farmer,

Table 5. Machine System Capacity:
Results from Initial Run of Harvest Model Computer Program

System Letter Code	Capacity in Tons per Hour
A	5.73
B	6.47
C	7.08
D	8.24
E	6.07
F	6.91
G	7.61
H	8.98
I	9.55
J	11.81
K	9.87
L	12.30
M	11.36
N	12.66
O	14.22
P	17.14
Q	9.55
R	11.81
S	9.87
T	12.30
U	13.39
V	13.76
W	16.04
X	22.22

Table 6. Input Data for Initial Run of Harvest Model Computer Program*

DESCRIPTION	FORTRAN Name	DATA
Acreage	A(I)	20., 35., 50., 80., 110., 140.,
Yield in Tons (wet) per acre	Y(I)	20., 24., 28.

DESCRIPTION	FORTRAN Name								
Machine Index Number	M TYPE (I)	1 IH350	2 IH550	3	4 NH23	5 NH26	6 JD4000	7 IH724	8 IH434
Machine List Price in $	M COST (I)	3100.,	4450.,	2609.,	702.,	902.,	9000.,	5894.,	3466.,
Machine Capacity in tons (wet)/ hr	CP(I)	20.,	40.,		20.,	35.,			
Machine Power Requirement in hp	P(I)	40.,	65.,		25.,	44.,			
Machine life in hours	LIFE(I)	2000.,	2000.,		2000.,	2000.,			
Machine F.M.I.	FMI(I)	0.85	0.92						

* For complete listing of program and input variables see Appendix B.

Table 6. ...continued

DESCRIPTION	FORTRAN - Name	DATA
Corn Row Width in feet	RWDTH	3.0
Wagon Cost in $/hour	WFCOST	1.66
Labor rate in $/hour/man	MRATE	1.50
Average Distance from field to silo in miles	DIST	0.25
Hauling Speed in mph	MPH	3.0
Returning Empty Wagons in mph	MPHR	4.0
Power required to Unload Wagon in hp	PWU	5.0
Average Wagon Load Weight in Tons	WT	5.0
Empty Wagon Weight in Tons	WG	1.5
Fuel Costs in $/hp-hr	PC	0.0152
Coefficient of rolling resistance on field	FCT	0.3
Coefficient of rolling resistance on path	FCH	0.05

however, is not only interested in finding a machine system with a low unit cost of harvesting, he is also interested in a machine system which would have a high capacity; that is, one which would decrease his harvest duration.

The criticality report is a useful tool in indicating the best way of shortening the harvest duration. As was previously stated, the criticality report states the number of times a particular type of activity was on the critical path. This is reported for each machine system. The greater the number of times a type of activity, such as chopping, is critical, the more likely is the possibility of reducing the harvest duration by reducing that type of activities duration. In the case where two or more types of activity of equal criticality exist, the least expensive of them should be chosen as the candidate for shortening by increasing the capacity of the machine involved. In the example systems and criticality report presented in Table 3, it is seen that with machine system U, the chopping activity is very critical. By increasing the size of the forage chopper, which results in machine system W and a very much reduced chopping activity criticality, the harvest duration is reduced from almost 18 days to 15 days. But by increasing the size of the forage blower, which results in system V, the harvest duration is reduced by only one-half a day. This is because the unloading activity is non-critical.

Network 4 (Figure 4) which was used by machine systems M, N, O and P, had several critical paths with the input data used for this run of the program. The usefulness of the criticality report becomes dubious for a network such as this. However, these machine systems in which nearly all the activities are critical (see Table 3), could be said to be balanced. It is possible, considering the network logic, that if the duration of the chopping activity were increased sufficiently the network would become unbalanced and there would be only one critical path with all the chopping activities on it. The significance of the criticality report became more obvious in the sensitivity studies.

VII SENSITIVITY STUDY

A. Sensitivity to Hauling Distance

After observing large variations in hauling distance from the field to the silo during the field study, it was thought that large variations in machine system capacity and cost might result. To study the effects of these variations, the harvest system model computer program was run three times with average hauling distances of one tenth of a mile, one quarter of a mile and one mile. These values were chosen because they are the average and the two approximate extremes in hauling distance observed during the work study.

It is clear from the logic of the model that an increase or decrease in hauling distance will affect only the hauling and returning activities. Table 7 shows activity durations in minutes for each hauling distance. Hauling and returning times increase by 18.6 and 13.5 minutes respectively with an increase in hauling distance from one tenth to one mile. It was expected then, that machine systems in which the hauling and returning operations were critical would be most affected.

The criticality reports for each system at each different hauling distance are shown in Table 8. Machine systems A to H maintain the same criticality because their networks are

Table 7. Activity Durations: Sensitivity to Hauling Distance.

Activity	Duration		
	Hauling Distance		
	0.10 miles	0.25 miles	1.0 miles
CHOP			
1st Network:*			
small harvester	22.6 min.	22.6 min.	22.6 min.
large harvester	13.1 min.	13.1 min.	13.1 min.
Other Networks:			
small harvester	19.6 min.	19.6 min.	19.6 min.
large harvester	10.1 min.	10.1 min.	10.1 min.
HAUL	4.0 min.	7.0 min.	22.6 min.
UNLOAD			
small blower	17.0 min.	17.0 min.	17.0 min.
large blower	10.5 min.	10.5 min.	10.5 min.
RETURN	3.5 min.	5.8 min.	17.0 min.

* Recall that the first network requires extra time for unhitching. (see page 41)

Table 8. Criticality Reports: Sensitivity to Hauling Distance.

	Dist. = 0.10 miles					Dist. = 0.25 miles					Dist. = 1.0 miles				
SYSTEM LETTER CODE	CHOP	HAUL	UNLOAD	RETURN	DUMMY	CHOP	HAUL	UNLOAD	RETURN	DUMMY	CHOP	HAUL	UNLOAD	RETURN	DUMMY
A	10	10	10	9	0	10	10	10	9	0	10	10	10	9	0
B															
C	Criticality reports for machine systems A to H are identical.														
D															
E															
F															
G															
H	10	10	10	9	0	10	10	10	9	0	10	10	10	9	0
I	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
J	10	1	1	0	0	1	10	10	9	0	1	10	10	9	0
K	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
L	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
M	6	6	6	5	0	6	6	6	5	0	6	6	6	5	0
N	8	1	1	0	7	8	7	7	6	4	6	6	6	5	0
O	5	5	6	5	1	5	5	6	5	1	6	6	7	6	1
P	5	5	6	5	1	5	5	6	5	1	5	5	6	5	1
Q	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
R	10	1	1	0	1	1	10	10	9	0	1	10	10	9	0
S	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
T	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
U	10	1	1	0	0	10	1	1	0	0	6	9	9	8	0
V	10	1	1	0	0	10	1	1	0	0	6	9	9	8	0
W	1	1	10	0	9	1	1	10	0	9	1	9	10	8	5
X	1	1	10	0	9	1	0	10	8	5	1	9	10	8	5

The numbers indicate the number of times that particular activity was on the critical path.

sequential. Also, as explained previously, systems M to P using network 4 have several critical paths so the report is to some extent meaningless for them.

Shown in Figure 10 is the variation in cost per wet ton with increasing hauling distance for all machine systems at 80 acres harvested annually. As mentioned previously the complete results of the sensitivity studies are on file with the Department of Agricultural Engineering, McGill University.

Discussion of Results

It is plain, from Figure 10, that the marginal change in cost per ton with variation in hauling-distance, or slope, can be quite different, depending on the machine system used. For systems A and E, the slope is about 8¢ per 1/4 mile increase in hauling distance; for systems C and D, it is about 10¢ per 1/4 mile. The greatest change was with system T at about 14¢ per 1/4 mile. In all but a few cases, the apparent relationship was linear. The magnitude of the slope and the apparent nonlinearities can be explained to a large extent by the criticality report.

A machine system in which the hauling and returning activities are very critical compared with other activity types has a large slope. Good examples of this phenomenon are machine systems S, T and Q. Similarly, where a machine systems' activities of hauling and returning have a low criticality, as is the case of systems U and V, the slope is low.

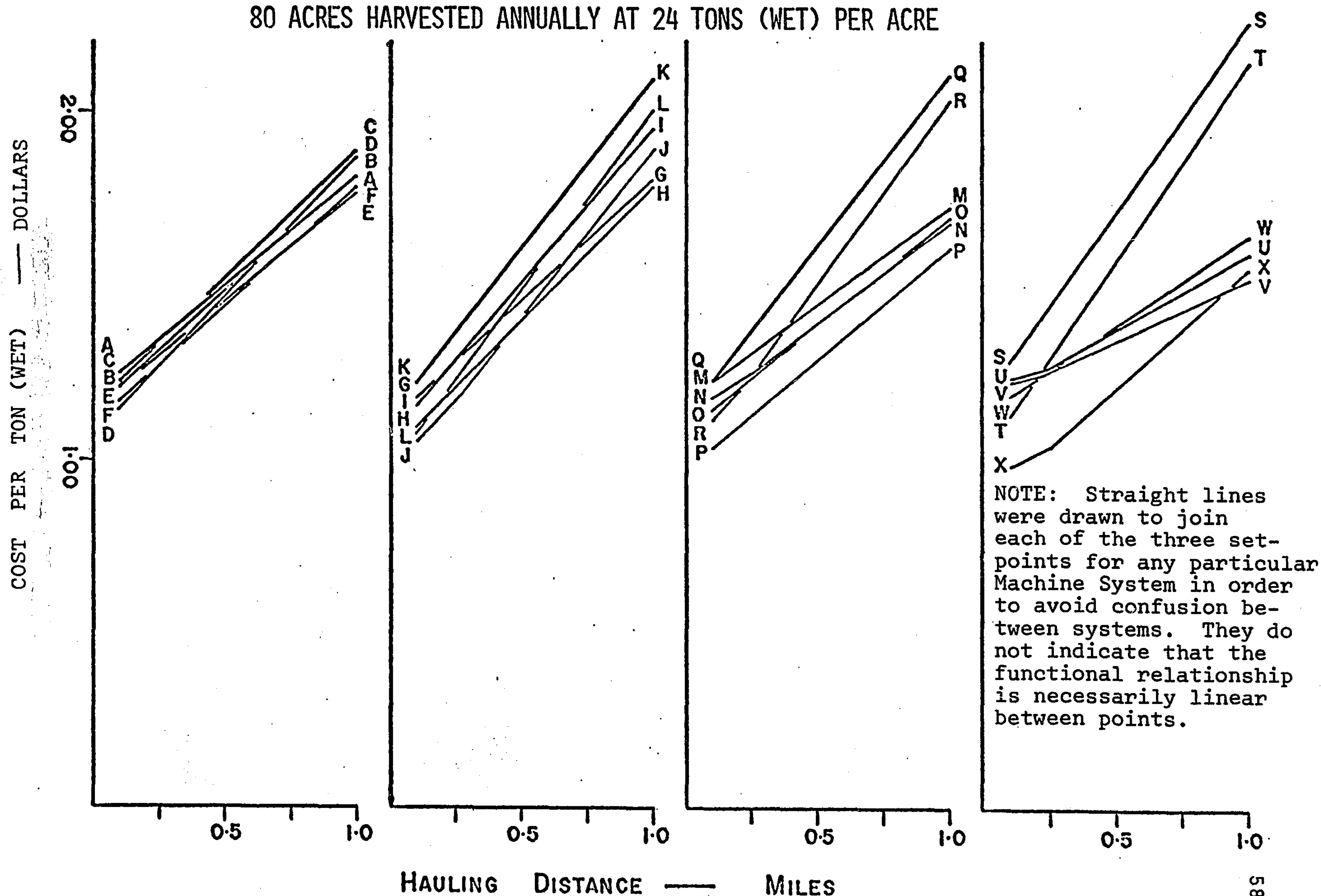


Figure 10. Cost per ton: Sensitivity to Hauling Distance. Machine Systems Identified by Letter Code.

Where the pattern of critical activities changes drastically with the change in hauling distance, then an apparent non-linear variation in the slope or marginal cost appears. Machine system X is a good example of this, as are machine systems U and V and to a less obvious extent system R. This is because at the low end of the hauling distance scale, the activities of hauling and returning are not critical, while at the high end they are. Somewhere between one of the set-points of 0.1 miles, 0.25 miles and 1.0 miles, the criticality pattern must have changed. This is the reason for the change in the slope.

The sensitivity of harvest unit cost to increasing hauling distance is a result of an increase in the time required to harvest. Thus machine system capacity in tons per hour varied inversely with harvest cost per ton and hauling distance. The machine system cost per hour of operation remains relatively constant with increasing hauling distance. Increasing annual acreage did little to alter the pattern of changing cost per ton with increasing hauling distance.

B. Sensitivity to Load Weight

During the field study, it was observed that some operators were only averaging three to four tons of silage per load while others were bringing in six tons and more per load. As with the sensitivity study of hauling distance, the model's computer program was again run three times with average load sizes of three tons, five tons and seven tons. Again, these values were chosen because they were the mean and the two approximate extremes in load sizes.

It was thought likely that while increasing load size would increase the duration of some of the activities, it would also increase the machine system's total capacity. The effect on individual activity time is shown in Table 9. The activity times of hauling and returning were unaffected as hauling speed and distance remained constant. But the activity times of the chopping and unloading activities increased in proportion with the increase in load size. However, the effects of increasing load size on systems with high criticalities for chopping and unloading cannot be deduced from this, as the system's capacity will be increased.

The criticality reports for each system at each different load size are shown in Table 10. Again, it should be recognized that systems A to H all have the same criticality because their networks are sequential. Besides systems M to P having several critical paths, systems W and X also have several at the lighter loads. Systems J and R are also somewhat special, since at the seven ton load level the activity times of the hauling (when rounded to integer values), unloading and returning sequence add up to the activity time for chopping. The result is that all activities are critical and the system may be said to be balanced. Figure 11 shows the variation in cost per wet ton with

Table 9. Activity Durations: Sensitivity to Load Weight

Activity	Duration in Minutes		
	Load Weight		
	3 Tons	5 Tons	7 Tons
CHOP			
1st Network:*			
small chopper	15.6	22.6	29.6
large chopper	9.9	13.1	16.4
Other Networks:			
small chopper	12.6	19.6	26.7
large chopper	6.9	10.1	13.4
HAUL	7.0	7.0	7.0
UNLOAD			
small blower	11.0	17.0	23.0
large blower	7.2	10.5	14.0
RETURN	5.8	5.8	5.8

* Recall that the first network requires extra time for unhitching. (see page 41).

Table 10. Criticality Reports: Sensitivity to Load Weight.

SYSTEM LETTER CODE	3 Ton Load CHOP	HAUL	UNLOAD	RETURN	DUMMY	5 Ton Load CHOP	HAUL	UNLOAD	RETURN	DUMMY	7 Ton Load CHOP	HAUL	UNLOAD	RETURN	DUMMY
A	10	10	10	9	0	10	10	10	9	0	10	10	10	9	0
B															
C															
D	Criticality reports for machine systems A to H are identical.														
E															
F															
G															
H	10	10	10	9	0	10	10	10	9	0	10	10	10	9	0
I	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
J	1	10	10	9	0	1	10	10	9	0	10	10	10	9	0
K	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
L	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
M	6	6	6	5	0	6	6	6	5	0	6	6	6	5	0
N	10	9	9	8	4	8	7	7	6	4	8	7	7	6	7
O	5	5	6	5	1	5	5	6	5	1	5	5	6	5	1
P	6	6	6	5	1	5	5	6	5	1	5	5	6	5	1
Q	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
R	1	10	10	9	0	1	10	10	9	0	10	10	10	9	9
S	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
T	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
U	10	1	1	0	0	10	1	1	0	0	10	1	1	0	0
V	10	1	1	0	0	10	1	1	0	0	10	1	1	0	0
W	1	9	10	8	5	1	1	10	0	9	1	1	10	0	9
X	6	10	10	8	5	1	9	10	9	5	1	1	10	0	9

The numbers indicate the number of times that particular activity was on the critical path.

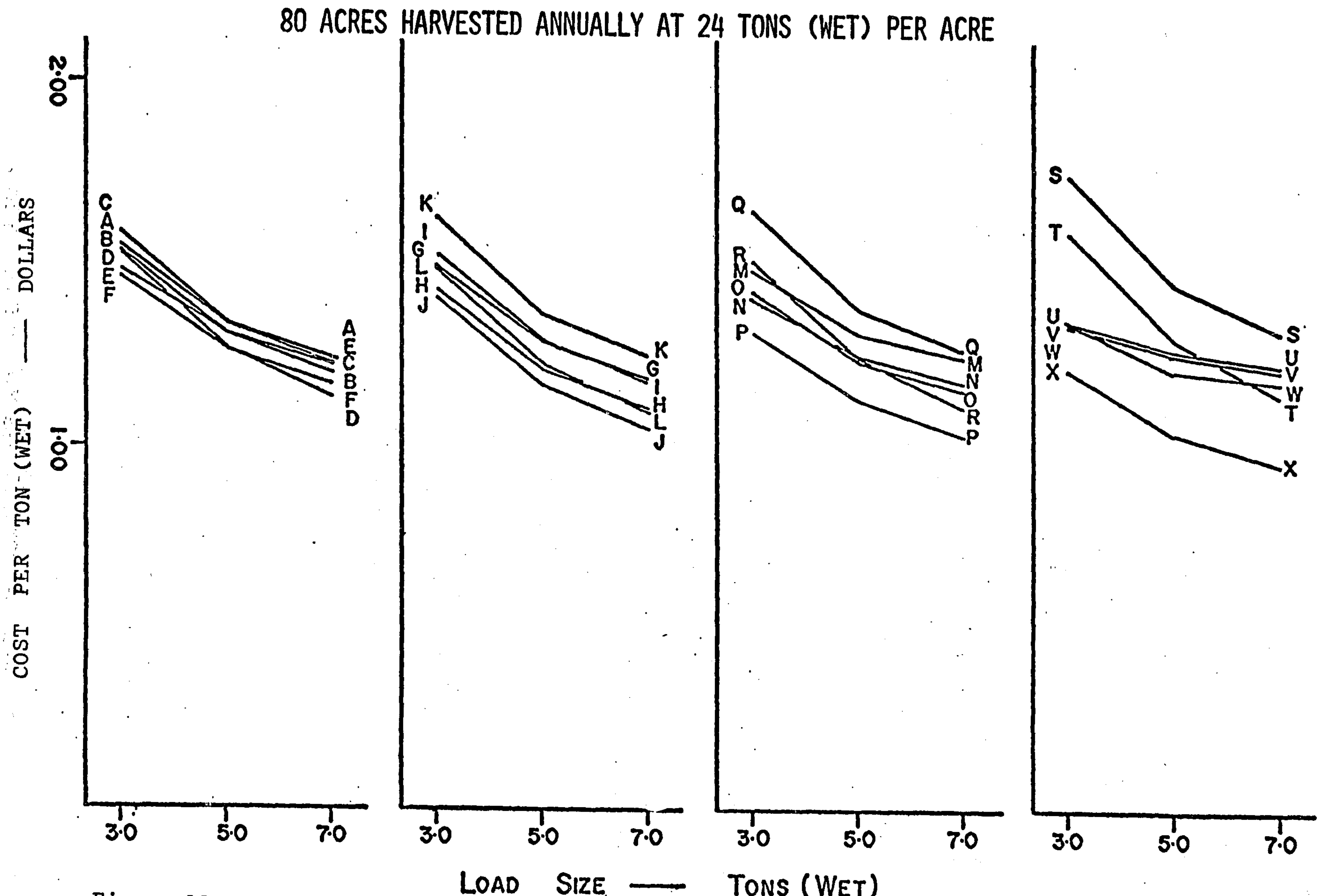


Figure 11. Cost per ton: Sensitivity to Load Weight. Machine Systems Identified by Letter Code. The Note of Figure 10 applies.

increasing load size for all machine systems at 80 acres harvested annually (annual acres).

Discussion

The most obvious characteristics of the sensitivity of system cost per ton to increasing load size is the negative slope and the apparent non-linearity (see Figure 11). As is expected this is in direct contrast to system cost per ton sensitivity to hauling distance, which has a positive slope (see Figure 10). It was observed from the program results that a machine system's capacity varies directly with load size. But a system's cost per ton varies inversely with capacity. Thus cost per ton varies inversely with load size. The reason for the negative slope and apparent non-linearity lies in the mathematical nature of a simple inverse function. By interpolation the cost at the 6 ton load point decreases by between 3.5 and 5¢ per ton for each one ton increase in load weight for most of the machine systems. There were exceptions.

For most of the systems, the criticality report indicates that the chopping activity is generally not very critical, or if it is, the other activities are also relatively critical. However, in the case of systems U and V, the chopping activity is the most critical activity and remains extremely critical for each load size. At the same time, the other activities are only on the critical path once or not at all. Since the chopping activity's duration increases with load weight, the result is an increasing duration for the whole network and a tendency to decrease system capacity. This effect is only accentuated by the fact that the chopping activity remains very critical as load size increases. For systems U and V, the increase in system capacity, as load size is increased from three to seven tons, is only about 14 percent while for the other systems, the increase is almost always greater than 25 percent. As a result, increasing load size does not decrease the cost per ton for systems U and V as much as the other systems.

C. Sensitivity to Field Machine Efficiency

Field machine efficiency, as it is affected by field size and shape and machine reliability, has long been regarded by agricultural engineers as an important factor in determining machinery capacity (49, 50, 47, 5). Previous definitions of field machine efficiency have always included time spent in waiting for other machines (50, 5). The definition used in this study (see chapter IV, page 20) does not include this waiting time and is referred to as revised FMI or revised field machine index.

This sensitivity study was done to determine the importance of field machine efficiency to both harvest unit-cost and capacity of a particular machine system. Since there were two sizes of forage choppers used in this study, two sets of revised field machine indices had to be used. They are listed in Table 11.

It was obvious that changing the revised field machine index of the forage harvester would affect the chopping activity only. The activity duration for the chopping activity and the capacities of the forage choppers are shown in Table 12. The variation in forage chopper revised FMI approximates that found in the field study. The resulting time differences are small. The total range for the small chopper is about five minutes. For the larger chopper, the total range is about two minutes. The range in capacities is about 4.5 tons per hour or about 26 percent for the small chopper, and about eight tons per hour or about 22 percent for the large chopper.

The criticality report for each level of chopper revised FMI is presented in Table 13. The only changes evident are criticality patterns for systems M, N, O and P, and more significantly the pattern for system X. A plot of the system unit cost versus forage chopper revised FMI is presented in Figure 12.

Discussion

As in the previous sensitivity study, slope of the cost per ton versus chopper revised FMI is negative (see Figure 12). The slope, however, is quite small. For machine systems A, B,

Table 11. Revised Field Machine Indices used in Sensitivity Study of Field Efficiency.

	Low Efficiency	Medium Efficiency	High Efficiency
Chopper 1	0.70	0.85	0.92
Chopper 2	0.77	0.90	0.97

Table 12. Chopping Activity Durations and Chopper Capacities for the Sensitivity Study of Field Efficiency.

Activity	Duration in Minutes		
	Low Efficiency	Medium Efficiency	High Efficiency
1st Network:			
Chopper 1	26.4 min.	22.6 min.	21.5 min.
Chopper 2	14.8 min.	13.1 min.	12.7 min.
Other Networks:			
Chopper 1	23.3 min.	19.6 min.	18.6 min.
Chopper 2	11.8 min.	10.1 min.	9.70 min.

	Capacity		
	Low Efficiency	Medium Efficiency	High Efficiency
Chopper 1	14.0 Tons/hr	17.0 Tons/hr.	18.4 Tons/hr.
Chopper 2	30.8 Tons/hr.	36.0 Tons/hr.	38.8 Tons/hr.

Table 13. Criticality Reports: Sensitivity to Forage Chopper Field Efficiency.

	Low Chopper Efficiency					Medium Chopper Efficiency					High Chopper Efficiency				
SYSTEM LETTER CODE	CHOP	HAUL	UNLOAD	RETURN	DUMMY	CHOP	HAUL	UNLOAD	RETURN	DUMMY	CHOP	HAUL	UNLOAD	RETURN	DUMMY
A	10	10	10	9	0	10	10	10	9	0	10	10	10	9	0
B															
C															
D			Criticality reports for machine												
E			systems A to H are identical												
F															
G															
H	10	10	10	9	0	10	10	10	9	0	10	10	10	9	0
I	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
J	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
K	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
L	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
M	10	9	9	8	4	6	6	6	5	0	6	6	6	5	0
N	8	7	7	6	4	8	7	7	6	4	8	7	7	6	4
O	5	5	6	5	1	5	5	6	5	1	5	5	6	5	1
P	6	6	6	5	0	5	5	6	5	1	5	5	6	5	1
Q	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
R	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
S	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
T	1	10	10	9	0	1	10	10	9	0	1	10	10	9	0
U	10	1	1	0	0	10	1	1	0	0	10	1	1	0	0
V	10	1	1	0	0	10	1	1	0	0	10	1	1	0	0
W	1	1	10	0	9	1	1	10	0	9	1	1	10	0	9
X	10	9	9	8	0	1	9	10	8	5	1	9	10	8	5

The numbers indicate the number of times a particular activity is on the critical path.

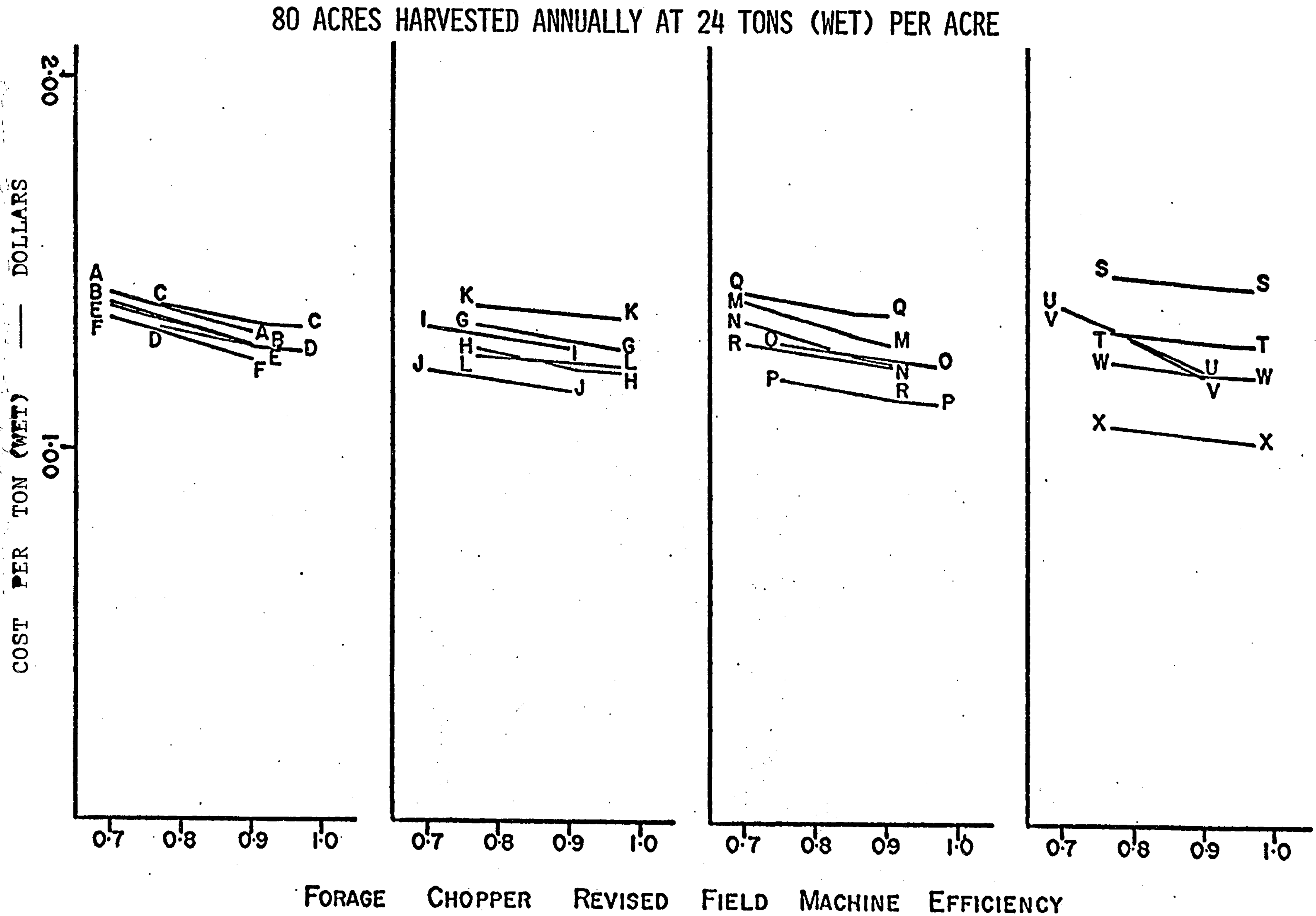


Figure 12. Cost per ton: Sensitivity to Forage Chopper Revised Field Machine Index*.
* For definition of Revised Field Machine Index or Revised FMI, see page 19.
The Note of Figure 10 applies.

E and F, it is approximately three cents per 10 percent change in revised FMI.

But for systems C and D, it is about 1.5¢ per 10 percent change in revised FMI. This is because the percentage of total harvest time attributable to the smaller chopper (Chopper 1) is much greater than that of the larger chopper (Chopper 2).

The range of slopes for the other systems can best be explained in terms of the criticality reports. For systems I, J, K and L, the slope is small, - about 1.5¢ per 10 percent change in revised FMI. This is because the chopping activity is not critical; it contributes little to the actual duration of harvesting. Systems M, N, O and P are less amenable to this kind of explanation because, as stated previously, they have several critical paths. Systems Q, R, S and T are similar to systems I, J, K and L in that the chopping activity is again not critical, consequently the slope is low; about 1¢ per 10 percent change in revised FMI. Systems U, V, W and X present a different pattern. With systems U and V, the forage chopper is very critical, consequently the slope is high; about 5¢ per 10 percent change in revised FMI. For systems W and X however, the chopping activity is not critical (except at the lowest revised FMI for system X) and the slope is about 1¢ per 10 percent change in revised FMI.

VIII ANALYSIS OF WEATHER EFFECTS

Silage corn harvesting operations may be affected by poor weather conditions in several ways. A heavy rain may increase the moisture content of the silage to the point where its future feed quality is impaired. Poor weather conditions may also cause sufficient operator discomfort as to force him to suspend field operations, although a tractor cab might attenuate this effect. A heavy rain may also wet the soil between the rows of corn to the extent that the field harvesting unit ceases to be mobile. It is conjectured that the mobility problem may be particularly true of a crop that has had applications of a herbicide which would leave the ground between the rows of corn almost devoid of vegetation.

From field observations most of the soil types found on the farms visited in the work study had a high clay content. It appeared, again from observations during the work study, that poor traction in the field was the limiting factor when bad weather interrupted the harvest. For the analysis of the effects of weather, a quantitative criterion for choosing days with good traction from bad days (i.e. work days from non-work days), must be found.

Rutledge and MacHardy (52) suggested that the necessary tractive ability for tillage operations was lost when soil moisture contents were above 95 percent of field capacity in the top three moisture zones of the soil or when there was snow on the ground, for most plastic soils in Alberta. Morey et al (41) used their criteria to select good working days in a study of optimum policies for grain corn harvesting in central Indiana. Therefore, it was thought to be justifiable to use, initially, this method in determining non-work days for corn silage harvesting on plastic Quebec soils.

The soil moisture corresponding to 95 percent of field capacity is different for different soil types. For clay loams, which are the predominant soil types in southwestern Quebec, the soil moisture corresponding to 95 percent of field capacity is approximately 3.6 inches of water per foot depth of soil (54). A method for calculating soil moisture on a specific day from weather data is now required.

Lake (25), who also worked in southwestern Quebec, used a "modified Thornthwaite" equation to determine potential evapotranspiration from the soil. His equation was as follows:

$$PE_a = Ca(T_a - 32°) \qquad ...9$$

where

PE_a = potential evapotranspiration; inches per month

C = a coefficient which varies with day length and latitude

a = a coefficient dependent on geographic climatic region

T_a = mean monthly temperature; degrees farenheit

Lake used a = 0.10 and the following values for c:

C	Month
1.28	June
1.26	July
1.18	August
1.04	September
0.91	October
0.80	November

He found that equation 9 gave good estimates of the monthly evapotranspiration, but that the potential evapotranspiration of individual days could be different from the monthly mean due to daily variation in cloud cover, vapour pressure deficit and other factors. It should be noted that the method of determining soil moisture used by Rutledge and MacHardy (52) did account for daily variations of cloud cover and vapour pressure. The method that Morey (41) used was first developed by Shaw (56) at Iowa State. Shaw's model accounted for daily variations of potential evapotranspiration by using open-pan evaporation data and the amount of surface runoff. He reported correlations of 0.95 and 0.96 between observed and predicted soil moisture.

Due to restrictions imposed by lack of complete weather data such as open-pan evaporation or vapour pressure, it was decided to use the method of determining soil moisture used by Lake (25), but on a daily basis. This also necessitates a minor modification of Rutledge and MacHardy's (52) non-work day criteria. Since Lake's method does not divide the soil into separate moisture zones, but instead simply is confined to a top layer of soil of indefinite thickness, this aspect of

Rutledge and MacHardy's criteria must be deleted. In equation 9, PE_a becomes the potential evapotranspiration in inches per day and T_a becomes the mean daily temperature. The soil moisture is then found from the following soil moisture budget as used by Lake:

$$SMC_i = SMC_{i-1} - PE_i + Rain_i \qquad \ldots 10$$

where

SMC = soil moisture content; inches of water per foot depth of soil.

PE = potential evapotranspiration; inches per day

Rain = amount of rainfall; inches per day

i = index, counting days.

A computer program was written to label work and non-work days for the months of July, August, September, October and November using rainfall and temperature data for 19 years for three stations in southwestern Quebec. After examining the results from one of the stations, it became obvious that the model was unrealistic. Several years were found with almost no work days, while others had almost no non-work days.

Broughton (8) suggested the following alterations to the model.

(1) Assume that, after a rain which raises the calculated soil moisture above field capacity, 24 hours are needed to lower soil moisture to field capacity by drainage and runoff.

(2) Soil moisture content should not be permitted to fall below the wilting point.

For the soil being considered (clay loam) field capacity is 3.8 inches of water per foot depth of soil, and the wilting point is 1.8 inches of water per foot depth of soil (54).

Using the same criteria for selecting non-work days as in the first computer run, a second run was made, this time incorporating the alterations to the soil moisture model suggested above. From the output of the second run non-work day probabilities were calculated from the following formula.

$$P_{NW} = \frac{N_{NW}}{N_{Total}} \qquad \text{...11}$$

where

P_{NW} = the probability of the occurrence of a non-work day in the period under consideration

N_{NW} = the number of non-work days occurring in this period

N_{Total} = the total number of days in this period

Since Rutledge and MacHardy (52) reported a definite pattern of persistence of non-work days in Alberta, it was thought that a similar pattern might exist for the Quebec locations under study. They used what was referred to as a "conditional" probability to indicate persistence of non-work days. This probability was calculated for the Quebec locations from the following formula.

$$P_{c_{NW}} = \frac{N_{c_{NW}}}{N_{c_{Total}}} \qquad \text{...12}$$

where

$P_{c_{NW}}$ = the probability of the occurrence of a non-work day if the preceding day was a non-work day, in the period under consideration.

$N_{c_{NW}}$ = the number of non-work days where the preceding day was a non-work day, in this period

$N_{c_{Total}}$ = the number of days where the preceding day was a non-work day, in this period.

The results of these calculations are presented in Tables 14, 15 and 16, and as well, P_{NW} for each of the three locations is plotted graphically in Figure 13.

As noted in Figure 13, there is a marked increase in the probability of a non-work day as the season progresses from July 1st, for all three locations. A similar significant increase in non-work day probabilities was observed by Rutledge and MacHardy. As is shown in Tables 14, 15 and 16, the conditional probabilities are all greater than the "unconditional" probability of a non-work day. This indicates a high degree of persistence in non-work days, according to this model. The pattern followed by the conditional probabilities in the results of Rutledge and MacHardy is the same.

It is not possible to assert with any degree of confidence that this model of weather effects on corn silage harvesting is accurate. Several years of field observations

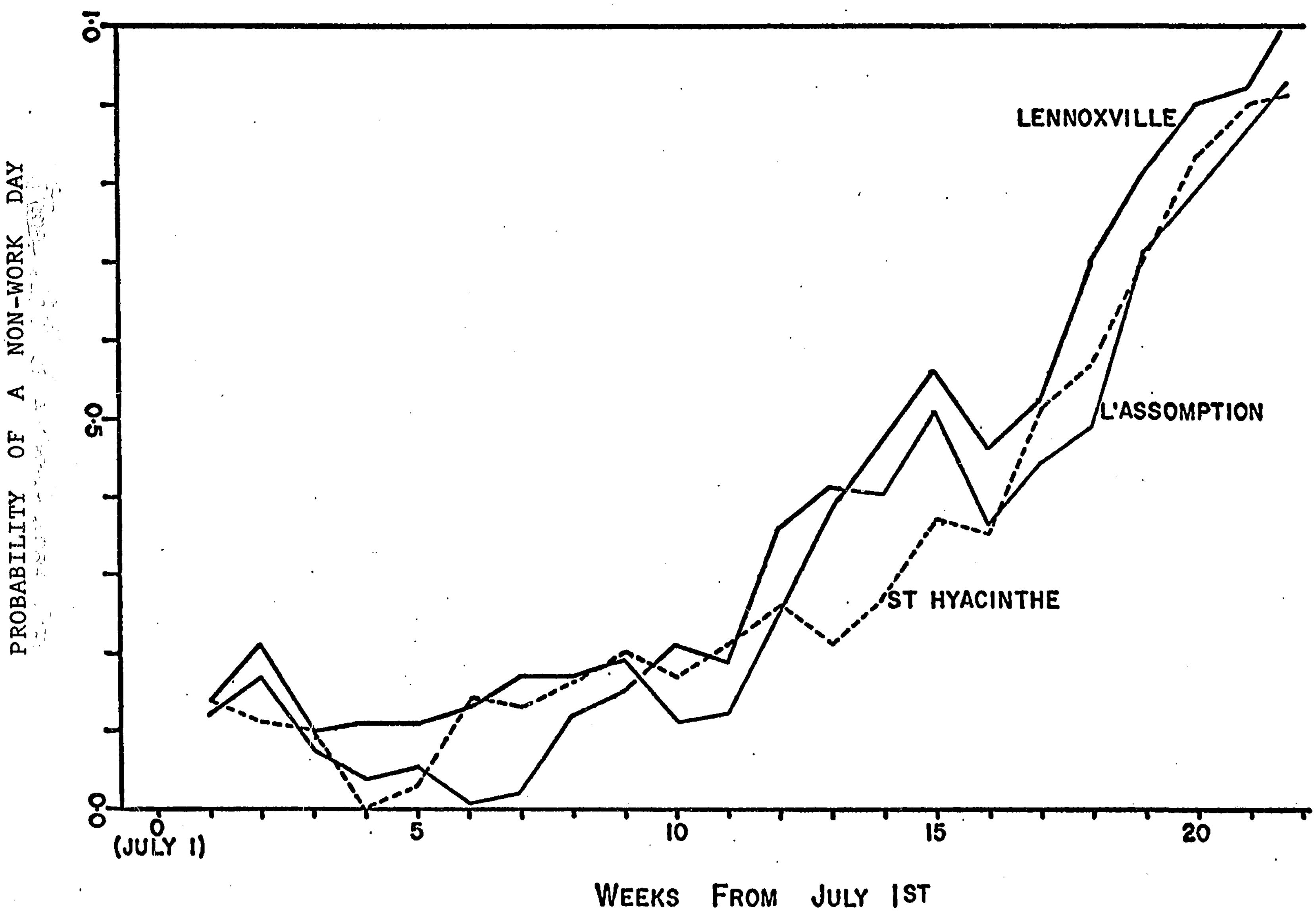


Figure 13. Probability of a Non-Work Day for Three Locations in Southwestern Quebec.

would be needed to confirm the theory. However, in view of the relative agreement of both the seasonal trends and the magnitude of the probabilities between these results and those of Rutledge and MacHardy, this model may hold some promise.

The occurrence of poor weather conditions and therefore non-work days can only increase the time taken to harvest. It cannot influence (according to the model developed in preceding chapters) the cost of harvesting as costs are only incurred on working days. A value that would be of immediate use, both in the model of harvesting and perhaps to the farmer himself, is the number of extra days that a harvest of a certain size, started at a particular time in the season and in a particular locality, would require due to weather interference.

A plot of the required harvest duration in days versus the actual duration, 18 years out of 19, is given for two stations in Figure 14. For example, a harvest in Lennoxville requiring 12 days, would probably take 14 extra days if it were started between August 26th and September 22nd. But the same harvest in L'Assomption would require six extra days.

Similar relationships could be found for the other four week periods. The probability results, however, indicate that the probable extra time required would be greater later in the season. At some point it would be found that the harvest probably could not be completed that year.

The problem of how the model for the effect of weather on corn silage harvesting can be incorporated into a general sub-optimization model is discussed in the next chapter.

Table 14. Non-Work Day Probabilities for L'Assomption, Quebec

Station 7014160 - L'Assomption - 1947-1965

Week		
	July 1 - July 28, 0.083 (0.717) monthly average	
1	0.12	(0.91)
2	0.17	(0.72)
3	0.07	(0.70)
4	0.04	(0.50)
	July 29 - August 25, 0.051 (0.80) " "	
5	0.05	(1.00)
6	0.01	(0.50)
7	0.02	(0.50)
8	0.12	(0.79)
	August 26 - September 22, 0.228 (0.94) " "	
9	0.15	(0.81)
10	0.21	(0.74)
11	0.19	(0.95)
12	0.36	(0.96)
	September 23 - October 20, 0.424 (0.92) " "	
13	0.41	(0.96)
14	0,40	(0.89)
15	0.51	(0.97)
16	0.36	(0.90)
	October 21 - November 17, 0.61 (0.99) " "	
17	0.44	(0.96)
18	0.49	(0.97)
19	0.71	(1.00)
20	0.79	(1.00)
21	0.87	(0.99)
22	0.93	(1.00) 5 days

Note: Bracketed figures indicate probabilities when previous day was a non-work day.

Table 15. Non-Work Day Probabilities for Lennoxville, Quebec. Note from Table 14. applies.

Station 7024280 - Lennoxville - 1947-1965

Week		
	July 1 - July 28, 0.14 (0.78)	
1	0.14	(0.72)
2	0.21	(0.83)
3	0.10	(0.67)
4	0.11	(0.86)
	July 29 - August 25, 0.14 (0.80)	
5	0.11	(0.81)
6	0.13	(0.70)
7	0.17	(0.81)
8	0.17	(0.86)
	August 26 - September 22, 0.17 (0.90)	
9	0.19	(0.86)
10	0.11	(0.67)
11	0.12	(1.00)
12	0.25	(1.00)
	September 23 - October 20, 0.47 (0.95)	
13	0.38	(0.94)
14	0.47	(0.93)
15	0.56	(0.99)
16	0.46	(0.94)
	October 21 - November 17, 0.73 (0.98)	
17	0.52	(0.98)
18	0.70	(0.98)
19	0.81	(0.99)
20	0.90	(0.99)
21	0.92	(0.99)
22	1.00	(1.00) 5 days

Table 16. Non-Work Day Probabilities for St. Hyacinthe, Quebec. Note from Table 14. applied.

Station 7027360 - St. Hyacinthe - 1947-1965

Week			
	July 1 - July 28, 0.09 (0.74)		
1	0.14	(0.85)	
2	0.11	(0.63)	
3	0.10	(0.92)	
4	0.00	(0.00)	
	July 29 - August 25, 0.11 (0.87)		
5	0.03	(1.00)	
6	0.14	(0.89)	
7	0.13	(0.84)	
8	0.16	(0.88)	
	August 26 - September 22, 0.21 (0.87)		
9	0.20	(0.82)	
10	0.17	(0.79)	
11	0.21	(0.92)	
12	0.26	(0.91)	
	September 23 - October 20, 0.30 (0.88)		
13	0.21	(0.87)	
14	0.27	(0.85)	
15	0.37	(0.96)	
16	0.35	(0.87)	
	October 21 - November 17, 0.65 (0.99)		
17	0.51	(1.00)	
18	0.57	(0.99)	
19	0.70	(0.99)	
20	0.83	(1.00)	
21	0.90	(0.99)	
22	0.91	(0.99)	5 days

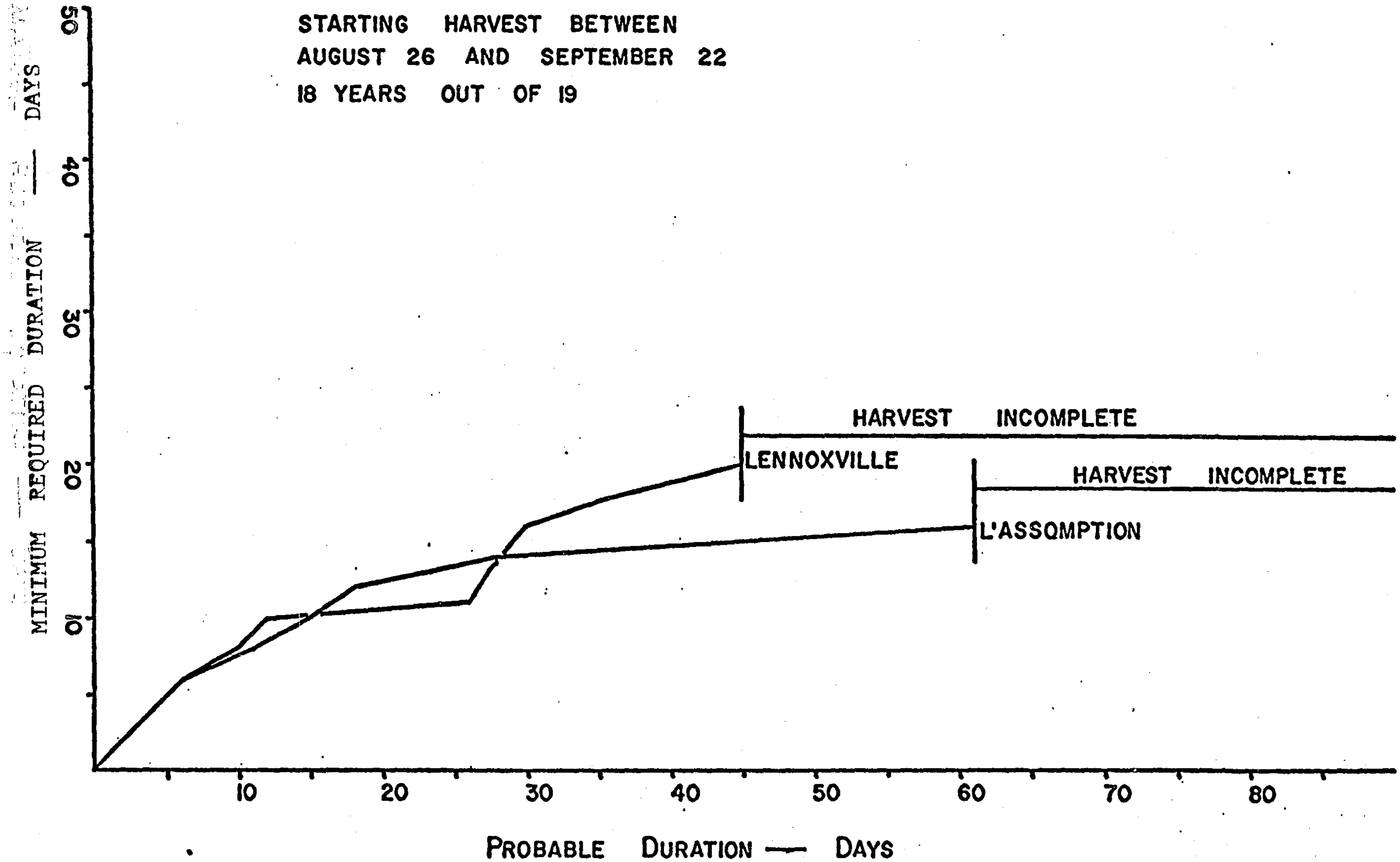


Figure 14. Probable Harvest Duration for Two Locations in Southwestern Quebec.

IX POSSIBILITIES FOR OPTIMIZATION

A good deal of research has been done on field machinery selection through the use of optimization techniques. However, only some of them (17, 21, 22, 27, 33, 34, 44, 46, 57...) made much effort to account for the effect of crop factors and the effect of weather on machine selection. Some of the more recent papers have, in fact, concentrated on modelling the effects of crop factors and weather without applying their models to the machinery selection problem (20, 41, 58). The optimization techniques brought to bear on the machinery selection problem have been calculus with lagrange multipliers (34, 24), queing theory and linear programming (33, 44), network techniques (29, 16, 28, 46), and simulation (17, 10, 53). None of them were completely satisfactory and, as Link (30) put it at a recent machinery management conference... "We are not out of the woods yet".

The optimizing method of traditional analytical economics appears to have been abandoned by agricultural engineers some years ago. Link's (29) main objection to it is best expressed in the following quote from his paper.

> "...it is also true that some basic factors are ignored. The most important of these is the factor of systems effects. All the machines on a farm are interrelated through a set of operating procedures and practices. Machines used for different crops may influence each other, as, for example, hay-harvesting and corn cultivation machinery..."

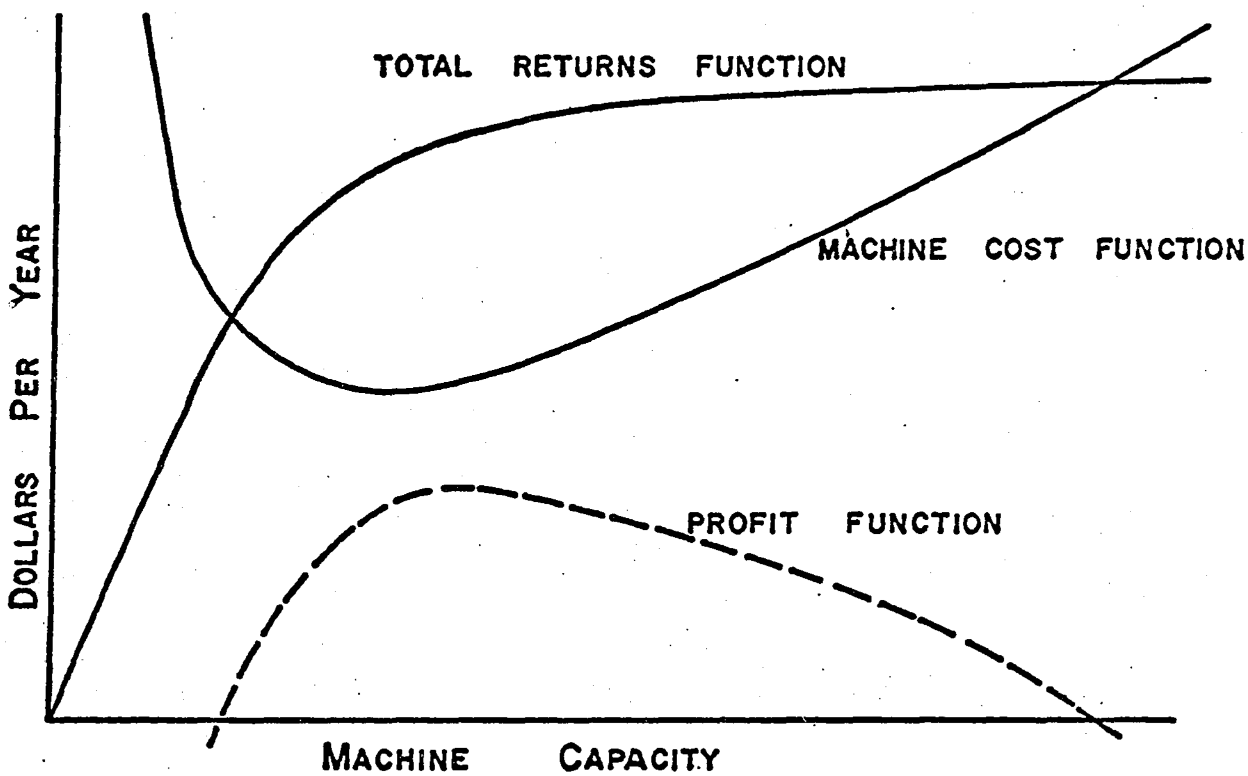
If the optimization process is recognized as a suboptimization and the interference from competing activities assumed to be inconsequential, then the analytic economics method may still be of some value. There is possibly some basis in fact for this assumption when it is recognized that for most dairy farmers in Quebec who harvest corn silage, there are no important seasonal competing activities. Hay harvesting will have been mostly completed earlier in the summer and fall plowing can't be done until the corn has been harvested anyhow.

The basis of the analytic economics approach to optimization is the economic relationship presented in Figure 15. The functions of total return versus machine capacity and machine cost versus machine capacity must be derived. The two functions are then algebraically subtracted as in equation 13 (Figure 15). The resulting profit function is differentiated, set equal to zero and solved for the maximum profit capacity. This method and other traditional analytic methods are thoroughly explained and explored in Wilde's excellent book on optimization (66). The greatest difficulty with this method is in defining the returns and costs functions.

There are some unique difficulties in deriving a monetary returns function for silage corn harvesting. One of them is that of putting a dollar value on the silage. It appeared from examination of the Dominion Bureau of Statistics publications of sales of farm products that there was no trade or market for corn silage in Quebec. The reason is readily apparent when the physical and biochemical characteristics of corn silage are considered. Its high water content (essential for the silage making process) and rapid spoiling due to prolonged exposure to air make it uneconomical to transport it to markets at any distance (38). Also, since the silage is not normally the sole feed for the dairy herd (35), it would be difficult to express its value in terms of dollars returned from the sale of milk. It is more convenient, then, to use some basis other than monetary value.

If it is valued in terms of its feed value, then the returns function in Figure 15 retains the same shape except that it is a function of tons of feed value versus machine capacity. The problem is then one of optimizing for minimum cost per ton of feed value.

Dairy scientists have not yet agreed on the best measure of the feed value of corn silage (35). The American Forage and Grassland Council rates corn silage by three measures; percent TDN (Total Digestible Nutrients), therms CNE (Calculated Net Energy), and percent crude protein ((35) page 40). At least one machinery optimization study (17) used



Profit = Total Return - Machine Cost ...13

Figure 15. Economic Relationship of Costs and Returns

dollars per hundred therms ENE (Estimated Net Energy) to rate hay harvesting systems. Since corn silage is high in energy relative to other forages the feed value used in this study is expressed in therms ENE. However, the ENE content of the corn plant varies over the growing season. This presents an added difficulty.

Complete information on the variation of crop value (ENE) and yield for silage corn with daily passage of the growing season was not readily available in Quebec. Brawn (7) admitted that this area of crop production research has been neglected. Only one study of the variation of yield and feed value of silage corn with harvest date was found for Quebec (9). However, only two harvest dates were covered, and it was felt that this did not provide sufficient data to derive a crop value versus time function. Crop value is not the only factor which influences the shape of the returns function.

As demonstrated in the previous chapter, weather can significantly reduce the realized capacity of harvesting machine systems and may thus also affect the returns function. Because of the probable parabolic shape of the crop value versus time function, the average crop value harvested by a system with a low capacity will be lower than the average crop value harvested by a system with a higher capacity. A good explanation of this using a yield versus time function and a mathematical derivation of a returns function was given by Link (29). He did not, however, account for weather, nor did he explain how to obtain the optimum harvest starting time. The fact that the probability of weather interrupting the harvest increases later in the season complicates the problem of deriving a returns function. Since a mathematical derivation could not be made, a numerical technique was proposed.

A computerized algorithm was developed to determine, using an iterative process, a returns function which accounted for both crop value versus time variation and weather interference. A flow chart of the complete algorithm is presented in Figure 16. The subroutine RATE would be a Monte Carlo simulation of the harvest, day-by-day, to determine the average reduced harvest rate caused by weather interference. The number of simulations would be limited to 1000 to reduce computing costs. The weather pattern input would be in the form of weekly total and conditional probabilities similar to those presented in Tables 14, 15 and 16. The subroutine RESET would simply indicate that the harvest could not be completed for a start in that week. The resulting values of therms ENE for a range of integer harvest rates would be used as data for a polynomial regression. The regression equation would then constitute the returns functions in Figure 15. A side benefit of the algorithm would be the table containing information on the best week to commence harvesting for a particular harvest rate or system capacity. The next step is the derivation of the machine cost function of Figure 15.

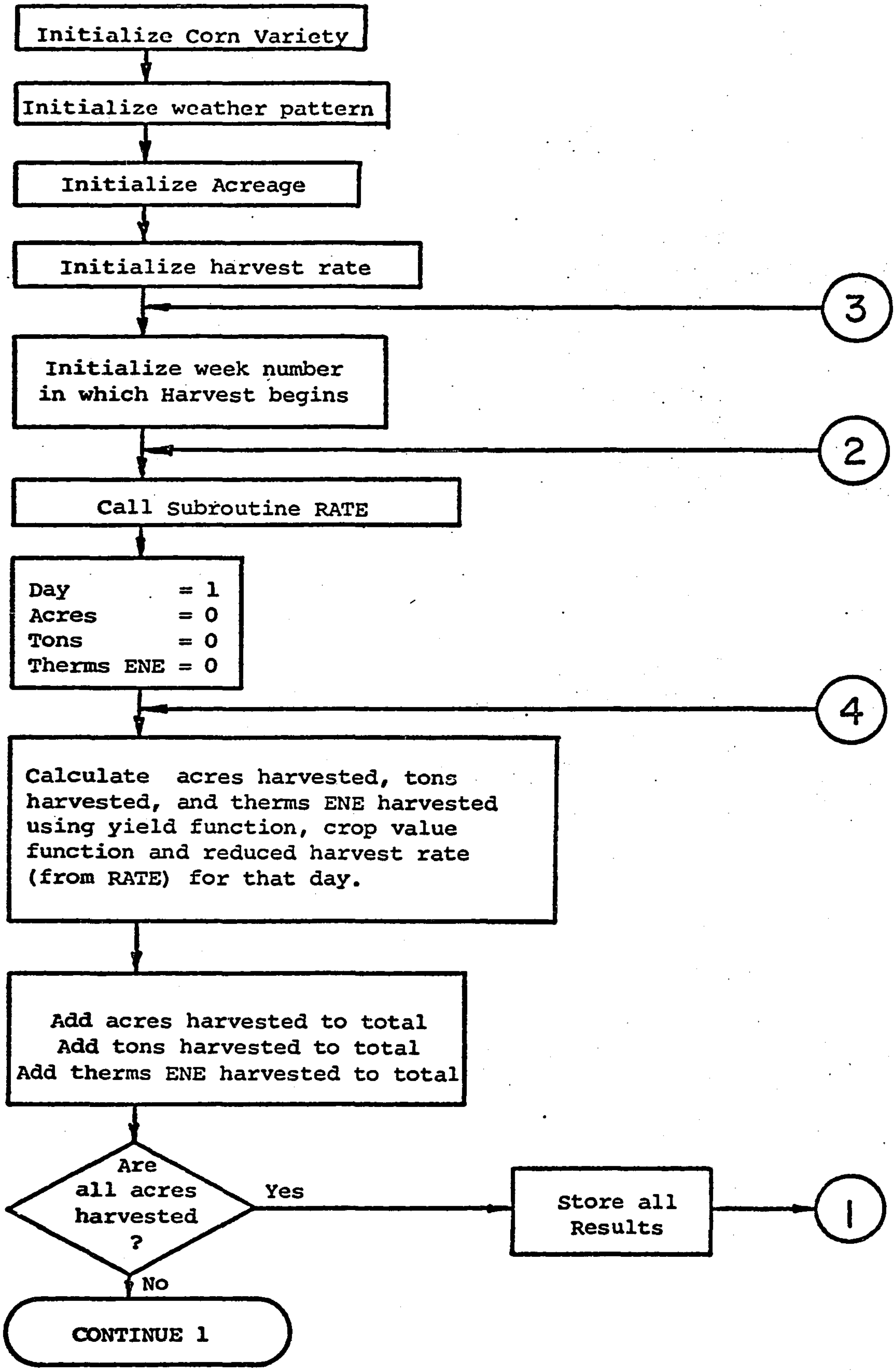


Figure 16. Flow Chart of Returns Function Algorithm.

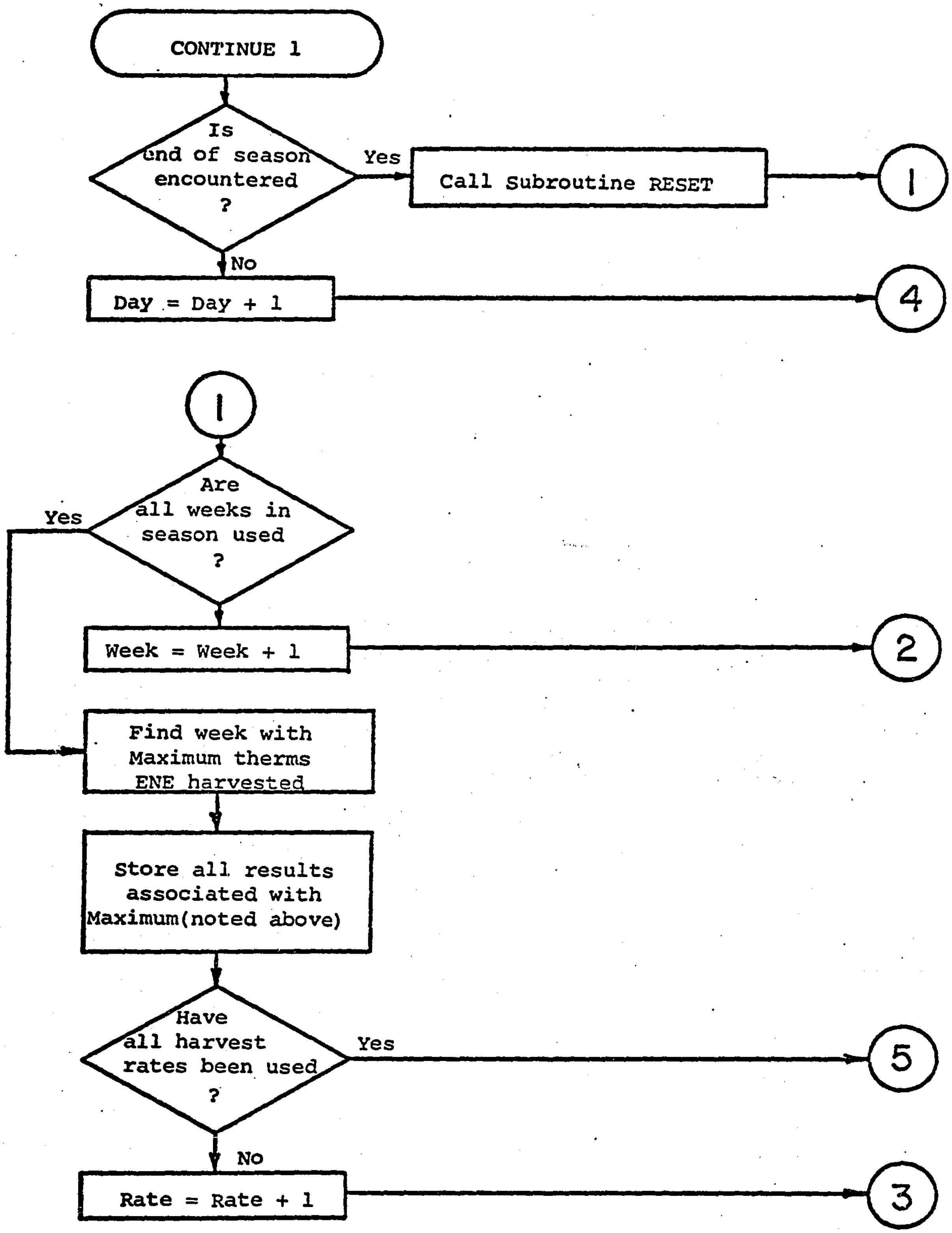


Figure 16. ...continued.

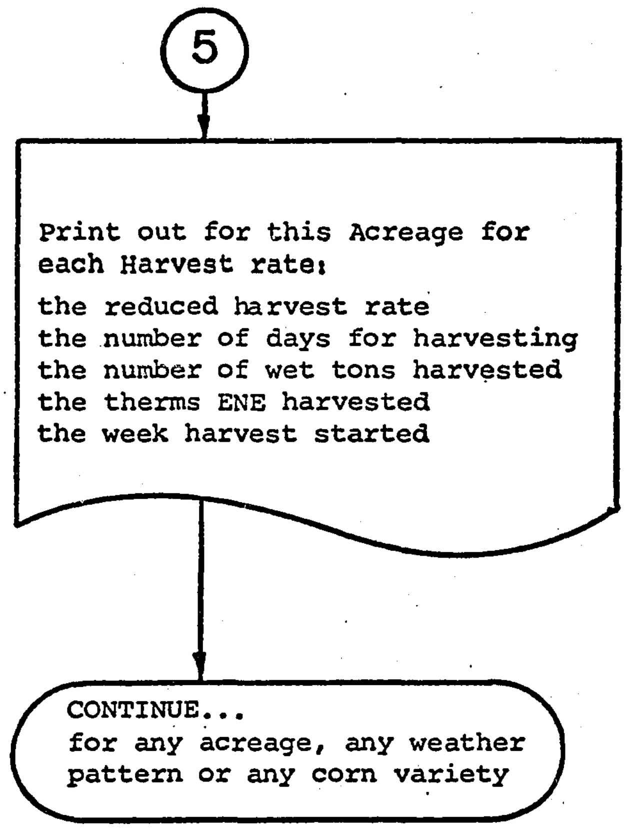


Figure 16. ...continued.

Data for a cost function was developed in previous chapters, however, a number of fundamental difficulties occur if the data is applied directly to the optimization model. As may be seen from Figure 17, yearly cost of operation is by no means a smooth or continuous function of capacity or harvest rate for the machine systems considered in this study. The other difficulty is that the cost function is not independent of the returns function. Figure 9 in chapter 6 plainly shows that cost per ton changes with yield. From the characteristic shape of the curves, it is easy to see that the total harvest cost will change significantly with yield.

In order to develop a cost function that takes into account the factors mentioned above, a computer simulation algorithm very similar to that proposed for the development of the returns function would have to be written. It would use as input the cost-per-ton versus tonnage harvested functions for each machine system, examples of which are illustrated in Figure 9, chapter VI. The yield function would also be used as input. The harvest would be simulated day-by-day for each machine system using the appropriate week for starting and the appropriate reduced system capacity (found from the proposed returns function algorithm). The output of this algorithm would be in graphical format similar to Figure 17. When the returns function is combined with this output, the optimum machine system for the particular acreage under study could then be found by calculating, for each machine system, the cost per unit of ENE.

The primary reason for not carrying out the optimization procedure was the previously mentioned lack of adequate data to derive a yield function and feed value function for the south-western region of Quebec. It is possible, however, to make an 'educated guess' as to which machine system might be the optimum. If the returns function was of the same general shape as the one in Figure 15, and if the spectrum of machine system costs versus capacity was of the same pattern as in Figure 17, then the optimum machine system for the 80 acre level would be system X. Since this was the highest capacity system investigated, it would have been the optimum system for all acreages above about 35 acres. Figure 9, chapter VI indicated that system X became the lowest cost system at about 35 acres. This may indicate that above this size of operation, higher capacity systems than system X might be even cheaper (or more profitable). Perhaps a third chopper size chopping three rows of corn is needed for these larger size operations. Below about 35 acres, it is impossible to say with any degree of accuracy which system would have been the optimum, without going through the optimization procedure.

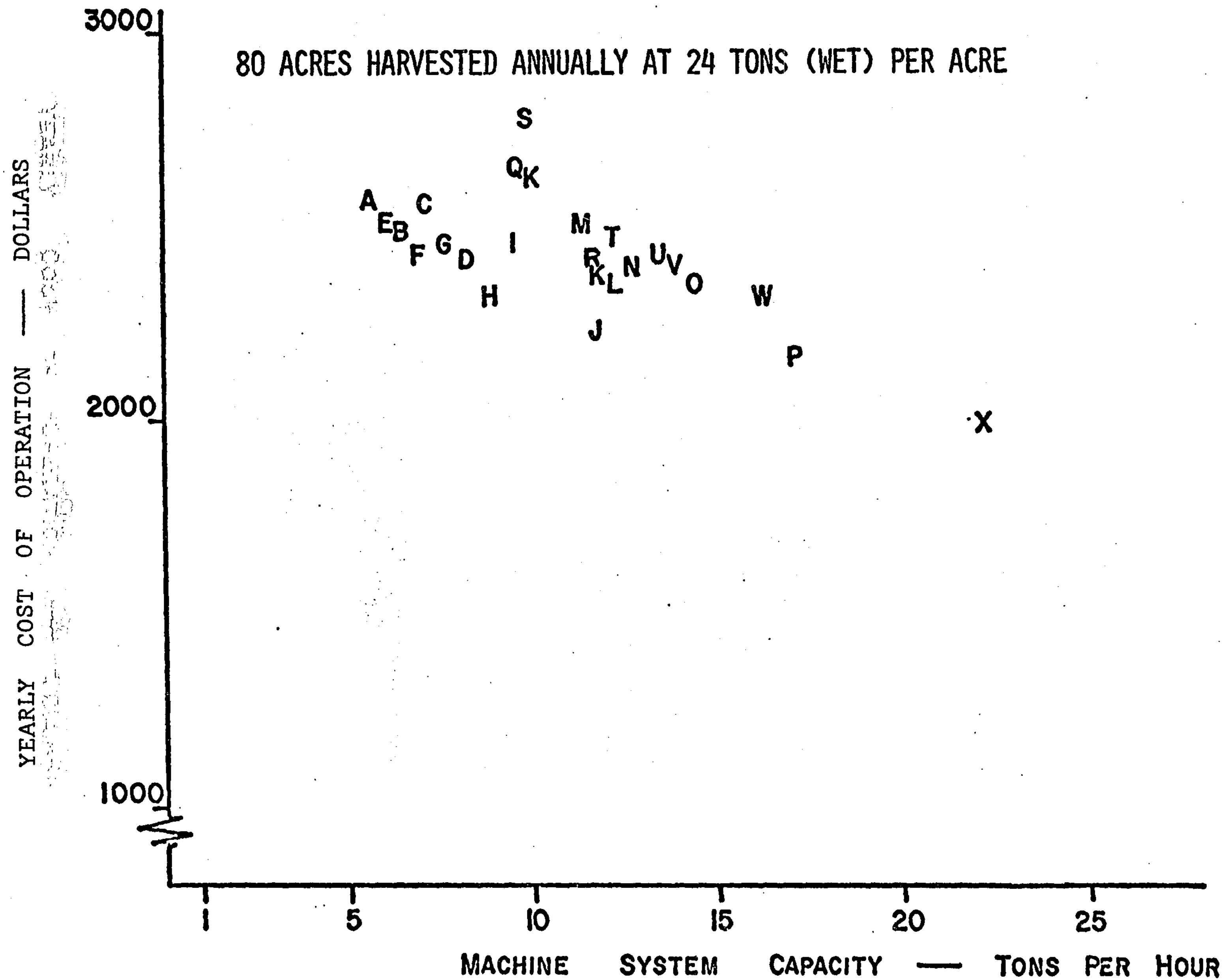


Figure 17. Yearly Cost of Operation versus Machine System Capacity. Enterprise Size of 80 Acres per Year at 24 Tons per Acre Machine Systems Identified by Letter Code.

X CONCLUSIONS

1. It was evident, both from the work study and from subjective observation, that forage choppers on the Quebec market came in only two different sizes. Similarly, forage blowers came in two sizes only. Several sizes of forage wagons of the self-unloading type were on the market, but only the size used in this study appeared to be in common use.

2. If a field efficiency is to be calculated for field machinery, it should not include time spent waiting for other machinery. Field efficiencies thus calculated would be of greater use to systems studies involving field machinery.

3. The activity network was found to be very useful in representing and studying the performance of silage-corn harvesting systems. It is particularly useful when the same network can be used to represent several different systems of machinery.

4. The harvest system computer program was very useful in calculating the costs and performance of the 24 machine systems studied. It was easy to use, although somewhat

expensive (averaging eight dollars a run on an IBM 360/75). It would be relatively easy to expand to accommodate a greater number of machine systems.

5. Using the harvest system computer program, it was found that above 840 tons of corn silage harvested annually, system X, the highest capacity machine system studied, was always the cheapest on a cost per wet ton harvested basis. Below that tonnage, systems J and U were the cheapest (see Table 4 for the machine and labor complement of each system). Increasing the tonnage harvested annually from about 500 tons to 3800 tons halved the cost per ton for most machine systems. This was the equivalent of raising the annual acreage grown from about 20 acres to 140 acres at an average yield of 24 tons per acre.

6. Machine system X, while it was the least cost system for acreages above about 35, was also the highest capacity system and the highest investment system. It was concluded that it is very likely that even higher capacity and higher investment machine systems may be lower in cost per ton for the larger acreages than system X.

7. The criticality report for each machine system was found to be useful in indicating the best way of upgrading a

harvesting system. However, this usefulness was decreased by a machine system whose resulting activity network had more than one critical path. It was thought likely that if the CPM subroutine had been able to handle real (in the computer programming sense) instead of integer activity durations, there would have been a considerably lessened incidence of multiple critical paths.

8. It was found in the study of machine system cost per ton sensitivity to variation in hauling distance that hauling distance is an important factor in determining harvesting costs. This is particularly true in view of the fact that the variation of hauling distance used in the study was approximately the variation found in the work study. The magnitude of this sensitivity, at an annual acreage of 80 and an average yield of 24 tons per acre, was as great as a 14¢ per ton cost increase with each increase of 1/4 mile in hauling distance. Wide variations of this sensitivity were found between machine systems, and the criticality reports were found useful in explaining these variations.

9. Variation in load size did not appear to be as important to harvest cost per ton as hauling distance. The range of load sizes found in the work study was between three and seven tons. The cost sensitivity for 80 annual acres and at 24 tons per acre, was between 3.5¢ and 5¢ per ton with a

load size change of one ton. The sensitivity was apparently non-linear for all the machine systems. The criticality reports were again found useful in explaining inter-machine system cost sensitivity variations.

10. Variation in forage chopper field efficiency caused very little variation in system cost per ton. For most of the machine systems the sensitivity, at 80 annual acres and at 24 tons per acre, was about 1.5¢ per ton increase with a decrease in forage chopper field efficiency of 10 percent. Only two systems had a relatively high sensitivity (about 5¢ per ton), but this was explained by the criticality report.

11. The sensitivity studies pointed out the importance of knowing which machine or operation during harvesting was the most critical. Any factor which directly affects the performance of that machine or operation will affect the total harvest cost to a greater degree than if the machine or operation were non-critical.

12. During the field study, soil moisture was subjectively found to play an important part in determining the harvest duration for silage corn. The analysis of weather as it determined soil moisture and thus harvest

duration was not completely satisfactory. It did, however, point out that significant differences in the patterns of work and non-work days may exist between three locations in southwestern Quebec. It also pointed out that the probability of a non-work day increased markedly starting in the 11th week after July 1st for these three locations.

13. The attempted optimization of silage corn harvesting systems was frustrated mainly by a lack of adequate data on yield and feed value variations during the growing season. There was also a lack of confidence in the model for weather interference. It was thought, however, that considerable benefit would accrue from the development of a computer program based on the algorithm developed in Figure 16.

XI SUGGESTIONS FOR FUTURE RESEARCH

1. The attempt at optimization revealed the severe lack of data on yield and feed value versus time functions for silage corn in Quebec. Considerable research effort needs to be devoted to obtaining information of this kind in a form suitable to incorporation into a machine system optimization study.

2. A large scale work study of up to 100 farms in Quebec would be useful in providing data to validate the results found in this thesis. At the same time, other kinds of forage harvesting could be studied.

3. A more accurate model of the effect of weather on soil moisture and thus on harvest duration is needed. Particular account should be taken of the effects of different soil types and the effect of underdrains on field trafficability.

4. A small scale study could be done on the activity of unloading a wagon during silage corn harvesting. The unloading activity is unique in comparison with the other activities. It involves the simultaneous use of two different machines working together. It was not completely evident

during the work study which of the machines, the self-unloading wagon or the forage blower, was responsible for the observed capacity of the unloading activity. The harvest model that was developed assumed that the forage blower was the critical machine.

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APPENDICES

APPENDIX A. Work Study Data

Sequence* Start Time	Forage Chopper Rates: Wet Tons Per Hour	Forage Chopper Rates: Dry Tons Per Hour	Forage Chopper Rates: Revised** FMI	Wet Weight Harvested Tons	Forage Blower Rates: Wet Tons Per Hour	Forage Blower Rates: Dry Tons Per Hour
FARM NUMBER 1 — DIRECT-CUT GRASS SILAGE, 0.43 miles hauling distance, 2.5 tons (wet) per acre average yield						
1:03 PM	8.60	2.58	Not calculated	3.01	12.04	3.61
2:20 PM	7.43	2.20		2.97	10.61	3.14
FARM NUMBER 4 — SILAGE CORN, 0.095 miles hauling distance, 22.6 tons (wet) per acre average yield						
	Single-row Chopper A				Forage Blower A	
Missed	12.4	Missed	Missed	4.16	15.29	Missed
11:40 AM	15.5	Missed	0.74	5.00	Missed	Missed
1:00 PM	18.8	4.22	0.72	5.83	21.05	4.74
1:30 PM	20.1	4.61	0.78	5.23	24.10	5.54
2:15 PM	15.1	3.75	0.94	4.14	22.26	5.52
2:35 PM	19.1	4.05	0.85	5.33	27.33	5.79
2:50 PM	16.2	3.85	0.87	4.63	22.58	5.27
3:00 PM	Missed	Missed	Missed	5.72	27.50	6.35
3:25 PM	14.5	3.71	Missed	4.28	24.74	6.33
4:10 PM	20.0	4.88	0.89	6.08	Missed	Missed
Averages	16.9	4.15	0.83	5.04	23.11	5.65

* Sequence Start Time is the time of day at which chopping of that particular load was started.

** See page 19 for definition of 'Revised FMI'.

APPENDIX A. ...continued

FARM NUMBER 5 SILAGE CORN

0.187 miles hauling distance, 19.8 tons (wet) per acre average yield

	Single-row Chopper B				Forage Blower B	
-----	24.0	5.60	0.85	4.81	24.05*	5.603*
-----	21.0	5.00	0.92	6.79	37.72	8.978
-----	21.5	5.62	0.84	6.78	42.37	11.06
-----	21.2	4.39	0.90	5.39	35.93	7.44
-----	Missed	Missed	Missed	5.38	41.38	8.36
-----	22.2	4.48	0.88	7.14	39.67	8.01
-----	23.6	4.77	Missed	7.15	37.63	7.60
Averages	22.25	4.98	0.88	6.21	39.12	8.57

*Tractor powering blower too small, larger one used for the rest of the loads.

FARM NUMBER 6 SILAGE CORN

15.77 tons (wet) per acre average yield

	Two-row Chopper C				Forage Blower C	
2:25 PM	25.8	7.04	0.93	3.79	22.69	6.19
3:45 PM	25.9	7.71	0.86	4.09	24.49	7.30
3:50 PM	24.2	7.11	0.95	3.82	32.65	9.60
-----	25.6	7.05	0.98	4.19	20.95	5.78
-----	25.6	6.47	0.94	4.03	30.30	7.64
-----	25.4	7.10	0.95	4.02	Missed	Missed
Averages	25.4	7.08	0.93	3.99	26.22	7.30

APPENDIX A. ...continued

FARM NUMBER 7 SILAGE CORN
0.848 miles hauling distance, 18.14 tons (wet) per acre average yield

	One-row Chopper D				Forage Blower D	
	11.70	2.35	0.79	5.56	41.80	8.40
	9.20	2.03	0.63	4.96	Missed	Missed
	Missed	Missed	Missed	6.01	32.14	6.20
	10.10	1.94	0.84	6.32	34.53	6.66
Averages	10.33	2.11	0.75	5.71	36.16	7.09

FARM NUMBER 8 SILAGE CORN
Over 1 mile hauling distance, 19.27 tons (wet) per acre average yield

2:26 PM	32.8	10.41	0.86	3.05	92.42	29.24
2:44 PM	31.4	8.34	0.73	3.43	68.6	18.17
1:15 PM	27.3	6.46	0.97	3.52	52.54	12.45
1:26 PM	25.9	6.06	0.95	3.28	48.95	11.49
1:35 PM	23.9	5.53	0.90	3.22	64.4	14.94
1:54 PM	26.0	6.23	0.88	3.43	51.19	12.28
2:05 PM	27.5	6.13	Missed	3.30	49.25	10.98
2:26 PM	22.3	4.92	0.99	2.95	59.00	12.98
2:35 PM	27.5	6.25	0.95	3.47	69.40	15.76
2:54 PM	27.0	6.22	0.95	3.42	69.4	15.8
3:03 PM	26.0	5.75	0.94	2.86	57.2	12.6
3:25 PM	29.3	6.60	0.92	4.05	60.45	13.6
Averages	27.24	6.57	0.91	3.33	61.82	15.02

APPENDIX B. Listing of Harvest Model Computer Program

Hardware and Software Requirements

The program was originally run on the McGill University computing center's IBM 360/75 computer, operating under the HASP operating system. The compiler used was IBM's release 19 FORTRAN G level.

Input Variables
(Listed in order of appearance in the program)

FORTRAN Name	Description
RWDTH	Row width of silage corn when planted - in feet
WFCOST	Self-unloading wagon fixed cost - in dollars per hour
MRATE	Labor cost - in dollars per hour per man
DIST	Distance from field to silo - in miles
MPH	Hauling rate for full wagons - in mph
MPHR	Hauling rate for empty wagons - in mph
PWU	Power required to unload wagon - in hp
WT	Load weight of silage in wagon - in tons
WG	Weight of empty wagon - in tons
PC	Power cost (for fuel, oil, grease) - in dollars per hp-hr
FCT	Coefficient of rolling resistance on loam
FCH	Coefficient of rolling resistance on pathway
MC	Moisture content (wet basis) of silage corn - in %
A	Crop acreage - in acres
Y	Crop yield - in wet tons per acre
MTYPE	Index identifying a particular machine or power unit
MCOST	List price of machine or power unit - in dollars
NA	Index for type of machine
CP	Capacity of machine - in wet tons per hour
CA	List price of machine - in dollars

P	Power requirement of machine - in hp
LIFE	Wear-out life of machine - in hours
CT	List price of power unit - in dollars
FMI	Field machine index
TOTAL	Number of activities in network
LAST	Number of nodes in network
WAGON	Number of wagons used with this network
HAULV	Number of hauling vehicles used with this network
MEN	Number of men used with this network
ACTIVA	Activity numbers going up from 1
PNA	Activity predecessor node
SNA	Activity successor node
TYPEA	Type of activity
NODEA	Node number starting from 1, sequentially
PNACA	Activity numbers leaving node, sequential
SNACA	Activity numbers entering node, sequential

```
      INTEGER CHOPER,BLOWER,TOTL,D,C,ERROR,TYPEA,ACTIV,PN,SN,SNAC,PNAC,C
     XCHOPR,CHAULP,CNLOAR,CRETRR,CDUMMR,TOTAL,TTL,ACTIVA,PNA,SNA,PNACA,S
     XNACA,F,E,CCHOP,CHAUL,CNLOAD,CRETRN,CDUMMY,TVCOT,SYSTEM,CHOPR,BLOWR
     X,TYPE,G
      REAL MCOST,LIFE,MPH,MPHR,MRATE,LT,MEN,LCOST,LTIMER,LTIME
      DIMENSION MTYPE(8),MCOST(8),FXCOST(8),CP(4),LIFE(4),CA(4),P(4)
      DIMENSION NA(4),FMI(4),CHOPER(4),CHOPT1(4),CHOPT2(4),CHOPC(4)
      DIMENSION HAULT(4),HAULC1(4),HAULC2(4),HAULC3(4),UNLOAT(4)
      DIMENSION UNLOAC(4),BLOWER(4),RETRNT(4),RETRN1(4),RETRN2(4)
      DIMENSION RETRN3(4),TYPEA(100,6),D(100),C(100),ACTIV(100),PN(100)
      DIMENSION SN(100),NODE(100),SNAC(100,10),PNAC(100,10),TYPE(100)
      DIMENSION A(6),Y(5),TOTAL(6),LAST(6),ACTIVA(100,6),PNA(100,6)
      DIMENSION SNA(100,6),NODEA(100,6),PNACA(100,10,6),SNACA(100,10,6)
      DIMENSION CCHOP(24),CHAUL(24),CNLOAD(24),CRETRN(24),CDUMMY(24)
      DIMENSION DTIME(24),FIXCOS(24),WAGON(6),HAULV(6),MEN(6),LCOST(24)
      DIMENSION SYSTEM(24),NETWRK(24),CHOPR(24),BLOWR(24),TVCOST(24)
      DIMENSION LTIMER(24),TCOST(24),CT(4),TTCOST(24)
      DIMENSION EET(100),EST(100),LET(100),EFT(100),LFT(100),LST(100)
      DIMENSION TFLOAT(100),PFLOAT(100),FFLOAT(100)
      DIMENSION LETER(28),COSTTN(24),COSTHR(24),TONHR(24)
      DATA LETER/'A','B','C','D','E','F','G','H','I','J','K','L','M','N
     1','O','P','Q','R','S','T','U','V','W','X','*',' ',' ',' '/
      READ(5,490) RWDTH,WFCOST,MRATE,DIST,MPH,MPHR,PWU,WT,WG,PC,FCT,FCH
  490 FORMAT(2X,9F6.2,F6.4,2F6.2)
      READ(5,500) (A(I),I=1,6)
  500 FORMAT(2X,6(2X,F4.0))
      READ(5,501) (Y(I),I=1,5)
  501 FORMAT(2X,5(2X,F3.0))
      READ(5,502) (MTYPE(I),I=1,8)
  502 FORMAT(2X,8(2X,I1))
      READ(5,503) (MCOST(I),I=1,8)
  503 FORMAT(2X,8(2X,F5.0))
      DO 100 I=1,4
  100 READ(5,504) NA(I),CP(I),CA(I),P(I),LIFE(I),CT(I),FMI(I)
  504 FORMAT(6X,I1,3X,F3.0,3X,F5.0,3X,F3.0,3X,F5.0,3X,F5.0,3X,F4.2)
      DO 101 J=1,6
      READ(5,505) TOTAL(J),LAST(J),WAGON(J),HAULV(J),MEN(J)
  505 FORMAT(6X,I3,3X,I3,3X,F2.0,2X,F2.0,2X,F2.0)
      TTL=TOTAL(J)
      DO 5 L=1,TTL
  102 READ(5,506) ACTIVA(L,J),PNA(L,J),SNA(L,J),TYPEA(L,J)
  506 FORMAT(8X,I3,6X,I3,6X,I3,6X,I1)
      IF(PNA(L,J).GE.SNA(L,J)) GO TO 806
      GO TO 4
  806 WRITE(6,821) PNA(L,J),SNA(L,J),L,J
  821 FORMAT(6X,'ERROR 806  PNA(L,J)=',I3,'  SNA(L,J)=',I3,'  FOR L=',I3
     X,'  AND J=',I1)
      GO TO 1000
    4 IF(L.EQ.1) GO TO 6
      IF(L.GT.1.AND.(ACTIVA(L,J)-100).LE.(ACTIVA(L-1,J)-100)) GO TO 822
    6 GO TO 5
  822 WRITE(6,823) ACTIVA(L,J),J
  823 FORMAT(6X,'ERROR 822 ACTIVITY CARDS OUT OF ORDER, ACTIVITY,',I3,'
     X J=',I4)
```

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```
          GO TO 1000
    5     CONTINUE
          LSAT=LAST(J)
          DO 15 M=1,LSAT
  103     READ(5,507) NODEA(M,J),(PNACA(M,N,J),N=1,10),(SNACA(M,N,J),N=1,10)
  507     FORMAT(2X,I3,2X,10I3,2X,10I3)
          IF(M.EQ.1) GO TO 15
          IF(NODEA(M,J).LE.NODEA(M-1,J)) GO TO 824
          GO TO 15
  824     WRITE(6,825) NODEA(M,J),J
  825     FORMAT(6X,'ERROR 824  NODE CARDS OUT OF ORDER, NODE',I3,'  J=',I1)
          GO TO 1000
   15     CONTINUE
  101     CONTINUE
          CALL FCOST(MTYPE,MCOST,FXCOST)
          CTH=MCOST(8)
          DO 600 G=1,2
          GO TO (601,602),G
  601     FMI(1)=0.70
          FMI(2)=0.77
          GO TO 604
  602     FMI(1)=0.90
          FMI(2)=0.97
  604     CONTINUE
          WRITE(6,1501)
 1501     FORMAT('1')
          DO 108 F=1,6
          AT=A(F)
          WRITE(6,104) AT
  104     FORMAT(30X,'CORN SILAGE AT ',F4.0,' ACRES/YEAR',/)
          DO 109 E=3,3
          YD=Y(E)
          TTON=AT*YD
          SPD1=(CP(1)*8.25)/(YD*RWDTH)
          SPD2=(CP(2)*8.25)/(YD*RWDTH*2.)
          WRITE(6,105) YD,SPD1,SPD2
  105     FORMAT(10X,'AT A YIELD OF ',F3.0,' TONS(WET)/ACRE',8X,'CHOPPER A A
         XT ',F4.2,'MPH    CHOPPER B AT ',F4.2,'MPH',/)
   38     CALL CHOP(CP,CT,AT,YD,LIFE,CA,P,WT,NA,FMI,CHOPER,CHOPT1,CHOPT2,CHO
         XPC,PC,SPD1,SPD2,WG,FCT)
   31     CALL HAUL(DIST,MPH,MCOST,HAULT,HAULC1,HAULC2,HAULC3,WG,WT,FCH,PC)
   32     CALL UNLOAD(CP,CT,AT,YD,LIFE,CA,P,PWU,CTH,WT,NA,UNLOAT,UNLOAC,BLOW
         XER,PC)
   33     CALL RETUR(DIST,MPHR,RETRNT,RETRN1,RETRN2,RETRN3,MCOST,WG,FCH,PC)
   34     I=0
   35     CONTINUE
          DO 30 J=1,6
          DO 40 K=1,4
    1     I=I+1
          TOTL=TOTAL(J)
          LAS=LAST(J)
          ERROR=0
          CALL SET(TOTL,D,C,K,J,CHOPT1,CHOPT2,TYPEA,CHOPC,HAULT,HAULC3,HAULC
         X2,HAULC1,UNLOAT,UNLOAC,RETRNT,RETRN3,RETRN2,RETRN1)
```

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```
0099             IF(ERROR.GT.0) GO TO 1000
0100           2 CONTINUE
0101             DO 400 L=1,TOTL
0102             ACTIV(L)=ACTIVA(L,J)
0103             PN(L)=PNA(L,J)
0104             SN(L)=SNA(L,J)
0105         400 TYPE(L)=TYPEA(L,J)
0106             DO 401 M=1,LAS
0107             NODE(M)=NODEA(M,J)
0108             DO 402 N=1,10
0109             SNAC(M,N)=SNACA(M,N,J)
0110         402 PNAC(M,N)=PNACA(M,N,J)
0111         401 CONTINUE
0112           3 CONTINUE
0113             CALL CPM(ACTIV,PN,SN,NODE,SNAC,PNAC,D,LAS,TOTL,LTIME,CCHOPR,CHAULR
                X,CNLOAR,CRETRR,CDUMMR,TYPE,EET,LET,TFLOAT,PFLOAT,FFLOAT,EST,EFT,LF
                XT,LST)
0114             IF(ERROR.GT.0) GO TO 1000
0115             CCHOP(I)=CCHOPR
0116             CHAUL(I)=CHAULR
0117             CNLOAD(I)=CNLOAR
0118             CRETRN(I)=CRETRR
0119             CDUMMY(I)=CDUMMR
0120             TVCOT=0
0121        1004 CONTINUE
0122             DO 200 L=1,TOTL
0123         200 TVCOT=TVCOT+C(L)
0124             TVLCOT=TVCOT/100.
0125             DTIME(I)=TTON/(((10.*WT)/(LTIME/60.))*8.)
0126             RATIO=(DTIME(I)*8.)/600.
0127             GO TO (150,151,152,153), K
0128         150 EXCOST=(FXCOST(1)+(FXCOST(7)*RATIO)+FXCOST(4)+(FXCOST(8)*RATIO))/(
                CDTIME(I))
0129             GO TO 157
0130         151 EXCOST=(FXCOST(1)+(FXCOST(7)*RATIO)+FXCOST(5)+(FXCOST(7)*RATIO))/(
                CDTIME(I))
0131             GO TO 157
0132         152 EXCOST=(FXCOST(2)+(FXCOST(6)*RATIO)+FXCOST(4)+(FXCOST(8)*RATIO))/(
                CDTIME(I))
0133             GO TO 157
0134         153 EXCOST=(FXCOST(2)+(FXCOST(6)*RATIO)+FXCOST(5)+(FXCOST(7)*RATIO))/(
                CDTIME(I))
0135         157 GO TO (155,154,154,154,154,154), J
0136         154 FIXCOS(I)=(WFCOST*WAGON(J)*8.)+((FXCOST(8)*RATIO*HAULV(J))/(DTIME(
                CI)*8.))+(MRATE*MEN(J)*8.)+EXCOST
0137             GO TO 156
0138         155 FIXCOS(I)=(WFCOST*WAGON(J)*8.)+EXCOST+(MRATE*MEN(J)*8.)
0139         156 LCOST(I)=TVLCOT+((FIXCOS(I)/(8.*60.))*LTIME)
0140             SYSTEM(I)=LETER(I)
0141             NETWRK(I)=J
0142             CHOPR(I)=CHOPER(K)
0143             BLOWR(I)=BLOWER(K)
0144             LTIMER(I)=LTIME/60.
0145             TVCOST(I)=(TVLCOT/LTIMER(I))*8.
```

```
0146              TCOST(I)=TVCOST(I)+FIXCOS(I)
0147              TTCOST(I)=DTIME(I)*TCOST(I)
0148              COSTTN(I)=TTCOST(I)/TTON
0149              COSTHR(I)=TTCOST(I)/(DTIME(I)*8.)
0150              TONHR(I)=TTON/(DTIME(I)*8.)
0151          40  CONTINUE
0152          30  CONTINUE
0153        1006  WRITE(6,106)
0154         106  FORMAT(/,2X,'SYSTEM  10 LD  10 LD  DAILY  DAILY  TOTAL  DAYS FOR
                 1COST FOR  COST  COST  TONS',9X,'CRITICALITY REPORT - ACTIVITIES',/
                 2,10X,'TIME   COST   VARY   FIXED  DAILY  THIS      THIS      PER
                 3 PER   PER ',6X,'CHOP  HAUL  UNLOAD  RETURN  DUMMY',/,24X,'COSTS
                 4COSTS  COSTS  TONNAGE   TONNAGE   TON    HOUR   HOUR')
0155              DO 201 I=1,24
0156         202  WRITE(6,203) SYSTEM(I),LTIMER(I),LCOST(I),TVCOST(I),FIXCOS(I),TCOS
                 CT(I),DTIME(I),TTCOST(I),COSTTN(I),COSTHR(I),TONHR(I),CCHOP(I),CHAU
                 CL(I),CNLOAD(I),CRETRN(I),CDUMMY(I)
0157         203  FORMAT(4X,A1,4X,F5.2,2X,F6.2,2X,F5.2,1X,F6.2,2X,F6.2,1X,F5.1,5X,F7
                 1.2,2X,F5.3,1X,F5.2,1X,F5.2,6X,I2,4X,I2,5X,I2,6X,I2,5X,I2)
0158         201  CONTINUE
0159         109  CONTINUE
0160              WRITE(6,1500)
0161        1500  FORMAT('1')
0162         108  CONTINUE
0163         600  CONTINUE
0164        1000  CONTINUE
0165              STOP
0166              END

 *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
 *OPTIONS IN EFFECT*  NAME = MAIN     , LINECNT =       56
 *STATISTICS*    SOURCE STATEMENTS =       166,PROGRAM SIZE =    82970
 *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
             C
             C               SUBROUTINE   FCOST
             C
                   SUBROUTINE FCOST(MTYPE,MCOST,FXCOST)
                   REAL IHI,MCOST
                   DIMENSION MTYPE(8),MCOST(8),FXCOST(8)
                   DO 100 N=1,8
                   DP=((MCOST(N)*.92)-(0.1*MCOST(N)))/10.
                   R=1.
                   H=0.
              104  H=(0.10*((MCOST(N)*.92)-(R*DP)))+H
                   IF(R.EQ.10.) GO TO 105
                   R=R+1.
                   GO TO 104
              105  IHI=H/10.
                   FXCOST(N)=DP+IHI
              100  CONTINUE
                   ANS=0.
                   IF(ANS.EQ.0.) GO TO 103
                   DO 102 N=1,8
              102  WRITE(6,101) MTYPE(N),MCOST(N),FXCOST(N)
              101  FORMAT(6X,I1,2F10.2,/)
              103  CONTINUE
                   RETURN
                   END

 *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
 *OPTIONS IN EFFECT*  NAME = FCOST   , LINECNT =      56
 *STATISTICS*    SOURCE STATEMENTS =       22,PROGRAM SIZE =       716
 *STATISTICS*  NO DIAGNOSTICS GENERATED
```

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```
C
C                SUBROUTINE   CHOP
C
      SUBROUTINE CHOP(CP,CT,AT,YD,LIFE,CA,P,WT,NA,FMI,CHOPER,CHOPT1,CHOP
     XT2,CHOPC,PC,SPD1,SPD2,WG,FCT)
      INTEGER CHOPER
      REAL MPH,MPHR,LIFE
      DIMENSION CP(4),CT(4),LIFE(4),CA(4),P(4),NA(4),FMI(4),CHOPER(4),CH
     XOPT1(4),CHOPT2(4),CHOPC(4),TCOST(2),DURA1(2),DURA2(2)
      WRITE(6,100)
  100 FORMAT(8X,'CHOP',5X,'TOTAL COST  DURATION  ACT/DUR 1  ACT/DUR 2  C
     XHOPPER  COST/HOUR')
  103 DO 101 I=1,2
      DUR=WT/(CP(I)*FMI(I))
      XT=100.*((10.*600.)/12000.)
      TART=0.12*(XT**1.5)
      TRCOST=((((TART/100.)*CT(I))/10.)/600.)*DUR
      Y=(AT*YD)/CP(I)
      XC=100.*((10.*Y)/LIFE(I))
      TARC=0.127*(XC**1.4)
      CCOST=(((((TARC/100.)*CA(I))/10.)/Y)*DUR)+(PC*P(I)*DUR)
      GO TO (10,11),I
   10 CCOST=CCOST+((SPD1*5280.*(WG+(WT/2.))*FCT*2000.*DUR*PC)/(550.*3600
     C.))
      GO TO 12
   11 CCOST=CCOST+((SPD2*5280.*(WG+(WT/2.))*FCT*2000.*DUR*PC)/(550.*3600
     C.))
   12 TCOST(I)=TRCOST+CCOST+(0.83*DUR)
      TCOSTH=TCOST(I)/DUR
      DURA1(I)=DUR+(5./60.)
      DURA2(I)=DUR+(2./60.)
      WRITE(6,102) TCOST(I),DUR,DURA1(I),DURA2(I),NA(I),TCOSTH
  102 FORMAT(20X,F6.2,4X,F5.3,6X,F5.3,6X,F5.3,7X,I1,6X,F6.2)
  101 CONTINUE
      DO 105 K=1,4
      IF(K.EQ.1.OR.K.EQ.2) GO TO 106
      GO TO 107
  106 CHOPT1(K)=DURA1(1)
      CHOPT2(K)=DURA2(1)
      CHOPC(K)=TCOST(1)
      CHOPER(K)=NA(1)
      GO TO 105
  107 IF(K.EQ.3.OR.K.EQ.4) GO TO 108
  108 CHOPT1(K)=DURA1(2)
      CHOPT2(K)=DURA2(2)
      CHOPC(K)=TCOST(2)
      CHOPER(K)=NA(2)
  105 CONTINUE
  104 CONTINUE
      RETURN
      END
```

OPTIONS IN EFFECT ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
OPTIONS IN EFFECT NAME = CHOP   , LINECNT =   56

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```
               C
               C         SUBROUTINE   HAUL
               C
 0001                 SUBROUTINE HAUL(DIST,MPH,MCOST,HAULT,HAULC1,HAULC2,HAULC3,WG,WT,FC
                     XH,PC)
 0002                 REAL MPH,MCOST
 0003                 DIMENSION HAULT(4),HAULC1(4),HAULC2(4),HAULC3(4),MCOST(8),CTH(3),T
                     XCOST(3),TCOSTH(3),TRCOST(3)
 0004                 CTH(1)=MCOST(6)
 0005                 CTH(2)=MCOST(7)
 0006                 CTH(3)=MCOST(8)
 0007                 WRITE(6,100)
 0008            100  FORMAT(8X,'HAUL',5X,'TOTAL COST  DURATION  ACT/DUR  COST/HOUR    W
                     XAGON POWER COST')
 0009            102  DUR=DIST/MPH
 0010                 XT=100.*((10.*600.)/12000.)
 0011                 TART=0.12*(XT**1.5)
 0012                 DO 4 I=1,3
 0013              4  TRCOST(I)=((((TART/100.)*CTH(I))/10.)/600.)*DUR
 0014                 WPCOST=(MPH*5280.*(WG+WT)*FCH*2000.*DUR*PC)/(550.*3600.)
 0015                 DO 5 I=1,3
 0016                 TCOST(I)=TRCOST(I)+WPCOST+(0.83*DUR)
 0017              5  TCOSTH(I)=TCOST(I)/DUR
 0018                 DURA=DUR+(2./60.)
 0019                 DO 6 I=1,3
 0020              6  WRITE(6,101) TCOST(I),DUR,DURA,TCOSTH(I),WPCOST
 0021            101  FORMAT(20X,F6.2,4X,F5.3,5X,F5.3,4X,F6.2,11X,F6.2)
 0022            103  DO 104 K=1,4
 0023                 HAULT(K)=DURA
 0024                 HAULC1(K)=TCOST(1)
 0025                 HAULC2(K)=TCOST(2)
 0026            104  HAULC3(K)=TCOST(3)
 0027            105  CONTINUE
 0028                 RETURN
 0029                 END

  *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = HAUL     , LINECNT =       56
  *STATISTICS*    SOURCE STATEMENTS =       29,PROGRAM SIZE =      1276
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
      C
      C                   SUBROUTINE   UNLOAD
      C
            SUBROUTINE UNLOAD(CP,CT,AT,YD,LIFE,CA,P,PWU,CTH,WT,NA,UNLOAT,UNLOA
           XC,BLOWER,PC)
            INTEGER BLOWER
            REAL MPH,MPHR,LIFE
            DIMENSION CP(4),CT(4),LIFE(4),CA(4),P(4),NA(4),UNLOAT(4),UNLOAC(4)
           X,TCOST(4),DURA(4),BLOWER(4)
            WRITE(6,100)
        100 FORMAT(8X,'UNLOAD   TOTAL COST  DURATION  ACT/DUR  COST/HOUR  BLOW
           XER')
        103 DO 101 I=3,4
            DUR=WT/CP(I)
            XT1=100.*((10.*600.)/12000.)
            TART1=0.12*(XT1**1.5)
            T1COST=((((TART1/100.)*CT(I))/10.)/600.)*DUR
            Y=(AT*YD)/CP(I)
            XB=100.*((10.*Y)/LIFE(I))
            TARB=0.127*(XB**1.4)
            BCOST=(((((TARB/100.)*CA(I))/10.)/Y)*DUR)+(PC*P(I)*DUR)
            WCOST=PC*PWU*DUR
            T2COST=((((TART1/100.)*CTH)/10.)/600.)*DUR
            TCOST(I)=T1COST+BCOST+WCOST+T2COST+(0.83*DUR)
            TCOSTH=TCOST(I)/DUR
            DURA(I)=DUR+(2./60.)
            WRITE(6,102) TCOST(I),DUR,DURA(I),TCOSTH,NA(I)
        102 FORMAT(20X,F6.2,4X,F5.3,5X,F5.3,4X,F6.2,7X,I1)
        101 CONTINUE
            DO 104 K=1,4
            IF(K.EQ.1.OR.K.EQ.3) GO TO 105
            GO TO 106
        105 UNLOAT(K)=DURA(3)
            UNLOAC(K)=TCOST(3)
            BLOWER(K)=NA(3)
            GO TO 104
        106 IF(K.EQ.2.OR.K.EQ.4) GO TO 107
        107 UNLOAT(K)=DURA(4)
            UNLOAC(K)=TCOST(4)
            BLOWER(K)=NA(4)
        104 CONTINUE
            RETURN
            END
```

```
*OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
*OPTIONS IN EFFECT*  NAME = UNLOAD  , LINECNT =     56
*STATISTICS*    SOURCE STATEMENTS =       37,PROGRAM SIZE =     1644
*STATISTICS*  NO DIAGNOSTICS GENERATED
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```
             C
             C          SUBROUTINE  RETUR
             C
0001                SUBROUTINE RETUR(DIST,MPHR,RETRNT,RETRN1,RETRN2,RETRN3,MCOST,WG,FC
                   XH,PC)
0002                REAL MPH,MPHR,MCOST
0003                DIMENSION RETRNT(4),RETRN3(4),RETRN2(4),RETRN1(4),MCOST(8),TRCOST(
                   X3),TCOST(3),TCOSTH(3),CTH(3)
0004          99    CTH(1)=MCOST(6)
0005                CTH(2)=MCOST(7)
0006                CTH(3)=MCOST(8)
0007                WRITE(6,100)
0008         100    FORMAT(8X,'RETURN   TOTAL COST  DURATION  ACT/DUR  COST/HOUR    WA
                   XGON POWER COST')
0009         102    DUR=DIST/MPHR
0010                XT=100.*((10.*600.)/12000.)
0011                TART=0.12*(XT**1.5)
0012                DO 4 I=1,3
0013           4    TRCOST(I)=((((TART/100.)*CTH(I))/10.)/600.)*DUR
0014                WPCOST=(MPHR*5280.*WG*FCH*2000.*DUR*PC)/(550.*3600.)
0015                DO 5 I=1,3
0016                TCOST(I)=TRCOST(I)+WPCOST+(0.83*DUR)
0017           5    TCOSTH(I)=TCOST(I)/DUR
0018                DURA=DUR+(2./60.)
0019                DO 6 I=1,3
0020           6    WRITE(6,101) TCOST(I),DUR,DURA,TCOSTH(I),WPCOST
0021         101    FORMAT(20X,F6.2,4X,F5.3,5X,F5.3,4X,F6.2,11X,F6.2)
0022         103    DO 105 K=1,4
0023                RETRNT(K)=DURA
0024                RETRN1(K)=TCOST(1)
0025                RETRN2(K)=TCOST(2)
0026         105    RETRN3(K)=TCOST(3)
0027         104    CONTINUE
0028                RETURN
0029                END

 *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
 *OPTIONS IN EFFECT*  NAME = RETUR   , LINECNT =      56
 *STATISTICS*    SOURCE STATEMENTS =       29,PROGRAM SIZE =     1252
 *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
C
C                        SUBROUTINE   SET
C
            SUBROUTINE SET(TOTL,D,C,K,J,CHOPT1,CHOPT2,TYPEA,CHOPC,HAULT,HAULC3
           X,HAULC2,HAULC1,UNLOAT,UNLOAC,RETRNT,RETRN3,RETRN2,RETRN1)
            INTEGER TOTL,D,C,ERROR,TYPEA,TYP
            DIMENSION CHOPT1(K),CHOPT2(K),TYPEA(100,6),CHOPC(K),HAULT(K),HAULC
           X3(K),HAULC2(K),HAULC1(K),UNLOAT(K),UNLOAC(K),RETRNT(K),RETRN3(K),R
           XETRN2(K),RETRN1(K),D(TOTL),C(TOTL)
            DO 100 L=1,TOTL
            TYP=TYPEA(L,J)
            GO TO (99,98,97,96,95), TYP
         99 IF(J.EQ.1) GO TO 94
            X2=CHOPT2(K)*60.
            D(L)=X2+.5
            C2=CHOPC(K)*100.
            C(L)=C2+.5
            GO TO 100
         94 X1=CHOPT1(K)*60.
            D(L)=X1+.5
            C1=CHOPC(K)*100.
            C(L)=C1+.5
            GO TO 100
         98 X3=HAULT(K)*60.
            D(L)=X3+.5
            IF(J.EQ.1.AND.(K.EQ.1.OR.K.EQ.2)) GO TO 1
            IF(J.EQ.1.AND.(K.EQ.3.OR.K.EQ.4)) GO TO 2
            C3=HAULC3(K)*100.
            C(L)=C3+.5
            GO TO 100
          1 C3=HAULC2(K)*100.
            C(L)=C3+.5
            GO TO 100
          2 C3=HAULC1(K)*100.
            C(L)=C3+.5
            GO TO 100
         97 X4=UNLOAT(K)*60.
            D(L)=X4+.5
            C4=UNLOAC(K)*100.
            C(L)=C4+.5
            GO TO 100
         96 X5=RETRNT(K)*60.
            D(L)=X5+.5
            IF(J.EQ.1.AND.(K.EQ.1.OR.K.EQ.2)) GO TO 3
            IF(J.EQ.1.AND.(K.EQ.3.OR.K.EQ.4)) GO TO 4
            C5=RETRN3(K)*100.
            C(L)=C5+.5
            GO TO 100
          3 C5=RETRN2(K)*100.
            C(L)=C5+.5
            GO TO 100
          4 C5=RETRN1(K)*100.
            C(L)=C5+.5
            GO TO 100
```

```
0049          95  D(L)=0
0050              C(L)=0
0051         100  CONTINUE
0052              ANS=0.
0053              IF(ANS.EQ.0.) GO TO 101
0054              DO 103 M=1,K
0055         103  WRITE(6,102) CHOPT1(M),CHOPT2(M),CHOPC(M),HAULT(M),HAULC3(M),HAULC
                X2(M),HAULC1(M),UNLOAT(M),UNLOAC(M),RETRNT(M),RETRN3(M),RETRN2(M),R
                XETRN1(M)
0056         102  FORMAT(2X,13F5.3,//)
0057         101  CONTINUE
0058              RETURN
0059              END

 *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
 *OPTIONS IN EFFECT*  NAME = SET     , LINECNT =        56
 *STATISTICS*    SOURCE STATEMENTS =          59,PROGRAM SIZE =      2900
 *STATISTICS*  NO DIAGNOSTICS GENERATED
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```
C
C               SUBROUTINE   CPM
C
          SUBROUTINE CPM(ACTIV,PN,SN,NODE,SNAC,PNAC,D,LAS,TOTL,LTIME,CCHOPR,
         XCHAULR,CNLOAR,CRETRR,CDUMMR,TYPE,EET,LET,TFLOAT,PFLOAT,FFLOAT,EST,
         XEFT,LFT,LST)
          REAL LTIME
          INTEGER FIRST,TOTAL,ACTIV,D,C,PN,SN,SNAC,PNAC,EET,TFLOAT,PFLOAT,FF
         XLOAT,EST,EFT,LAS,TOTL,TYPE,TYP,CCHOPR,CHAULR,CNLOAR,CRETRR,CDUMMR
          DIMENSION ACTIV(100),D(100),PN(100),SN(100),NODE(100),SNAC(100,10)
         X,PNAC(100,10),EET(100),LET(100),TFLOAT(100),PFLOAT(100),FFLOAT(100
         X),EST(100),EFT(100),LFT(100),LST(100),TYPE(100)
        1 TOTAL=TOTL
          LAST=LAS
          FIRST=NODE(1)
          J=1
          LET(J)=0
        2 EET(J)=0
          DO 23 J=2,LAST
          K=1
          IF(SNAC(J,K).EQ.0) GO TO 120
          GO TO  121
      120 WRITE(6,122) SNAC(J,K),J,K
      122 FORMAT(6X,'ERROR 120  SNAC(J,K)=',I4,'  J=',I2,'  K=',I2,/)
          ERROR=1+ERROR
          GO TO 103
      121 EET(NODE(J))=D(SNAC(J,K)-100)+EET(PN(SNAC(J,K)-100))
       22 K=K+1
          IF(SNAC(J,K).EQ.0.) GO TO 23
          IF(D(SNAC(J,K)-100)+EET(PN(SNAC(J,K)-100)).LE.EET(NODE(J))) GO TO
         X22
          EET(NODE(J))=D(SNAC(J,K)-100)+EET(PN(SNAC(J,K)-100))
          GO TO 22
       23 CONTINUE
        3 J=LAST
          LTIME=EET(J)
       24 LET(NODE(J))=EET(NODE(J))
       28 J=J-1
          K=1
          IF(PNAC(J,K).EQ.0) GO TO 130
          GO TO 131
      130 WRITE(6,132) PNAC(J,K)
      132 FORMAT(6X,'ERROR 130  PNAC(J,K)=',I4,/)
          GO TO 103
      131 LET(NODE(J))=LET(SN(PNAC(J,K)-100))-D(PNAC(J,K)-100)
       26 K=K+1
          IF(PNAC(J,K).EQ.0.) GO TO 25
          IF(LET(SN(PNAC(J,K)-100))-D(PNAC(J,K)-100).GT.LET(NODE(J))) GO TO
         X26
          LET(NODE(J))=LET(SN(PNAC(J,K)-100))-D(PNAC(J,K)-100)
          GO TO 26
       25 IF(NODE(J).EQ.FIRST.OR.NODE(J).LT.FIRST) GO TO 27
          GO TO 28
       27 CONTINUE
```

```
      C
      C   . FLOAT CALCULATIONS
      C
            CCHOPR=0
            CHAULR=0
            CNLOAR=0
            CRETRR=0
          4 CDUMMR=0
            DO 40 I=1,TOTAL
         41 IF(SN(I).LE.0.OR.PN(I).LE.0) GO TO 140
            GO TO 141
        140 WRITE(6,142) SN(I),PN(I),I
        142 FORMAT(6X,'ERROR 140   SN(I)=',I4,'   PN(I)=',I4,'   I=',I2,/)
            GO TO 103
        141 TFLOAT(I)=LFT(SN(I))-FET(PN(I))-D(I)
            PFLOAT(I)=LFT(SN(I))-FET(SN(I))
            FFLOAT(I)=TFLOAT(I)-PFLOAT(I)
            IF(TFLOAT(I).LE.0) GO TO 143
            GO TO 40
        143 TYP=TYPE(I)
            GO TO (144,145,146,147,148), TYP
        144 CCHOPR=CCHOPR+1
            GO TO 40
        145 CHAULR=CHAULR+1
            GO TO 40
        146 CNLOAR=CNLOAR+1
            GO TO 40
        147 CRETRR=CRETRR+1
            GO TO 40
        148 CDUMMR=CDUMMR+1
         40 CONTINUE
      C
          5 ANS=0.
      C
          6 IF(ANS.EQ.0.) GO TO 104
            DO 50 I=1,TOTAL
         51 IF(SN(I).LE.0.OR.PN(I).LE.0) GO TO 150
            GO TO 151
        150 WRITE(6,152)  SN(I),PN(I),I
        152 FORMAT(6X,'ERROR 150   SN(I)=',I4,'   PN(I)=',I4,'   I=',I2,/)
            ERROR=ERROR+1
            GO TO 103
        151 EST(I)=EET(PN(I))
            EFT(I)=EST(I)+D(I)
            LFT(I)=LFT(SN(I))
            LST(I)=LFT(I)-D(I)
         50 CONTINUE
          7 WRITE(6,70)
         70 FORMAT(6X,'ACTIVITY  DURATION  EARLIEST  EARLIEST  LATEST  LATEST
           X  TOTAL  INTERFERING  FREE',/,26X,'START',5X,'FINISH    START   FI
           XNISH   FLOAT  FLOAT',8X,'FLOAT',/,26X,'TIME',6X,'TIME',6X,'TIME
           X TIME',/)
          8 CONTINUE
            DO 62 I=1,TOTAL
```

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```
0091        61 WRITE(6,60) ACTIV(I),D(I),EST(I),EFT(I),LST(I),LFT(I),TFLOAT(I),PF
              XLOAT(I),FFLOAT(I)
0092        60 FORMAT(7X,I5,5X,I5,5X,I5,5X,I5,4X,I5,3X,I5,4X,I5,3X,I5,6X,I5)
0093        62 CONTINUE
0094       104 CONTINUE
0095       103 CONTINUE
0096           RETURN
0097           END

 *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
 *OPTIONS IN EFFECT*  NAME = CPM      , LINECNT =       56
 *STATISTICS*    SOURCE STATEMENTS =        97,PROGRAM SIZE =      4432
 *STATISTICS*  NO DIAGNOSTICS GENERATED

 *STATISTICS*  NO DIAGNOSTICS THIS STEP
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```
          SUBROUTINE PLOTA(XAXIS,YAXIS,M)
          DIMENSION XAXIS(M),YAXIS(M)
          DIMENSION YSCALE(51),XSCALE(101),LSCALE(101)
          LOGICAL*1 CHART(51,101),LETTER(28),LSL(101)
          DATA LETTER/'A','B','C','D','E','F','G','H','I','J','K','L','M','N
         1','O','P','Q','R','S','T','U','V','W','X','*',' ',' ',' '/
          BTIME=0.
          BCOST=0.
          DO 110 I=1,M
          IF(YAXIS(I)-BCOST) 100,100,11
    11    BCOST=YAXIS(I)
    100   IF(XAXIS(I)-BTIME) 110,110,12
    12    BTIME=XAXIS(I)
    110   CONTINUE
          IF(BCOST.LT.50.) GO TO 13
          LSC=BCOST/50.
          LC=1
          GO TO 120
    13    LSC=50./BCOST
          LC=2
    120   IF(BTIME.LT.100.) GO TO 14
          LST=BTIME/100.
          LT=1
          GO TO 125
    14    LST=100./BTIME
          LT=2
    125   DO 121 J=1,51
          GO TO (126,127), LC
    126   YSCALE(J)=J*LSC
          GO TO 128
    127   YSCALE(J)=J/LSC
    128   CONTINUE
          DO 111 K=1,101
    111   CHART(J,K)=LETTER(26)
    121   CONTINUE
          DO 114 K=1,101
          GO TO (129,130), LT
    129   XSCALE(K)=K*LST
          GO TO 114
    130   XSCALE(K)=K/LST
    114   CONTINUE
          DO 112 I=1,M
          GO TO (131,132), LC
    131   J=YAXIS(I)/LSC
          GO TO 133
    132   J=YAXIS(I)*LSC
    133   GO TO (134,135), LT
    134   K=XAXIS(I)/LST
          GO TO 136
    135   K=XAXIS(I)*LST
    136   IF(J.GT.51.OR.K.GT.101.) GO TO 137
          GO TO 138
    137   WRITE(6,50) J,K
    50    FORMAT(3X,'ITS NOT WORKING',2X,I3,2X,I3)
```

```
              GO TO 51
        138   CHART(J,K)=LETTER(I)
        112   CONTINUE
              WRITE(6,23)
         23   FORMAT('1',3X,'COST IN DOLLARS        GRAPH OF COST VS TIME',/)
              DO 200 K=1,101
              LSCALE(K)=XSCALE(K)
        200   LSL(K)=LETTER(26)
              DO 201 K=1,101
              IF(K.EQ.1) GO TO 201
              IF(LSCALE(K-1).NE.LSCALE(K)) LSL(K)=LETTER(25)
        201   CONTINUE
              DO 113 LJ=1,51
              J=52-LJ
              WRITE(6,20) YSCALE(J),(CHART(J,K),K=1,101)
        113   CONTINUE
         20   FORMAT(' ',5X,F10.0,'+',101A1)
              WRITE(6,22) (LSL(K),K=1,101)
         22   FORMAT(' ',16X,101('+'),/,16X,101A1,///,51X,'TIME IN DAYS')
              IF(LT.NE.1) GO TO 24
              WRITE(6,60) LST
         60   FORMAT(40X,'WARNING- MAX TIME GREATER THAN 100 DAYS  LST=',I3)
         24   CONTINUE
         51   CONTINUE
              RETURN
              END

  *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = PLOTA   , LINECNT =       56
  *STATISTICS*    SOURCE STATEMENTS =        79,PROGRAM SIZE =      9132
  *STATISTICS*  NO DIAGNOSTICS GENERATED

  *STATISTICS*  NO DIAGNOSTICS THIS STEP
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END OF
REEL