Simulation of the loading and hauling subsystems of a logging system
by Leonard Roy Johnson

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in Industrial and Management Engineering
Montana State University
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Abstract:
The logging system consists of five subsystems; namely, felling, bucking, skidding, loading, and
hauling. Productivity of the felling and bucking subsystems depends largely upon the skill of the men
doing the work and can be subjected to a minimum amount of analysis. Skidding represents a materials
handling system that is being subjected to a great deal of technical analysis. Loading and hauling,
however, stand in need of investigation. Both are materials handling systems that need analysis of the
best equipment for a particular situation.

This thesis presents a simulation model that investigates the many variable combinations existing in the
loading and hauling subsystems. Development of the model required two steps: (1) identification of
the events and activities common to loading and hauling subsystems and (2) definition of owning and
operating costs relevant to the two sub-systems. Calculation of relevant costs resulted in the criteria
used to compare the numerous variable combinations. The criteria is a ratio of investment to output
expressed in dollars per thousand board feet of merchantable timber. Identification of appropriate
events and activities allowed use of the simulation language, GASP II, in testing various alternatives.

The result of this investigation is a fully developed model capable of testing alternatives of the many
logging situations in existence. Since any "best" combination depends upon the particular logging
situation being simulated, no general conclusion regarding a single best combination can be made.
Specific results depend on proper data supplied by a model user. The model developed here will then
solve for the results requested by the user.
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Date [June 5, 1970]
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SUBSYSTEMS OF A LOGGING SYSTEM

by

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ABSTRACT

The logging system consists of five subsystems; namely, felling, bucking, skidding, loading, and hauling. Productivity of the felling and bucking subsystems depends largely upon the skill of the men doing the work and can be subjected to a minimum amount of analysis. Skidding represents a materials handling system that is being subjected to a great deal of technical analysis. Loading and hauling, however, stand in need of investigation. Both are materials handling systems that need analysis of the best equipment for a particular situation.

This thesis presents a simulation model that investigates the many variable combinations existing in the loading and hauling subsystems. Development of the model required two steps: (1) identification of the events and activities common to loading and hauling subsystems and (2) definition of owning and operating costs relevant to the two sub-systems. Calculation of relevant costs resulted in the criteria used to compare the numerous variable combinations. The criteria is a ratio of investment to output expressed in dollars per thousand board feet of merchantable timber. Identification of appropriate events and activities allowed use of the simulation language, GASP II, in testing various alternatives.

The result of this investigation is a fully developed model capable of testing alternatives of the many logging situations in existence. Since any "best" combination depends upon the particular logging situation being simulated, no general conclusion regarding a single best combination can be made. Specific results depend on proper data supplied by a model user. The model developed here will then solve for the results requested by the user.
CHAPTER I

LOGGING, MODELS, AND SIMULATION

The timber industry is one of the oldest in the world. Timber has long been used for shelter, transportation, and for other human needs. Before timber can be utilized for any of these needs, however, conversion from a standing tree to a log must take place. The total process composes a portion of what is now known as the timber and wood products industry. The total system consists of several subsystems, one of which is the subsystem for conversion of trees to logs and the subsequent transportation of these logs to some location for further processing. This subsystem, known as the logging subsystem, shall be considered in this thesis as a system in itself.

LOGGING HISTORY

At some time in the history of the logging system there evolved five distinct steps which allowed a standing tree to be converted to a log and later transported to a conversion mill. Felling and bucking make up the first two subsystems of the logging system and together compose the logmaking portion of the logging system. The felling subsystem consists of conversion of a standing tree to either a tree-length log or a log-length log, which is cut to a certain specified length.

Transportation of the logs from the processing point to a cleared area, called a landing, must follow felling and bucking. This
intermediate transportation takes place in the skidding subsystem. At
the landing, loading of long-distance carriers takes place. The loading
process occurs in the loading subsystem, a subsystem which also per­
forms a materials handling function. The final subsystem of the logging
system encompasses the long-ranged transportation of the logs from the
landing to a conversion mill. Transportation for this subsystem,
known as the hauling subsystem, usually takes place on either a logging
truck with trailer or a railroad car. In some instances some or all
of the hauling may take place in water, which would be the case when
logs are floated in a river. Although these five subsystems were
essentially established early in the life of the logging industry,
technical analysis within the industry has been developed only recently.

The technical analysis was needed to evaluate some of the alter­
native equipment and methods in terms of cost savings which they could
offer the logging contractor. The analysis was complicated by a rash
of variables which were difficult to describe and quantify; Hence, in
many cases during equipment investigation, the analysis was restricted
to a certain geographical location. The general state of logging
analysis also had been restricted to certain specific subsystems of the
logging system and generally to certain geographical areas. A great
deal of research in the Northern Rocky Mountain region dealt with the
skidding subsystem. The logmaking subsystems, felling and bucking,
depend almost entirely upon the man doing the work. In the loading
and hauling subsystems little research has been done to date, and
analysis pertaining to equipment choice and system design would be of great benefit. These two phases of the logging system will be analyzed in this thesis.

A technical analysis in any area may be approached from one of two directions. One alternative is to gather data and then design a model to fit and utilize the data. The second alternative involves formulation of a model of the system being analyzed and then gathering of the data necessary to obtain results from the model. The latter alternative probably finds some use in all models. There must be some knowledge of the desired objective and of the direction to that objective in all types of analyses. The degree of model development depends upon several factors, the primary one being the problem of collecting real information and data.

Analysis of the loading and hauling subsystems takes the form of a fully developed model for which little actual data is currently available. Much of the data necessary for utilization of the model will fit only a particular location and logging site. Thus, it is the responsibility of the user to supply information pertinent to his individual problem. Once the user makes an effort to obtain the input data for the model, and thus is forced to make an investigation of his present system, he will be in a better position not only to use and apply the model, but also to make intelligent decisions concerning the total logging system.
If the reader finds information unavailable at this point, he may refer to the data used in the case studies presented later in the thesis. These data are estimates and general averages for the Northern Rocky Mountain region. However, the results presented in the case studies should not be taken as general conclusions for the region without first examining the data used to reach the conclusions. As in all mathematical models, the results will be no more valid than the input used. Even a perfect model could not transform incorrect input into valid results.

Hopefully, this model can be of value in both the academic and logging communities. For this reason terms and symbols common to the logging industry and those common to mathematical model building will both be extensively defined.

MODELS

A beginning of this clarification process demands a more complete definition of the word model. Models of any type attempt to represent reality. They duplicate real world situations, perhaps on a different scale or for a lower cost.¹ A map, for example, is a model of the land area it represents. Most models used in business and industry, however,

take form as mathematical representations of man-machine systems. A mathematical model uses mathematical equations to express relationships among critical elements of the system under study. A model, once formulated duplicates the actual operation of the system through some type of model manipulation. The model user applies results from the manipulation to aid him in making correct decisions.

SIMULATION

Manipulation of mathematical models may take place in several ways. Simulation is one method used to manipulate models and is utilized in this thesis. Simulation involves an effort to reproduce the actual operation of the system, usually over some period of time. Every system consists of a set of parameters including the input, output, processes, feedback-control, and certain restrictions. The parameters are related to each other by certain bonds called relationships. In the mathematical model the mathematical equations express that these relationships. The processes of a system generally consist of certain specific activities. A simulation model duplicates the occurrence of each system activity and the effect the activity will have on other parts of the system. The end of a system activity signals the beginning

---

of a new activity. If a user knows exactly what occurs at the beginning and ending of each activity within an actual system, he can duplicate the system with a simulation model. The beginning and ending of system activities are known as events. For example, if the log carrier arrived at the landing to be loaded, the subsequent activity would be loading. The beginning and ending of the loading activity would be marked by two events. The arrival of the carrier would signal the beginning of the loading activity. The end-of-loading event would signal the end of the loading activity, which would occur after the log carrier was loaded.

Since most system activities consume time, a simulation model generally duplicates the actual system over a certain period of time. For example, the loading of log carriers might be simulated for a week to find the total number of carriers loaded. This would be accomplished by specifying the results and effects of two events; namely, arrival of carriers and end-of-loading of carriers. The arrival event marks the beginning of loading and also schedules the time for completion of loading, or the end-of-loading event. The end-of-loading event marks the end of loading and schedules the next arrival event.

---

The simulation model is developed by specifying the various activities of the system, by determining what events mark the beginning and ending of activities, and finally by designing a set of relationships among events of the system. A description of the simulation model for the loading and hauling subsystems consists largely of an event description. All models must, however, have some objective and criteria by which decisions are made. The objective of this entire study aims at giving the logging contractor a better base for making decisions regarding equipment selection and system design.

The simulation model developed here allows for comparisons of various loader types, number and quality of trucks, and general system designs by indicating which combination gives the least total cost expressed in dollars per unit of productivity.

SUMMARY

Although the actual simulation model can be described in terms of its events and activities, clear understanding of the model demands a more complete description of the variables and cost structure of the loading and hauling subsystems. The succeeding chapters deal with these subject areas. A description of the model and presentation of the case studies follow the chapters just mentioned.
The logging system exists as a subsystem of the timber and wood products industry. As a subsystem, its input arrives from another subsystem of the industry just as its output is delivered to still another subsystem. Input to the logging subsystem arrives from the planning phase of the timber and wood products industry. This system includes forestry research and forest utilization. Consideration of conservation, tree size and maturity, and the regrowth of trees will result in an output of the planning system dictating which trees the logging system can process. This immediately determines the location of the logging site and the maximum volume of merchantable timber. These inputs serve as constraints and restrictions to the logging system.

Output of the logging system is used in a conversion phase of the timber and wood products industry. The conversion phase takes form as one of a variety of processing mills. The mill function may be as simple as fencepost production or as complex as paper processing. Different processing mills require various sizes and types of logs placing still another constraint upon the logging system.

Although the basic logging system remains the same for all locations, volumes, and log destinations, the basic equipment types will vary. This
model simulates logging sites in the Northern Rocky Mountain region where logs are produced for plywood or lumber mills. Modification of the region location would generally involve a change in all data concerned with equipment productivity and reliability. Thus, a first assumption implies that only logging sites within this region were considered. A second assumption holds that log-carriers consist of logging trucks with trailers, which eliminates from consideration use of rivers and rail cars as log carriers. This assumption corresponds to the general practice in the Northern Rocky Mountain region.

Modifying the second assumption involves changing cost information and simulation events associated with the hauling subsystem.

Regardless of assumptions made about the equipment used in the logging system, the basic system will contain the five subsystems mentioned in Chapter 1. The flow of timber through the logging system is shown below in Figure 1. Felling and bucking compose the processing

![Diagram of logging system flow](image)

Figure 1: Flow of timber through subsystems of the logging system
subsystems of the logging system. In these two subsystems, which are generally combined under the heading of logmaking, trees are processed at the stump area. Here, the tree has grown to maturity. Processing of a tree implies converting from a standing tree to a log-length or tree-length log. The entire logmaking process generally requires one or more men, each equipped with a chainsaw. The productivity of the logmaking function depends almost entirely upon the number and the skill of the men involved in the process. Because of this, logmaking has not been subjected to a great deal of analysis and does not appear to require analysis presently.

The logs obtained from the logmaking function must be moved to the processing mill before the logging system can render any value to the total timber industry. Transportation of logs to the mill takes place in three distinct materials handling subsystems. Logs first move from the stump area to the landing in an intermediate transportation function, called the skidding subsystem. As previously mentioned, the landing is some cleared area in the forest where logs may be piled or placed in preparation for loading. The landing provides a more advantageous area from which to load logs. Transportation in the skidding subsystem may take place with one of two broad categories of skidding equipment. In one category, over-the-ground vehicles, called rolling-stock skidders, drag logs from the stump area to the landing. In the second category logs are hauled or "flown" through the
air using overhead lines and special support gear. Within this second mode of transportation, known as yarding, three additional alternatives exist. The alternatives vary chiefly in the number of logs hauled and the type of equipment used. Common to all yarding alternatives is the method used to dispose of logs at the landing. This "method" consists of releasing the grip on the logs allowing them to fall where they may at the landing. On the other hand rolling-stock skidders "deck" logs into piles. This decking operation conserves space at the landing and sometimes provides for faster loading. It also involves a cost. The decking cost is assigned to the cost of loading and hauling as part of the input from the skidding subsystem. Thus the skidding method employed will affect the cost of the loading and hauling subsystems. Use of rolling-stock skidders generally creates a decking cost, but in the yarding alternatives this cost does not exist.

A large amount of research has evolved from the Forestry Sciences Laboratory in Bozeman, Montana.¹ Their research has explored the various skidding methods in detail. Rolling-stock skidders have been

¹This experimental laboratory functions as part of the U. S. Department of Agriculture and has an official address of:
   Forestry Sciences Laboratory
   Montana State University
   Bozeman, Montana 59715
analyzed to obtain the most economical type for a given set of conditions. Yarding operations, including the new concept of balloon yarding, have also received attention and research. Finally, the layout and location of skidding roads and landings were analyzed in previous research. This combined research makes the skidding subsystem a well-researched area.

The two final subsystems of the logging system also involve materials handling. The loading subsystem consists of the movement of logs from log decks, usually found at the landing, to nearby long-range transporters, consisting of trucks or rail cars. Hauling, as the name implies, involves the movement of the logs from the landing to the conversion mill. The logs are unloaded there, by and at the expense of the conversion mill. The loading and hauling subsystems are closely related through the interaction of several variables in each of the subsystems. The primary output of the loading subsystem consists of a load of logs on a long-distance carrier. The output of the hauling subsystem and thus of the logging system consists of the load of logs at the conversion mill. The output rate for both systems, however, depends upon a combination of factors in both the loading and hauling subsystems. An analysis of just one of the systems, therefore, would restrict its contribution to the total logging system. Since little has been done to quantify the various combinations of factors which can exist, the next chapter explores in greater detail the elements of the loading and hauling subsystems.
CHAPTER 3

FACTORS AFFECTING LOADING AND HAULING

The previously mentioned objective of this simulation model centers around the determination of which combination of loading and hauling variables will result in the lowest cost of operation. Simulation analysis, however, will generally not find an optimal solution. The "best" combination resulting from operation of the simulation model will be best only in terms of the alternatives compared. However, use of a systematic approach of comparisons should result in a combination very close to an optimal solution.

LOG DECKS

Continuous introduction of new equipment and methods prohibits a complete description of all loading and hauling factors. However, factors in most general areas will be mentioned in some detail. The position and location of logs at the landing will affect the speed of the loader in picking and sorting logs. This relates to the quality of the log deck, which was briefly described in the previous chapter. Decks may exist in one of three quality classes. Class one decks are analogous to matchsticks in a box, with even ends and all logs parallel. This configuration makes the logs easily accessible and takes up the least amount of space. When some log ends are uneven and not parallel, a class two deck exists. Logs not lying parallel
with the main portion of the deck are said to be jackstrawed. Class three decks have no ends even and are so badly jackstrawed that the major part of the deck is difficult to define.

Intuition suggests that the loader could load faster from a class one deck than from a class three deck. It also suggests that a better deck class would result from a higher decking cost. Therefore, the time and effort used in building a log deck could affect the productivity of the logging system. The actual effect of deck quality will merit further discussion when the cost structure is described.

VOLUME AND TERRAIN

One of the inputs to the logging system, the allowable cut of timber, will affect the best loading and hauling combination. A restricted volume will limit the necessary daily production. Often this limited volume stems from the amount of timber a mill will buy, so that volume may be controlled from two sources. Generally, a limitation from the mill will cause more system slowdown than one from the planning system, since the planning system restrictions will occur before any operations begin in a certain area.

The type of terrain and its main characteristic, slope, affect the type of landing which best suits a situation. Two types of landings exist. A continuous landing uses part of the logging road as a landing, while the alternative, an excavated landing, requires a scraped or cleared area every few thousand yards along the logging road. The
excavated landing provides more area and convenience for loading, but under specific circumstances, involves an extra expense. Above a certain percent slope, an excavated landing is generally too expensive. Exceptions to this rule occur when special equipment requires an excavated landing.

LOADER CATEGORIES

There are six general categories for loaders. Within each category, various sizes and capacities also exist. The category and lifting capacity of a particular loader specify the time needed to load a truck. Lifting capacity depends upon the age and original size of the loader and primarily determines its original cost. A system with a particular set of conditions operates best with a particular loader. The particular loader needed will be one result obtainable from the thesis model.

Loaders in the six general categories have many similarities. All, of course, perform the loading function. With one exception, all have power units which remain stationary while loading. Logs are grasped with some type of pincher or clamp and lifting is accomplished using either cables and a support boom or a hydraulic arm. The exception, a front-end loader, moves with the logs and lifts them with forks attached to its hydraulic arms. To accomplish loading, this unit, usually a crawler or rubber-tired tractor, will move to the log deck, lift one or several logs with the forks, move to the log carrier, and
place the logs on the carrier. The forks operate on the same principle as a "farmhand" on a farm tractor or a blade on the front of a bulldozer.

Of the remaining five loader categories, only one uses a hydraulic arm to load logs. The fully articulated, hydraulic loader is similar to a backhoe, which is normally used for excavating dirt. As the name implies, this loader uses hydraulic principles to accomplish its loading function and can maneuver its hydraulic arm in almost any direction. Because of its maneuverability, the loader works very fast. Its original productivity is generally the greatest of all loader categories.

A loader with air or hydraulic pinchers employs some of the principles of a fully articulated, hydraulic loader, but varies in size and in operation of the lifting arm. Only the pinchers are hydraulic in this third loader category. Since the smallest loaders are generally found in this category, they are usually mounted on some other vehicle for movement. Hydraulic pinchers grasp the log and a steel boom accomplishes lifting. Since most loaders in this category are small, the timber size will greatly affect a decision to use it.

Loaders in the three remaining categories use cables and either tongs or a gravity grapple to accomplish loading. Loaders in two of the categories possess a feature known as a heelboom to facilitate lifting of logs. Hence, the loader categories are named "heelboom with gravity grapple" and "heelboom with tongs." The heelboom with gravity grapple employs a grapple to pick up logs. This grapple opens and subsequently holds logs because of the gravity principle. The logs
are lifted and shortly butted into the heelboom. Then the logs, heelboom, and usually the power unit pivot together on a support base with the logs eventually being placed on the carrier.

The heelboom with tongs lifts logs and places them on carriers in the same manner as the heelboom with grapple. If tongs are used, however, an extra man, called a tongsetter, must be employed. He hooks the tongs into the logs before they are lifted to the carrier. These tongs resemble ice tongs and can pick up only one log per loading cycle.

Loaders in the remaining category are named long-boom loaders. Essentially long-boom cranes with gravity grapples attached, they are used in steep terrain. The extra length of the boom gives it the added capability of reaching logs from scattered decks without repositioning as often. If this special situation does not exist, the long-boom loader might be slower and more expensive than loaders in other categories. Sketches of the various loader categories are shown in Figure 2.

Within each loader category appear four distinct sizes. In reality the variance in specifications of different loader brands prevent the sizes from becoming exclusive classifications. The sizes, however, should represent general classes into which most loaders can be fitted.

Determining the best loader size presents another problem for the simulation model. The timber size eliminates some loader sizes immediately. If a loader cannot lift a single log, that particular size classification can be eliminated. A loader may be over or under-designed when related to timber sizes and productivity. An over-
(a) Fully Articulated Hydraulic Loader
(b) Loader with air or hydraulic pinchers
(c) Heelboom loader with gravity grapple
(d) Heelboom loader with tongs
(e) Front-end loader
(f) Long-boom loader

Figure 2: Sketches of Loaders in the Six Categories
capacity loader wastes the loading potential not used, whereas, an under-capacity loader will not perform its required task.

TRUCK FACTORS

Loader activity depends upon the presence of log carriers at the landing. The number of log carriers in the system affects the time a loader is idle. Hence, the number of carriers also affects the number of loads produced in a day. The best number of log carriers to employ in the system depends partially upon a balance between the cost to own and operate additional log carriers and the income derived from the increased productivity.

As previously mentioned, trucks are used as log carriers in this model. Six model categories exist also for truck types. These categories follow a cost breakdown, since all models have the same log capacity. The first category encompasses all used trucks. The other five categories are classified in cost groups ranging from $10,000 to $30,000. This cost refers to the original cost of the tractor portion of the logging truck.

The number of daily trips made by logging trucks also depends upon the distance between the logging site and the conversion mill. Related to travel to and from the landing is the road condition. Consider three road classifications: pavement, primary road, and spur road. Pavement, as the name implies, consists of a paved surface highway. Primary road consists of a graveled surface road which, if on
forest service land, is built to forest service specifications. The road leading from the primary road to the landing is called a spur road. Each road type implies an average speed for logging truck travel. Thus, with distance, average speed, and an allowance for delays specified as input data, the maximum number of trips per day for any single truck can be determined.

**SYSTEM DESIGN**

The method used to schedule the truck arrivals at the landing will affect loader idle time. An improper schedule may create a queue of trucks at certain times and at other times may cause excess loader idle time.

Normally, hauling takes place on a logging truck with a standard trailer. The standard logging trailer needs the rear part of the tractor to complete the trailer system. This combination, once loaded, forms a unit which cannot be separated until completion of unloading. This situation means that the truck-trailer unit must make a complete round trip to and from the landing.

A modification kit for the standard trailer makes it possible for the tractor and trailer to become separable units. This kit adds expense to the original truck-trailer cost, but might be compensated with added versatility in the logging system. Fully loaded trailers can be unhooked at any location. This new dimension allows trucks to haul trailers to and from an intermediate location called a prehaul.
dock. Usually several trucks serve as highway trucks to haul trailers to and from the mill. One or two trucks also pull trailers to and from the landing. Because these trucks, called shuttle trucks, have less distance to travel to the landing, the number of loads produced in a day generally increases.

Use of the prehaul trailers results in the addition of three other variables to the system. Where previously the total number of trucks was considered, now this variable must be subdivided into the best number of shuttle and highway trucks. Additionally, the location of the prehaul dock should facilitate the greatest number of trips in a day. Finally, consideration must be given to the possibility of keeping extra prehaul trailers in the system. Essentially, these would serve as intermediate inventory for the system and permit some lag and delay in truck schedules. These three variables exist only for cases with prehaul trailers, but will merit consideration in those cases.

There is a further modification of the hauling systems whereby a preload bunk remains at the landing. Preload bunks provide the loading subsystem with the capability of producing when no trucks are at the landing. Rather than loading trucks, the loader fills the preload bunk with a load of logs. When trucks arrive at the landing, they are loaded by lifting the loaded bunk with jacks, backing the truck under the bunk, and lowering the bunk load onto the truck. Once the preload bunk has been filled, the loader remains idle until a truck
arrives to pick up the bunk load. Savings result from decreased truck
time at the landing. This will reflect some change in loader pro-
ductivity, since decreased time at the landing might allow another daily
trip for a particular truck.

SUMMARY

A single combination of the above variables implies an associated
owning and operating cost. The minimum cost, in turn, implies the
best combination. Costs associated with each variable are detailed
in the cost structure of this model, which is discussed in the next
chapter.
CHAPTER 4

DESCRIPTION OF COST STRUCTURE

As well as incurring a certain cost, each combination of the variables mentioned in the previous chapter can also produce a certain volume of timber. Timber volume represents system productivity usually expressed in board feet or thousand board feet. A board foot, the common volume expression in logging, is a piece of green lumber one foot long, one foot wide, and one inch deep. When a large volume of timber is under consideration, a thousand board feet generally represents a volume unit. The thousand board feet unit will be expressed in its common symbol notation, MBF. The decision criterion, previously mentioned as cost in dollars per unit of productivity, can be more explicitly defined as cost in dollars per MBF. It therefore represents a ratio of investment to output and is a criterion common to logging research. The variable names found throughout the remainder of this thesis are expressed in the same form used to identify them in the computer program.

TOTAL COST PICTURE

Calculation of the total cost to own and operate a unique loading and hauling combination necessitates development of a cost model which includes all cost elements. Although the development results in a model, it shall be called the cost structure to avoid confusion with
the simulation model. The cost structure includes all elements from decking cost to the cost of truck idle time at the conversion mill. The inclusion of decking cost accounts for the cost to deck logs, but not the cost to skid logs to the landing. The inclusion of truck idle time at the mill accounts for the cost for the idle time incurred while the truck was being unloaded, but not the actual unloading cost. Total cost is formed from five subcosts: the cost of decking, the actual loading cost, the cost of loader breakdowns, the cost of loader unproductive time incurred while waiting for trucks, and the cost to own and operate a certain number of trucks. These costs, respectively named COST 1, COST 2, COST 3, COST 4, and COST 5, are added to obtain total cost, CSTOT. Figure 3 on the following page depicts these five costs in the cost structure form.

COST 1: COST OF DECKING

Decking occurs after logs have arrived at the landing and cables holding the logs have been unhooked. The three deck classifications and their probable effect on loader productivity were mentioned in Chapter 3. Little data is currently available to support the proposition that an improved log deck will increase loader productivity. A relationship between deck quality and loader productivity is not included in this thesis, but establishment of this relationship presents an area for future investigation. Inclusion of the decking cost exists principally as a tie-in to the skidding system. Except when rolling-stock skidders
Figure 3: Cost structure used to calculate the total owning and operating cost incurred by system variables.
are used, the decking cost is zero. Yarding subsystems generally do not involve any decking activity. Rolling-stock skidders, however, incur a decking cost, equal to the owning and operating cost incurred during the decking time.

Several factors affect the owning and operating cost of a skidder while it is decking logs. These factors include the cost to own and operate the skidder, the wage of the skidder operator, and his skill rating. The percent of a skidding day spent decking logs must also be known. Finally, the average number of skidding trips per hour and the average timber volume hauled each trip need to be supplied.

The decking cost, COST I, will depend initially upon the skidding system being used. A calculation is made only if rolling-stock skidders are used. For other skidder types, this cost becomes zero. Calculation of COST I, expressed in dollars per MBF, involves division of the owning and operating cost in dollars per hour by the productivity in MBF per hour. This is shown below in equation 1.

$$\text{COST I} = \frac{\text{WGSO} + \text{COOS}}{\text{SCPH} \times (0.10 \times \text{PDS}_{12}) + (0.90 \times \text{PDS}_{11})}$$

(1)

where:

- COST I = the decking cost in dollars per MBF;
- WGSO = the wage of the skidder operator in dollars per hour;
- COOS = the owning and operating cost of the skidder in dollars per hour;
SCPH = the average number of skidding cycles per hour made by the skidder, where a skidding cycle is a round trip from the landing to the woods;

PDS12 = the productivity of the skidder in MBF per skidding cycle per hour when logs are decked to a class two deck; it is multiplied by 0.10 since approximately ten percent of the skidder's decks are class two;

PDS11 = the productivity of the skidder when logs are decked to a class one deck, where approximately ninety percent of the skidder's decks are class one decks.

WGSO, COOS, and SCPH must be specified as data in the model. They represent carryovers from information necessary in the skidding subsystem. The estimates of the percent of the number of decks in each quality class were obtained from observations of rolling stock skidders. They could be changed or made variables of the model if the current estimates are not valid for a particular situation. Determination of PDS12 and PDS11 necessitate two further calculations shown in equations 2 and 3.

\[ PDS12 = \frac{SVPC}{(TQ2/60.0)} \times RTSO, \quad (2) \]

and

\[ PDS11 = \frac{SVPC}{(TQ1/60.0)} \times RTSO, \quad (3) \]

where:

PDS12 and PDS11 are as previously defined;
SVPC = the skidding volume per cycle, which is the average timber volume skidded to the landing each trip;

TQ2 = the time in minutes required to deck logs into a class two deck;

TQL = the time required to deck to a class one deck;

RTSO = the skill rating of the skidder operator expressed as a percent where 100% is considered average.

The relationship of the factors involved in the cost of decking are shown in Figure 4 on the following page. Output of the decking phase is a log deck of a certain quality. This deck quality will, in reality, have some effect on productivity of the loader. However, this simulation model assumes that the effect is negligible.

COST 2: THE LOADING COST

The second sub-cost accounts for all costs incurred while the loader is actually loading carriers. Because it is expressed in dollars per MBF, the total cost for a certain time period must be divided by the timber volume loaded in that period. Primary factors affecting COST 2 include the loader productivity expressed in MBF per unit time, the operating cost of the loader, the cost to own the loader, the cost to build extra landings, and finally the cost resulting when weather prohibits normal operations. The relationship of these factors is shown in Figure 5.
Figure 4: Factors affecting COST 1, the decking cost
Figure 5: Factors affecting COST 2, the actual loader cost of loading
Calculation of loader productivity, usually expressed in MBF per unit of time, depends upon proper identification of the effects of several elements. The effect of some of these elements has been assumed to be negligible. For instance, the deck quality and landing characteristics probably have an effect on loader productivity, but all their effects are not included in this model. The probable effect and assumption concerning deck quality received attention earlier. Landing characteristics are chiefly defined in terms of the alternatives which exist: continuous landings and excavated landings. The effect of landing type is included only for front-end loaders. This loader needs a relatively level landing, and therefore, sometimes incurs a cost for the building of the landing. The landing cost is treated more extensively in a later part of this chapter.

Factors having a definite contribution to loader productivity include the original productivity of the loader, the age of the loader in years, and the skill rating of the loader operator. Original productivity reflects the ability of a loader to load logs when it is new, and is dependent upon loader size and type. Loader size and type determine the lifting capacity of the loader, and hence, the number of logs which can be lifted per cycle.

As the loader grows older, its lifting capacity will likely decrease. This reflects loss of power in the engine and wearout of loader parts. When the loader's capacity to lift logs decreases, its productivity must necessarily decrease.
The skill rating of the loader operator is one of the most difficult elements to measure and probably has the greatest effect upon loader productivity. The rating is expressed as a percent with 100 percent representing the normal operator as defined by time study specialists. Productivity relates directly with the operator rating. A 20 percent increase in the operator rating would result in a 20 percent increase in productivity. A pictorial description of these relationships is shown in Figure 6.

Figure 6: Factors affecting loader productivity
Productivity is expressed in MBF per unit of time. In this model, the unit of time used is a year. Calculation of yearly MBF necessitates recording the number of loads produced in a year. Multiplication of yearly loads by the average MBF per truck produces MBF per year, the productivity of the loader. This result does not account for the allowance that must be made for the portion of timber that cannot be utilized. The merchantable volume of timber on any truck load does not equal the total timber volume. Subtraction is made for that part which has some defect. Defects usually take such forms as rot, breakage, splits, crooks, and knots. It can generally be expressed as a percent defect common to a certain location and tree species.

Knowledge of the above variables can result in the calculation of productivity as

$$\text{PRODL} = (\text{AVMBF} \times \text{LOADS}) \times (1 - \text{DEFCT}),$$

where:

- $\text{PRODL}$ = the productivity of the loader in MBF per year;
- $\text{AVMBF}$ = an average truck load expressed in thousand board feet per truck and is part of the data of the model;
- $\text{LOADS}$ = the total number of truckloads produced in a year, as determined in the simulation model;
- $\text{DEFCT}$ = the average percent defect in logs which is used to degrade actual volume to useful volume and is obtained from data of the model;
Age and original productivity of the loader and the skill rating of its operator are accounted for in a part of the computer program where determination of the length of time needed to load a truck takes place. The time in minutes is found in the part of the program named XDTM. The principal calculation made is shown in equation 5.

\[
XDTM = \frac{OPDV}{RTLO}\left(LCAT, NYEAR, ISV, ICLAS\right),
\]

where:

\[XDTM\] = the loading time of a truck in minutes;

\[OPDV\left(LCAT, NYEAR, ISV, ICLAS\right)\] = the time in minutes required to load a truck with an average load with a loader in category LCAT, of age NYEAR, in an original size class ISV, when timber has an average diameter in timber class ICLAS;

\[RTLO\] = the skill rating of the loader operator expressed as a percent with 100% being average.

The values of OPDV and RTLO are fed into the model as data. ICLAS, a subscript of OPDV, is data characteristic of a specific location. NYEAR varies as the simulation progresses in time. LCAT and ISV are variables of the model and will vary as different cases are studied.

The method used here to determine loading time represents a first attempt to quantify productivity of a loader affected by the factors mentioned above. A more complete explanation of the method used to
obtain loading times is given in Appendix I. Loader productivity remains an area for future research. When such research follows, the simulation model should be modified to incorporate factors which better depict an actual situation.

**Loader Operating Cost**

The cost of operating a loader includes effects from several sources. The original productivity of the loader, generally related to loader size, will influence the fuel consumption of the loader. A large loader usually requires more fuel than a small one. Loader age is linked with preventive maintenance which is necessary to keep a loader in good condition.

Other factors affecting loader operating cost relate more directly to the actual cost. These include fuel and maintenance costs. Fuel information, which is part of the data of the model, contains fuel cost, fuel consumption, and a variable stating whether the loader is gasoline or diesel powered.

Fuel cost is expressed in dollars per gallon of fuel. Data include both the cost of diesel fuel, called FLCTD, and the cost of gasoline, called FLCTG. Fuel consumption, named FLCNL, must be stated in gallons per brake horsepower per operating hour. Brake horsepower, generally called BHP, describes the power of a particular engine. Thus, specification of fuel consumption in this manner allows for the inclusion of loader size as an operating cost factor. In the simulation model
FLCNL is converted to fuel consumption in gallons per operating hour by multiplying it with the brake horsepower of a particular loader. This calculation is shown in equation 6.

\[ FLCN = FLCNL \times BHP_{(LCAT, ISV)} \]  

(6)

where:

- \( FLCN \) = the fuel consumption in gallons per operating hour for a loader in category LCAT and in size class ISV;
- \( FLCNL \) = the fuel consumption in gallons per BHP per operating hour as described above as part of the data of the model;
- \( BHP_{(LCAT, ISV)} \) = the brake horsepower of a loader in category LCAT and in size class ISV.

Total fuel cost is calculated over the unit time period, in this case a year. The calculation is shown in equation 7.

\[ FLCSL = \left[ FLCTD \times VDFL_{(LCAT)} + (FLCTG \times VGL_{(LCAT)}) \right] \times FLCN \times AOPHL, \]  

(7)

where:

- \( FLCSL \) = the total fuel cost for the unit time period;
- \( FLCTD \) = the cost of diesel fuel expressed in dollars per gallon;
- \( VDFL_{(LCAT)} \) = variable specifying whether diesel fuel is used to power the loader in category LCAT such that if \( VDFL \) is 0, diesel fuel is not used, whereas a 1 indicates use of diesel fuel;
- \( FLCTG \) = the cost of gasoline expressed in dollars per gallon;
VGL\textsubscript{(LCAT)} = a variable specifying whether gasoline is used to power the loader in category LCAT where a 0 indicates gasoline is not used, a 1 indicates use of gasoline;

FLCN = fuel consumption in gallons per operating hour as described earlier;

AOPHL = actual operating hours of the loader per year considering that the loader loads only a fraction of the year.

Calculation of actual loader operating hours takes place at the end of each simulated year. The total scheduled operating time minus the total idle time will yield the actual operating time. Although costs and productivity are calculated with a year as the basic time unit, within the simulation model time must be kept on a smaller scale. Here, a minute is the smallest element of time. Thus, when actual operating time is found it must be divided by 60 to convert from minutes to hours. The calculation of AOPHL is shown below in equation 8.

\[
AOPHL = \frac{TNOW - TENYR - TLIT}{60.0} \quad (8)
\]

where:

AOPHL = actual operating hours of the loader;

TNOW = the simulation time in minutes at the end of the year;

TENYR = the simulation time in minutes at the beginning of the year (or end of the previous year) implying that (TNOW - TENYR) yields the number of minutes in the year;
TLIT = the total number of minutes the loader was idle during the year.

Note in equation 7 that VDFL and VGL have a mutually exclusive relationship. If one has the value zero, the other must be one. Thus, if VDFL were zero, VGL would have to be one.

The effect of age on the fuel consumption of the loader is not accounted for in this thesis. Little data is available to justify formulation of a relationship. The model uses an average fuel consumption for all ages and categories of loaders. Investigation of the relationship of these factors presents another area for future research.

The cost of preventive maintenance, in this model, is expressed as the yearly expense necessary to keep the loader in good condition. Expression of the cost in this manner does not reflect the relationship between age and preventive maintenance cost, but does introduce the area as one also requiring future research. If a relationship between preventive maintenance and age were found, the amount of preventive maintenance could become a variable of the system and a search would be made to find the best maintenance schedule. As the model now stands, yearly preventive maintenance expenditure, called XMNCL, is read in the model as data.

The factors just mentioned that affect the operating cost are shown in Figure 7.
Calculation of the cost to operate the loader takes form as

\[ CSOPL = FLCSL + XMNCL + (AOPHL \times WGLO) + (AOPHL \times WGTS \times TSV_{LCAT})^0 \]

where:

- \( CSOPL \) = the cost to operate the loader in dollars per year;
- \( FLCSL \) = the cost for fuel during the year expressed also in dollars per year;
- \( XMNCL \) = preventive maintenance expenditures in dollars per year;
- \( AOPHL \) = the actual loader operating hours during the year expressed as hours per year;
- \( WGLO \) = the wage of the loader operator expressed in dollars per hour;
- \( WGTS \) = the wage in dollars per hour of the tongsetter whenever a heelboom with tongs is employed;
$TSV_{(LCAT)}$ = a variable specifying whether a tongsetter is needed for a loader in category LCAT, where $TSV$ is zero for all but the heelboom with tongs, when it takes the value one.

Although the wages of the loader operator and tongsetter are included in the operation cost, they could just as easily be identified as factors directly affecting the loading cost. They are included in the calculation of the cost to operate for convenience.

**Loader Owning Cost**

The loader accrues a cost every hour of the day. Called the owning cost, it is usually expressed in dollars per hour. Hours used to calculate the owning cost may include every hour of the day or just the scheduled operating hours. Although the cost actually continues through the entire day, charging it only to scheduled work hours places a larger penalty on system idle time.

Owning costs include the cost of depreciation, the cost of equipment insurance, interest cost, the cost of taxes, administrative costs, and the cost of workmen's compensation insurance. To obtain owning cost in dollars per scheduled work hour one divides the yearly total of the above costs by the scheduled work hours in a year. These factors are shown in Figure 8.
Figure 8: Factors affecting the cost to own the loader

**Depreciation** Depreciation cost accounts for the decreasing value of equipment due to age or use. The total cost of depreciation equals the difference between the purchase price of the equipment and its selling price after being used for a certain period of time. This resale price, generally called the salvage value, can be expressed as a percent of the purchase price. Calculation of depreciation cost in dollars per hour requires knowledge of the economic life of the equipment in years and the scheduled operating hours per year. Once these are known, a
straight-line method of depreciation can be used to solve for the depreciation cost. The reasons for using this depreciation method are explained later.

Economic life of equipment is the period of time when the equipment is used for its intended job. It ends when degradation to a new service or liquidation occurs. It can also be defined as the time over which the equipment has its lowest uniform equivalent annual cost. The two definitions support each other, but the first is more applicable in this thesis. Economic lives used here consist of averages based upon general observations of persons familiar with logging operations. Little effort has been made to date to establish economic lives according to the second definition. The simulation model developed here could probably be modified to provide answers to this problem and presents another area open to future research. Economic lives in use here, however, are fed into the model as data.

Logging operations depend, in a manner similar to construction work, upon the weather and the season of the year. Daily working hours and working days per month are affected by the particular month of the year. Estimates of these values were made for each month of the year from which a calculation of the expected yearly operating hours resulted. These were also part of the model data.

---

Estimates of the working days in a month accounted only for the season of the year. Monthly weather patterns received consideration in another part of the model. Estimates of the probability that a day's weather would permit work were fed into the model as data. The probabilities considered the likelihood of rain, that days would be too cold, and that spring thaw would make the ground impassable. Consideration of weather in this manner represented a more realistic situation since bad weather would be as equally likely during a busy time as during a breakdown period.

The estimates of scheduled operating hours and monthly weather probabilities used in this thesis are shown in Figure 9 on the following page. In agreement with the first assumption of this model, these estimates correspond to the situation in the Northern Rocky Mountain region.

Straight-line depreciation implies that equipment value decreases uniformly from the time of purchase to the time of disposal. It is calculated using purchase price, salvage value, economic life, and expected yearly operating hours. It exists as the simplest of several depreciation methods. Other methods generally employ an accelerated depreciation form whereby the largest amount of depreciation is charged in the earliest years of equipment life. The chief advantage of accelerated depreciation lies in the tax savings which can result.²

²Taylor, op. cit, pp. 292-332.
<table>
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<th>Month</th>
<th>Average Operating Hours Per Day</th>
<th>Working Days Per Month</th>
<th>Scheduled Working Hours Per Month</th>
<th>Probability Day's Weather Is Good</th>
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<td>18</td>
<td>72.0</td>
<td>0.72</td>
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</tbody>
</table>

Total for Year  

|             | 254 | 2040.6 |

Figure 9: Scheduled working days and expected good weather for each month. The data is for the Northern Rocky Mountain region.  

---

This data was obtained from estimates made by staff members of the Forestry Sciences Laboratory and should be adjusted to fit particular logging situations.
Because of the simplicity of straight-line depreciation and its common use in the logging community, however, it will be adopted in this model. If a particular user simulates a situation in which accelerated depreciation is normally used, program modifications may be made in the portion used for depreciation calculations. The present calculation is shown in equation 10.

\[
\text{DEPR} = \frac{\text{CDV} - (\text{SVL}(\text{LCAT}) \times \text{CDV})}{\text{USL}(\text{LCAT}) \times \text{EYOH}},
\]

where:

- \text{DEPR} = \text{depreciation cost in dollars per hour};
- \text{CDV} = \text{the purchase price of the loader};
- \text{SVL}(\text{LCAT}) = \text{the salvage value of the loader in category LCAT expressed as a percent of the purchase price};
- \text{USL}(\text{LCAT}) = \text{the salvage value of the loader in category LCAT expressed as a percent of the purchase price};
- \text{EYOH} = \text{the expected yearly operating hours representing the scheduled work hours in a year}.

Cost of insurance, interest, and taxes. Equipment insurance cost, generally expressed as a percent of the equipment's book value, is combined in this model with the cost of interest and the cost of taxes. Since all three costs are expressed as percents, combination of the three results in a single percent, called TIIPR. This combination procedure is in agreement with the suggested method of some equipment manufacturers, such as Caterpillar Tractor Company. Calculation of the total cost of
Insurance, interest, and taxes requires summation over the economic life of the equipment of TII/PR multiplied by the book value of the loader in each year of the loader's life. The expression \( \sum_{i=1}^{n} x_i \) represents the summation of all "\( x \)" values from 1 to \( n \). Using this expression, the calculation of the cost of insurance, interest, and taxes takes the form shown in equation 11.

\[
CINS = \sum_{i=1}^{n} (\text{TII/PR} \times \text{VALUE}_i),
\]

where: \( n = \text{USL(LCAT)} \)

where:

- \( CINS \) = the total cost of insurance, interest, and taxes over the life of the loader;
- \( \text{USL}(\text{LCAT}) \) = the economic life in years of a loader in category LCAT;
- \( \text{TII/PR} \) = the yearly cost of insurance, interest, and taxes expressed as a percent of book value, TII/PR is fed into the model as data;
- \( \text{VALUE}_i \) = the book value of the loader in the \( i^{th} \) year of its economic life.

Book value of the loader in any year "\( i \)" is found by subtracting yearly depreciation, DEPRY, from the book value in the previous year, \( (i-1) \). Thus for year two the book value of the loader would be

\[
\text{VALUE}_2 = \text{CDV} - \text{DEPRY},
\]

(12)
where:

\[ \text{VALUE}_2 = \text{the book value of the loader in year two}; \]
\[ \text{CDV} = \text{the purchase price of the loader}; \]
\[ \text{DEPRY} = \text{the yearly cost of depreciation}. \]

In general, the book value in any year \( i \) will be

\[ \text{VALUE}_i = \text{VALUE}_{i-1} - \text{DEPRY} \]  
(13)

or

\[ \text{VALUE}_i = \text{CDV} - (i \times \text{DEPRY}). \]  
(14)

Administrative cost. The administrative cost, which includes the cost of paperwork, supervision, and other miscellaneous items, is also expressed as a percent of the book value of the loader. Thus, calculation of total administrative costs takes place in a manner similar to the calculation of the cost of insurance, interest, and taxes; namely,

\[ \text{ADMC} = \sum_{i=1}^{n} (\text{ADMPR} \times \text{VALUE}_i), \]  
(15)

where: \( n = \text{USL(LCAT)} \), and

where:

\[ \text{ADMC} = \text{the total administrative cost over the economic life of the loader}; \]
\[ \text{USL(LCAT)} = \text{the economic life of a loader in category LCAT}; \]
\[ \text{ADMPR} = \text{the yearly administrative expense expressed as a percent of loader book value}; \]
\[
\text{VALUE}_i = \text{the book value of the loader in the } i^{\text{th}} \text{ year of its economic life},
\]

\textbf{Workmen's Compensation.} Cost of workmen's compensation insurance is another element of loader owning cost calculated from a percent insurance rate. In this case, however, the percent charge for insurance is multiplied by the sum of the wages involved in the loading system. These wages include the wage of the loader operator and the tongsetter. Cost of workmen's compensation insurance is shown calculated in equation 16.

\[
\text{WCOMP} = \left[ \text{WGLO} + (\text{WGTS} \times \text{TSV}_{(\text{LCAT})}) \right] \times \text{WCPPR}, \tag{16}
\]

where:

- \(\text{WCOMP}\) = the cost of workmen's compensation insurance in dollars per hour;
- \(\text{WGLO}\) = the wage of the loader operator in dollars per hour;
- \(\text{WGTS}\) = the wage of tongsetter in dollars per hour;
- \(\text{TSV}_{(\text{LCAT})}\) = a variable specifying whether a tongsetter is needed when category LCAT is in use;
- \(\text{WCPPR}\) = the percent of the wages which must be paid by the employer for workmen's compensation insurance.

\textbf{Summary.} Knowledge of the elements of the owning cost result in

\[
\text{COSWL} = \text{WCOMP} + \frac{\text{CDV} + \text{CINS} + \text{ADMC} - (\text{SVL}_{(\text{LCAT})} \times \text{CDV})}{\text{EYOH} \times \text{USL}_{(\text{LCAT})}}, \tag{17}
\]
where:

\[ CSOWL = \text{the cost to own the loader in dollars per hour}; \]
\[ WCOMP = \text{the cost of workmen's compensation insurance in dollars per hour}; \]
\[ CDV = \text{the purchase price of the loader}; \]
\[ CINS = \text{the total cost of insurance, interest, and taxes over the economic life of the loader}; \]
\[ ADMC = \text{the total administrative expense incurred during economic life of the loader}; \]
\[ \text{USL(LCAT) = the economic life of a loader in category LCAT expressed in years.} \]

The loader owning cost applies not only to the loading cost, but also to the cost of breakdowns and loader idle time. Here, it must be charged to loading cost for every minute of actual operation.

Cost of Extra Landings

The continuous and excavated types of landings received some attention in Chapter 3. Below a specific slope, excavated landings find the most general use. Above this slope they are rarely found, generally because of the expense required to build them. For all but one of the loader categories, productivity from a continuous landing is assumed to be the same as productivity from an excavated landing. The one exception, a front-end loader, needs an excavated landing in which to maneuver to and from a carrier. Therefore, for
all loaders except the front-end type, any cost for landings will be
the same and need not be included in cost of operations. Another
reason for exclusion of the landing cost relates to the general
situation surrounding excavated landings. Usually they utilize
relatively level areas, which are more common in less steep terrain,
and thus, actually require little actual excavation.

The need for an excavated landing by a front-end loader neces­s-
sitates building it at a cost which would not be incurred if another
loader type were used. This model assumes that the cost of landings,
CLND, is incurred only when using a front-end loader and when working
in terrain above a 40 percent slope. If the cost of building landings
is CLMSC and the number of landings built in a year is NLAND, the
yearly landing cost results from

\[ CLND = CLMSC \times NLAND. \]  

(18)

Cost of Bad Weather

Occurrence of bad weather prevents normal operations. Since the
hours spent idle were originally scheduled as operating hours, the
cost to own the loader must be charged as a cost of bad weather. Work
takes place during bad weather, however, if repairs are being made on
the loader. Subtraction of the time when both the loader was broken
down and weather was bad from the total minutes of bad weather yields
amount of time charged for idle time due to weather. The cost is calculated as

\[ \text{CWTHR} = \frac{\text{DIDIT} \times \text{CSOWL}}{60.0} \]

where:

\( \text{CWTHR} \) = the cost per year for idle time which was caused by bad weather;

\( \text{DIDIT} \) = the time in minutes that the system was idle because of weather;

\( \text{CSOWL} \) = the cost to own the loader in dollars per hour calculated as shown earlier.

Summary: Calculation of COST 2

The cost factors just mentioned, when found in dollars per year, are divided by yearly productivity yielding a cost in dollars per MBF. This cost represents the actual loading cost, COST 2. COST 2 portrays the minimum loading system cost possible in this model. If the loader incurred no breakdowns and had no idle time, this cost would represent the total for the loading subsystem. COST 2 is calculated as shown in equation 20.

\[ \text{COST 2} = \frac{\text{CSOPL} + (\text{CSOWL} \times \text{AOPHL}) + \text{CLND} + \text{CWTHR}}{\text{PRODL}} \]
where:

\[
\begin{align*}
\text{COST 2} &= \text{the loading cost expressed in dollars per MBF;} \\
\text{CSOPL} &= \text{the loader operating cost calculated in dollars per year;} \\
\text{CSOWL} &= \text{the owning cost of the loader in dollars per hour;} \\
\text{AOPHL} &= \text{the actual number of hours spent loading logs;} \\
\text{CLND} &= \text{the yearly cost to build extra landings;} \\
\text{CWTHR} &= \text{the yearly cost of idle time caused by bad weather;} \\
\text{PRODL} &= \text{the productivity of the loader specified in MBF per year.}
\end{align*}
\]

COST 3: COST OF LOADER BREAKDOWNS

Loader breakdowns primarily affect the third cost, COST 3. It involves two distinct subcosts; namely, the cost of the unproductive time caused by the breakdown and the cost to repair the breakdown.

Cost of Unproductive Time

Unproductive time is associated individually with each person and piece of equipment in the system. The unproductive time of a loader in a day will not necessarily equal the unproductive time of the operator. Unproductive time defines scheduled work time in which no productive activity takes place. The cost associated with unproductive time includes a sum of all costs which continue in spite of an idle system.
The total unproductive time connected with a loader breakdown is noted as the duration of the breakdown. It further separates into two elements—repair time and the time spent waiting for parts. Factors affecting the cost of loader unproductive time may continue for the duration of the breakdown or may only apply to one of its elements. Wages of the loader operator and tongsetter, the cost to own the loader and trucks connected with the loader, and an intangible cost of delay to the system comprise the elements affecting the cost of unproductive time.

The loader operator generally repairs loader breakdowns. He may require some outside help, but will always be involved in the repair job. The loader operator will be productive, therefore, while the rest of the system is idle. He is charged some unproductive time only while waiting for parts. A fraction of this time will even be spent in productive activity. This results from assignment of the operator to some other task where his useful work is a fraction of his normal output. The percent utilization of the operator, called ULELO, is estimated and fed into the model as data. The percent of the loader operator, and hence his wage, not utilized is charged to the cost of unproductive time.

Other personnel made idle by the breakdown are utilized in a similar manner but for the entire duration of the breakdown. The tongsetter, if one is used, and the truck drivers will be assigned to
other tasks where their output will be a fraction, ULE, of their normal output. The percent of these wages which is not productive is charged to the cost of unproductive time.

The cost to own the loader continues through the duration of the breakdown, and its unproductive time contributes to the cost of the breakdown. It is the same as calculated for COST 2, that being CSOWL.

Trucks originally assigned to an inoperable loader will either become idle or be partially utilized elsewhere. The percent of the time trucks can be utilized elsewhere is labeled ULTRK. The portion of truck time not utilized is multiplied by the cost to own the trucks and then added to the cost of the breakdown.

A breakdown of a critical piece of equipment, such as a loader, generally causes problems stemming from the resulting production delay. The cost of the system delay is very difficult to measure since it must account for effects, not only in the loading and hauling subsystems, but also in the entire logging system and its other components subsystems. Examples of factors affecting this delay cost are the extra cost of overtime needed to make up work, the possible cost of rot in timber due to the delay, and the cost of pushing a completion date back from its intended time. Some or all of these, or other examples could exist for each loader breakdown making any determination of such a cost very difficult. The cost of a delay is recognized, but in this model it is assumed to be the same for all situations. Thus, the comparative value of the model will still be
valid unless the duration of breakdowns varies significantly under different combinations. Under current model assumptions, this should not occur.

Breakdowns in all equipment range from minor to major. A minor breakdown would probably not last as long nor cost as much as a major breakdown. In this model breakdowns were classified into three distinct severity levels. Level one represents a minor breakdown with the least duration, repair time, and cost of parts. Level two corresponds to an intermediate level and level three to a major breakdown. Duration, repair time, and cost of the breakdown generally increase as the severity level increases.

Cost to Repair Breakdowns

Breakdown repair cost consists of the cost of repair parts and the cost of repair personnel. The cost of repair parts is determined for each severity level from a unique set of input data. Specifying the maximum, minimum, and average cost, and the standard deviation of the cost allows a portion of the program to determine the cost of a particular simulated breakdown. The value obtained is technically called a random deviate from the normal distribution. The input data specify a particular normal distribution, the program then generates a random deviate, and the resulting cost of parts is calculated. A more complete description of a normal distribution is included in Appendix 2.
Repair personnel are used only when the loader operator cannot make the repairs himself. The cost of outside help is calculated as the wage of the outside help multiplied by the repair time of the breakdown. Certain assumptions were made in this model regarding the amount of outside help needed at each severity level. It was assumed that no outside help would be needed for severity level one and that help would always be needed for severity level three. Second severity level breakdowns require help a certain percent of the time, called POLR.

The factors affecting COST 3 are shown in Figure 10.

Summary: Calculation of COST 3

The total cost of loader breakdowns in a year is obtained by summing the costs of the individual breakdowns occurring in the year. Calculation of the cost of a single breakdown takes place at the occurrence of the breakdown. One of two situations follows a loader breakdown. If the duration of the breakdown is less than some cut-off-time, called COT, trucks will wait at the landing for the loader repair. If not, trucks will leave the landing and return to the mill unloaded.

In the first situation the breakdown cost must include the cost of trucks waiting at the landing. This cost is calculated as

$$\text{CWAIT} = \frac{(WGTD + \text{COWTK})_{(J)} \times DBKLR}{60.0},$$

(21)
Figure 10: Factors affecting COST 3, the cost of loader breakdowns
58

where:

\[
\text{CWAIT} = \text{the cost for a single truck and driver to wait at the landing;}
\]

\[
\text{WGTD} = \text{the wage of the truck driver in dollars per hour;}
\]

\[
\text{COWTK}(J) = \text{the cost to own truck J in dollars per hour as calculated later in the thesis;}
\]

\[
\text{DBKLR} = \text{the duration of the breakdown in minutes.}
\]

After the costs for waiting trucks and parts have been determined, the cost of the loader breakdown is calculated as

\[
\text{CBKLR} = \text{CPRTS} + (\text{CWAIT} \times \text{TKWTN}) + \\
\frac{\text{WGLO} \times (\text{DBKLR} - \text{RPTBK}) + \text{DBKLR} \times \text{CSOWL} + \text{WGLO} \times \text{RPTBK}}{60.0} \frac{\text{RPTBK} \times \text{WGMP} \times \text{OUTSD} + \text{WGTS} \times \text{DBKLR} \times \text{TSV}}{60.0} \frac{(\text{LCAT})'}{60.0}
\]

(22)

where:

\[
\text{CBKLR} = \text{the cost of the loader breakdown in dollars;}
\]

\[
\text{CPRTS} = \text{the cost of repair parts for the breakdown;}
\]

\[
\text{CWAIT} = \text{the cost of a truck which waits at the landing in dollars per truck;}
\]

\[
\text{TKWTN} = \text{the number of trucks waiting at the landing during repair or the breakdown;}
\]

\[
\text{WGLO} = \text{the wage of the loader operator in dollars per hour;}
\]

\[
\text{DBKLR} = \text{the duration of the breakdown in minutes;}
\]

\[
\text{RPTBK} = \text{the repair time of the breakdown in minutes;}
\]
CSOWL = the cost to own the loader in dollars per hour;

WGMP = the cost in dollars per hour of outside help needed to repair some breakdowns;

OUTSD = a variable which is one if outside help is needed and zero if it is not needed;

WGTS = the wage of the tongsetter in dollars per hour;

TSV(LCAT) = a variable which is zero if a loader in category LCAT does not need a tongsetter and one if it does need one.

If the duration of the breakdown is greater than the cut-off-time, trucks will return to the mill. In this case, cost of a loader breakdown includes the cost of an extra round trip to the processing point for every truck at the landing when the breakdown occurred. The cost of the extra trip depends upon whether standard or prehaul trailers are used. The calculation for the first case is shown in equation 23 and for the second case in equation 24.

\[
CEXTP = \frac{TRIPT(1,J,NSET) \times (WGTD + COWTK(J))}{60.0} \times [TFLCN \times (FLCTD \times VDFT_{(ITCA)}) + (FLCTG \times VGT_{(ITCA)})] \\
\times (XMIPA + XMIPR + XMIS) \times 2.
\]  (23)
or

\[
C_{\text{EXTP}} = \frac{2.0 \times T_{\text{RIPT}}(4,J,NSET) \times (W_{\text{GTD}} + C_{\text{OWTK}}(J))}{60.0}
+ \left[ T_{\text{FLCN}} \times \left( (F_{\text{LCTD}} \times V_{\text{DFT}}(\text{ITCA})) + (F_{\text{LCTG}} \times V_{\text{GFT}}(\text{ITCA})) \right) \right]
\times (X_{\text{MIPPA}} + X_{\text{MIPPR}} + X_{\text{MIS}} - X_{\text{MIDK}}) \times 2.
\]

(24)

where:

- \( C_{\text{EXTP}} \) = the cost of an extra round trip in dollars per trip per truck;
- \( T_{\text{RIPT}}(I,J,NSET) \) = the time in minutes required for a round trip of type I in truck J where NSET is a simulation storage array;
- \( W_{\text{GTD}} \) = the wage of the truck driver in dollars per hour;
- \( C_{\text{OWTK}}(J) \) = the cost to own truck J in dollars per hour;
- \( T_{\text{FLCN}} \) = the fuel consumption of the truck in gallons per mile;
- \( F_{\text{LCTD}} \) = the cost of diesel fuel in dollars per gallon;
- \( V_{\text{DFT}}(\text{ITCA}) \) = a variable which is zero if a truck in category ITCA does not use diesel fuel and one if it does use it;
- \( F_{\text{LCTG}} \) = the cost of gasoline in dollars per gallon;
- \( V_{\text{GFT}}(\text{ITCA}) \) = a variable which is zero if a truck in category ITCA does not use diesel fuel and one if it does use it;
- \( X_{\text{MIPPA}} \) = the number of miles of pavement;
- \( X_{\text{MIPPR}} \) = the number of miles of primary road;
- \( X_{\text{MIS}} \) = the number of miles of spur road;
- \( X_{\text{MIDK}} \) = the number of miles from the mill to the prehaul dock.
The cost of a breakdown, COST 3, for this situation is determined as

\[
CBKLR = CPRTS + (TKRTN \times CEXTP) + \\
\frac{WGLO \times (DBKLR - RPTBK) \times (1 - ULELO)}{60.0} + \\
\frac{DBKLR \times CSOWL + RPTBK \times WGMP \times OUTSD}{60.0} + \\
\frac{COWTK \times TK \times (DBKLR - TAF) \times (1 - ULTRK)}{60.0} + \\
\frac{SMWGS \times DBKLR \times (1 - UFE)}{60.0} + \frac{WGLO \times RPTBK}{60.0}
\]

(25)

where:

- \(CBKLR\) = the cost of a loader in dollars per breakdown;
- \(CPRTS\) = the cost of parts needed to repair the breakdown;
- \(TKRTN\) = the number of trucks returning from the mill to their processing point;
- \(CEXTP\) = the cost of an extra round trip from the landing to the processing point;
- \(WGLO\) = the wage of the loader operator in dollars per hour;
- \(DBKLR\) = the duration of the breakdown in minutes;
- \(RPTBK\) = the repair time of the breakdown which may be less than or equal to the duration;
- \(ULELO\) = the percent utilization obtained from the loader operator while he is waiting for parts;
- \(CSOWL\) = the owning cost of the loader in dollars per hour;
WGMP = the wage paid to outside repair personnel in dollars per hour;

OUTSD = a variable which is zero if outside help is not needed and one if it is needed;

COWTK\(_J\) = the cost to own truck J in dollars per hour;

TK = the number of trucks servicing the loader;

TAF = the portion of the breakdown duration accounted for in CEXTP;

ULTRK = the percent utilization obtained from the trucks while the loader is down;

SMWGS = the sum of the wages of all truck drivers and the tong-setter, if he is used;

UFE = the percent utilization of the truck drivers and tong-setter while the loader is down.

As previously mentioned, COST 3 is the sum of all breakdowns occurring in a year, called CCRBK, divided by yearly productivity. It is calculated as

$$\text{COST 3} = \frac{\text{CCRBK}}{\text{PRODL}},$$

(26)

where:

COST 3 = the cost in dollars per MBF to repair breakdowns;

CCRBK = the yearly cost required to repair breakdowns;

PRODL = yearly productivity in MBF.
The frequency of loader breakdowns and therefore, the total cost of breakdowns is generally affected by loader quality and type, by the preventive maintenance schedule, and by the loader age. Ideally, these factors would all have a certain measurable effect on breakdown frequency. However, as in many areas of this model, lack of data prevents formulation of a meaningful relationship among these factors. It represents another area open to future research.

Although no specific data are currently available, general research in reliability engineering has shown some general conclusions regarding breakdowns and reliability. Generally three distinct breakdown periods exist in the life of equipment as shown in Figure 11.

\[\text{failure rate} \quad \text{failure rate} \quad \text{failure rate}\]

\[\text{equipment age} \quad \text{equipment age} \quad \text{equipment age}\]

Figure 11: Failure rate of equipment versus the age of equipment showing three distinct areas of breakdowns

The region of early failures indicates a decreasing failure rate caused by the elimination of initial "bugs". The presence of the high failure rate associated with this region can be avoided by requiring a break-in period for equipment when it is assigned to a non-critical activity. This model assumes that the loader used has been given a break-in period and thus, will not experience breakdowns in period one.

In period three the loader begins to wear out and therefore, experiences an increase in the failure rate. The incidence of this period can be delayed by servicing the machine with a proper preventive maintenance schedule throughout the loader's life. The preventive maintenance schedule used in this thesis was specified as a yearly amount spent for preventive maintenance. Another assumption made here is that this yearly amount will be sufficient to delay the incidence of wear out failures to some point beyond the economic life of the loader.

Loader breakdowns will thus occur only during period two, the region of chance failures. Research in reliability engineering has further shown that when failures are attributable to chance and the failure rate is constant, the frequency of breakdowns can be described as a negative exponential distribution. This distribution is described further in Appendix 2. Since the frequency of breakdowns follows a negative exponential distribution, the only necessary data is the mean time between loader breakdowns for each severity level. Use of the
theoretical distribution for frequency of breakdowns implies an assumption that it fits the logging situation. It was also assumed that the distributions of duration of breakdowns and the repair time were also described by the negative exponential distribution. When data becomes available regarding breakdowns, use of this distribution and the validity of other breakdown assumptions should be reviewed.

When a loader breaks down, some of the larger logging contractors replace it with a reserve or spare loader. This will not happen here. Should such a situation exist, events concerned with breakdowns would have to be modified.

COST 4: LOADER UNPRODUCTIVE TIME

The largest portion of loader idle time can be attributed to the lack of trucks at the landing. If there are no trucks available for loading or to empty the preload bunk, the loader cannot be productive. The availability of trucks can be related to several factors as shown in Figure 12. The number of trucks and the distance to the processing point will, of course, directly affect the total trips from the landing in any day. Use of standard or prehaul trailers or of a preload bunk affects the number of trips in the same manner. The truck schedule will, as previously mentioned, control the even flow of truck arrivals. Its principal control element is the increment of time allowed between each truck for unforeseen delays. The size and type of loader will determine how long a truck takes at the landing.
Figure 12: Factors affecting COST 4, the cost of idle time at the landing.
and hence, the number of trips the truck can make. Finally, the slope of the terrain influences the type and amount of each road category.

These factors combine to influence the variable known as WTIT, the time the loader waits for trucks. An increase in the number of trucks at the landing should, to a certain point, cause a decrease in loader idle time. The critical point occurs when the loader is saturated with trucks or 100 percent utilized. The number of trucks at this point is not necessarily the best number of trucks, however, since there must be a balancing of increased truck cost with decreased cost of idle time.

The distance and type of road from the landing to the processing point affect the round-trip-time of a truck. This, in turn, affects the number of daily trips per truck. The road type governs the average truck speed since an average speed is associated with each of the three road types mentioned earlier.

The type trailer used dictates the destination of the load of logs. The use of standard trailers requires a trip to the processing mill, whereas trucks with prehaul trailers travel only to the prehaul dock. The use of a preload bunk should decrease turnaround time at the landing, and thereby affect the total number of daily trips.

The scheduling technique used in this thesis entails scheduling the initial arrival of each truck at the beginning of each day. Succeeding arrivals are generated during the events of the simulated
day. The first truck is scheduled to arrive either at the beginning of the day or at the time the loader should have completed loading the preload bunk. The second truck is scheduled at a time when the first truck should have completed processing. Subsequent trucks are scheduled in the same manner so that initially trucks incur a minimum waiting time. The first truck scheduled rotates each day to balance the number of loads among trucks. The time allowance, SCINC, includes a time between each truck to provide for unforeseen contingencies. It may be varied to find the best allowance time.

Changing more than the allowance portion of the scheduling technique would require change of the computer subprogram named SCHTK, and would also require a knowledge of computer programming.

The slope of the terrain has some effect on the amount of spur road necessary at a logging site. Since the slope or grade of logging roads seldom exceeds six percent, roads built in steep terrain require the development of "switchbacks." Use of switchbacks in turn implies an increase in the amount of spur road.

Miles of spur road, in this thesis, remains a constant fed into the model as data. At a real logging site it would probably vary as development of the site proceeded. It is assumed here to be the distance from the primary road to the middle of the logging site, but represents a situation which could be modified to suit particular needs.
Most of the above elements influence waiting time by their effect on the round-trip hauling time to and from the processing point. The hauling time for a particular case is found in the subprogram TRIPT.

Eight cases exist ranging from a round trip from the landing to the mill to a one way trip from the prehaul dock to the landing. A sample calculation of the total time needed to make a round trip from the landing to the mill is shown in equation 27.

\[
\text{TRIPT}(I,J,NSET) = \frac{\text{TIM} + \text{ULMIL} + (2 \times 60 \times \frac{\text{XMIPA}}{\text{XPHPA}} + \frac{\text{XMIPR}}{\text{XPHPR}} + \frac{\text{XMIS}}{\text{XPHS}} \times \text{RTTD}(ITKN))}{\text{RTTD}(ITKN)}
\]

where:

- \( \text{TRIPT}(I,J,NSET) \) = the hauling time in minutes required for a trip of code I (in this calculation, one) using truck number J where NSET is a simulation storage array;
- \( \text{TIM} \) = the time allowed for personal needs during the trip;
- \( \text{ULMIL} \) = the time required to unload the logs at the mill;
- \( \text{XMIPA} \) = the miles of pavement;
- \( \text{XPHPA} \) = the average truck speed on pavement;
- \( \text{XMIPR} \) = the miles of primary road;
- \( \text{XPHPR} \) = the average truck speed on primary road;
- \( \text{XMIS} \) = the average number of miles of spur road;
- \( \text{XPHS} \) = the average truck speed on spur road;
- \( \text{RTTD}(ITKN) \) = the skill rating of the driver of truck number ITKN.
Although the previous factors govern the amount of unproductive time, the cost is determined from the costs incurred by system elements which are forced to be idle. These elements include the loader, its operator, and the tongsetter. The cost of unproductive time per unit of productivity is, therefore

\[
\text{COST 4} = \frac{(\text{CSOWL} + \text{WGLO} + (\text{WGTS} \times \text{TSV(LCAT)}) \times \text{WTIT})}{60.0 \times \text{PRODL}},
\]

where:

\[
\begin{align*}
\text{COST 4} &= \text{the cost of loader unproductive time caused by no trucks at the landing in dollars per MBF;} \\
\text{CSOWL} &= \text{the cost to own the loader in dollars per hour;} \\
\text{WGLO} &= \text{the wage of the loader operator in dollars per hour;} \\
\text{WGTS} &= \text{the wage of the tongsetter in dollars per hour;} \\
\text{TSV(LCAT)} &= \text{a variable which is zero if a loader in category LCAT does not need a tongsetter and one if it does;} \\
\text{WTIT} &= \text{the total time in minutes spent waiting for trucks during a year;} \\
\text{PRODL} &= \text{the productivity of the loader in MBF per year.}
\end{align*}
\]

\[\text{COST 5: COST TO OWN AND OPERATE TRUCKS}\]

The cost to own and operate a certain number of trucks composes the final element of the total cost structure. The total cost of this element, COST 5, consists of six distinct cost elements:
1. The cost to own a hauling unit
2. The cost to operate the unit
3. The cost of truck breakdowns
4. The cost due to weather which prevents operations
5. The cost of extra landings
6. The cost of loader idle time if all trucks are down.

These are shown below in Figure 13.

Figure 13: Factors affecting COST 5; the cost to own and operate a certain number of trucks
Owning Cost of Trucks

The cost to own a truck includes the same factors as did the cost to own a loader. These are the cost of depreciation, the cost of insurance, interest, and taxes, administrative costs, and the cost of workmen's compensation insurance. The owning cost of the entire unit, however, includes cost to own truck tractors, trailers, and preload bunks. Use of prehaul trailers implies keeping several extra trailers to be used at the dock. The cost of these extra trailers is included in the owning cost and divided equally among all trucks.

Calculation of the cost to own is shown as:

\[
\text{COWTK}(K) = \frac{\text{CSTK} \cdot \text{ITCA}) - (\text{SVLTK} \times \text{CSTK} \cdot \text{ITCA}) + \text{CINS} + \text{ADMC}}{\text{EYOH} \times \text{USTK} \cdot \text{ITCA}} + \text{WCOMP} + \text{XGSK} + \text{XCSTR} + \text{EXTRC},
\]

where:

- \(\text{COWTK}(K)\) = the cost to own truck number "K" in dollars per hour, including the cost of bunks and extra trailers;
- \(\text{CSTK} \cdot \text{ITCA})\) = the original cost of the truck-tractor;
- \(\text{SVLTK}\) = the salvage value of the loader, expressed as percent of the purchase price;
- \(\text{CINS}\) = the total cost of insurance, interest, and taxes, through the economic life of the loader;
- \(\text{ADMC}\) = the total administrative cost incurred through the life of the loader;
EYOH = the expected yearly operating hours;

USTK\(\text{(ITCA)}\) = the economic life of a truck in class ITCA;

WCOMP = the cost of workmen's compensation insurance in dollars per hour;

XCSBK = the cost to own a preload bunk, if one is used, expressed in dollars per hour per truck;

XCSTR = the cost to own the truck-trailer in dollars per hour;

EXTRC = the cost to own extra trailers in dollars per hour divided equally among all trucks.

The cost to own the bunk is calculated just as other cost-to-own calculations as

\[
X_{\text{CSBK}} = \frac{C_{\text{SBK}}(\text{KSYS}) (S_{\text{VLBK}}(\text{KSYS}) \times C_{\text{SBK}}(\text{KSYS})) + C_{\text{INS}} + A_{\text{DMC}}}{EYOH \times U_{\text{SBK}}(\text{KSYS}) \times TK}, \quad (30)
\]

where:

\(X_{\text{CSBK}}\) = the cost to own the preload bunk in dollars per hour;

\(C_{\text{SBK}}(\text{KSYS})\) = the original cost of the preload bunk in the trailer-bunk combination KSYS;

\(S_{\text{VLBK}}(\text{KSYS})\) = the salvage value of the bunk at the end of its economic life expressed as a percent of the original cost;
USBK\textsuperscript{(KSYS)} = the economic life of the bunk in years;

TK = the number of trucks in the loading-hauling subsystem.

The economic life of the bunk is assumed to be equal to that of the loader. The economic life of a trailer is assumed equal to that of the truck with which it operates. These assumptions can be changed simply by changing the computer statements concerned with these factors.

The calculation of the cost to own the trailer, XCSTR, takes the form as:

\[
XCSTR = \frac{CSTR(KSYS) - (SVLTR(KSYS) \times CSTR(KSYS)) + CINS + ADMC}{EYOH \times USTR(KSYS)}, \quad (31)
\]

where:

XCSTR = the cost to own the trailer in dollars per hour;

CSTR\textsuperscript{(KSYS)} = the original trailer cost in trailer-bunk combination KSYS;

SVLTR\textsuperscript{(KSYS)} = the trailer salvage value expressed as a percent of the original cost;

USTR\textsuperscript{(KSYS)} = the economic life of the trailer in years.

Extra prehaul trailers permit some lag and delay in truck arrivals at the prehaul dock. Their cost must be allocated equally among the trucks of the system. The calculation is shown as:

\[
EXTRC = \frac{XCSTR \times EXTRK}{TK}, \quad (32)
\]
where:

EXTRC = the cost per truck to own extra prehaul trailers;

EXTRK = the number of extra trailers in the system.

The factors effecting the cost to own trucks are shown below in Figure 14.

Figure 14: Factors affecting the cost to own a truck-trailer unit
Operating Cost of Trucks

The cost to operate a certain number of trucks depends upon the same factors affecting the cost to operate the loader; these factors are cost of fuel, cost of maintenance, and the wage of the truck driver.

However, the calculation of fuel consumption cost in this case requires a knowledge of the total number of miles traveled and the fuel consumption in gallons per mile. The total operating hours must also be known to allow calculation of the total wage paid the truck driver. Preventive maintenance cost is again specified by a yearly maintenance expense. The cost to operate the truck is calculated as

\[
\text{COPT}_K = \text{MILES}_K \times \text{TFLCN} \times \left( \left( \text{FLCTD} \times \text{VDFT}_{(\text{ITCA})} \right) + \left( \text{FLCTG} \times \text{VGT}_{(\text{ITCA})} \right) \right) + \frac{\text{WGTD} \times \text{HOUR}_K + \text{XMNCT}_K + \text{CWTTHR}_K}{60.0}, \tag{33}
\]

where:

\[
\begin{align*}
\text{COPT}_K & = \text{the cost to operate truck } K \text{ during the year;} \\
\text{MILES}_K & = \text{the number of miles traveled by truck } K \text{ during the year;} \\
\text{TFLCN} & = \text{the cost of diesel fuel in dollars per gallon;} \\
\text{FLCTD} & = \text{the cost of diesel fuel in dollars per gallon;} \\
\text{VDFT}_{(\text{ITCA})} & = \text{a variable which is zero if diesel fuel is not used in a truck in category ITCA and one if it is used;} \\
\text{FLCTG} & = \text{the cost of gasoline in dollars per gallon;} \\
\text{WGTD} & = \text{the wage paid truck drivers;} \\
\text{HOUR}_K & = \text{the total number of operating hours;}
\end{align*}
\]
A variable which is zero if gasoline is not used and one if it is used;

\[ \text{WGTD} = \text{the wage of the truck driver in dollars per hour}; \]

\[ \text{HOUR}_K = \text{the yearly operating hours for truck "K"}; \]

\[ \text{XMNCT}_K = \text{the yearly amount of preventive maintenance}; \]

\[ \text{CWTHR} = \text{the yearly cost due to bad weather}. \]

Cost of Truck Breakdowns:

A truck breakdown results in a cost to repair the breakdown and a cost of idle time. The frequency, duration, and repair times of breakdowns are again found from a negative exponential distribution. Hence, the only necessary data are the average values of these three times for each severity level. Breakdown severity is again categorized in three distinct levels, each level having the same significance it has in loader breakdowns.

The cost to repair a truck breakdown contains three elements; namely, the cost of repair parts, the cost of repair personnel, and the cost to tow a truck to its repair point. The cost of parts is derived from a normal distribution in the same manner as for a loader breakdown. Repair personnel are also used to repair truck breakdowns, but their cost will be less than that for loader repair personnel. This results from truck repair at a shop rather than at the landing. However, an additional cost appears in truck breakdowns; there is a cost involved in towing the truck to the repair point. It is obtained by multiplying the miles towed by the cost per mile for towing.
Certain assumptions regulate the amount of outside repair help needed and the occurrence of towing. The probability that outside help will be needed to repair a breakdown of severity level "I" is specified as \( P_{OIK} \). Use of this probability permits a determination of the need for outside help. Towing occurs only in a second or third severity level breakdown. A first severity level breakdown will be repaired on location.

Unproductive time caused by the breakdown produces a cost composed of the owning cost of the truck and a certain percent of the driver's wage.

The cost of the truck breakdown is calculated as

\[
CBKTK = CPRTS + \frac{DBKTK \times COWTK(K)}{60.0} + \frac{RPTTK \times OUTSD \times WGMT}{60.0} + (MILTW \times CSTOW) + \frac{WGT \times (DBKTK - RPTTK) \times (1 - ULETD)}{60.0} + \frac{WGT \times RPTTK}{60.0}
\]

(34)

where:

- \( CBKTK \) = the cost of a truck breakdown in dollars;
- \( CPRTS \) = the cost of repair parts;
- \( DBKTK \) = the duration of a truck breakdown in minutes;
- \( COWTK(K) \) = the cost to own truck "K" in dollars per hour;
- \( RPTTK \) = the repair time of a breakdown in minutes;
- \( OUTSD \) = a variable which is zero if outside repair help is needed and one if it is not needed;
WGMT = the wage paid repair personnel in dollars per hour;

MILTW = the number of miles a truck is towed;

CSTOW = the towing cost in dollars per mile;

WGTD = the wage of the truck driver in dollars per hour;

ULETD = the percent utilization obtained from a truck driver while waiting for parts.

At the end of a year the yearly cost of breakdowns is found by summing the costs of individual breakdowns.

**Cost of Extra Landings**

Just as the front-end loader required an excavated landing for maneuvering, a preload bunk requires an excavated landing to allow for maneuvering. Hence, if a preload bunk is in use, the cost of building extra landings must be charged to COST 5. The cost of landings, in this case CSLND, is calculated just as it was for front-end loaders. If a certain combination includes both a front-end loader and a preload bunk, the cost of extra landings is charged only to the cost of operating the front-end loader.

**Idle Time When All Trucks Break Down**

A concurrent breakdown of all trucks in the system forces the loader to remain idle until at least one truck is repaired. An unproductive loader accrues a cost stemming from the cost to own the loader. This cost is calculated as
\[
\text{CNTKI} = \frac{\text{DITIT} \times \text{CSOWL}}{60.0},
\]

where:

- CNTKI = the cost of loader unproductive time caused by all trucks being down;
- DITIT = the number of minutes during the year that all trucks were down;
- CSOWL = the cost to own the loader in dollars per hour.

**Summary: Calculation of COST 5**

COST 5 is the cost to own and operate a certain number of trucks. As such it includes the costs just presented. It is a summary of all cost elements involved in hauling: actual hauling cost, breakdown cost, and cost of unproductive time. This final cost element is calculated as:

\[
\text{COST 5} = \sum_{J=1}^{TK} \frac{\text{COPTK}(J)}{\text{PRODL}} + \text{CCTBK} + \text{CSLND} + \text{CNTKI}
\]

\[
+ \frac{(\text{COWTK}(J) \times \text{YRHR}) + \text{WGTD} \times \text{TISYS} \times \text{XLOAD}}{\text{PRODL} \times 60.0 \times \text{PRODL}},
\]

where:

- COST 5 = the cost to own and operate a certain number of trucks in dollars per MBF;
- COPTK(J) = the cost to operate truck number "J" for a year;
CCTBK = the total cost of all truck breakdowns occurring during the year;

CSLND = the cost of extra landings built during the year for the preload bunk;

CNTKI = the total cost of loader idle time caused by the concurrent breakdown of all trucks;

PRODL = the yearly productivity of the loading and hauling subsystem;

COWTK(J) = the cost to own a single truck "J" expressed in dollars per hour;

YRHRS = the total number of truck-hours in the year when production could have taken place (as further explained below);

WGTD = the wage of the truck driver in dollars per hour;

TISYS = the average time in minutes spent by a truck at the landing;

XLOAD = the number of truck loads produced in a year.

The total number of truck-hours available for work, YRHRS, represents the number of possible work hours multiplied by the number of trucks. The possible work hours of a single truck involve all scheduled work hours when either the truck or the loader were not broken down. Thus, the possible work hours include all operating hours and any unproductive time not already recognized. The variable,
YRHRs; represents a total for all trucks and is calculated as

\[ YRHRs = \frac{(TNOW - TENYR) - CDBTK - (TK \times CDBLR)}{60.0} \]  

(37)

where:

- \( YRHRs \) = the total truck-hours in a year available for productive activity;
- \( TNOW \) = the time in minutes when the current year ended;
- \( TENYR \) = the time in minutes when the previous year ended;
- \( CDBTK \) = the total duration in minutes of all truck breakdowns;
- \( TK \) = the number of trucks in the system;
- \( CDBLR \) = the total duration in minutes of all loader breakdowns.

**SUMMARY: THE TOTAL COST**

The total cost of a specific loading and hauling combination is found by summing its five cost elements. COST 1 represented the cost to deck logs to a certain quality deck. It was expressed in dollars per MBF and is largely dependent upon the skidding system in use.

COST 2 expressed the actual loading cost in dollars per MBF. Its critical factors were the productivity of the loader, the cost to own and operate the loader, and the actual hours of operation. COST 3 accounted for the cost of loader breakdowns expressed again in dollars per MBF. It was composed of the following two elements: the cost to repair the breakdown and the cost of the resulting unproductive time.

COST 4 described the cost of an unproductive loader resulting from an
absence of log carriers at the landing. It was affected primarily by the number of trucks in the system and the distance of these trucks from their processing point. Finally, COST 5 portrayed the cost to own and operate a certain number of trucks. The calculation resulted from consideration of truck owning cost, the cost to operate the truck, the total miles traveled, and the number of hours worked.

Summation of these five sub-costs result in a total cost expressed in dollars per MBF. This is shown as

\[ \text{CSTOT} = \text{COST 1} + \text{COST 2} + \text{COST 3} + \text{COST 4} + \text{COST 5}, \]  

(35)

where:

\[ \text{CSTOT} = \text{the total cost to own and operate the loading and hauling subsystems expressed in dollars per MBF.} \]

The total cost, CSTOT, is calculated at the end of each simulated year. A cumulative average total cost is also determined. It represents an average, however, which does not account for the time value of money. The time value of money, generally described by a rate or return, implies that all money used must earn a certain percent return. This return on investment is expressed as a rate which the money-user deems necessary to maintain a profitable business. A time value of money further implies that the value of a dollar today does not equal the value of the dollar one year from today.

A valid economic comparison of costs requires inclusion of the effect of the time value of money. Several methods of comparison account for the time value of money. A "present-worth" comparison
requires bringing costs back from a future time to the present. It represents a valid comparison only if economic lives are equal or if some assumptions are made regarding events associated with the alternative having the longest life. The events in question are those occurring after the end of the shortest economic life. This method will not be used for comparison here, but is needed in the method that will be used. 5

The method used is known as the "annual cost" method. The costs incurred are converted to equivalent annual costs. In this model, it requires conversion of the annual cost calculated in each simulated year to a "present-worth". The total "present-worth" of all costs will then be converted to an equivalent annual cost, called EQAC. This will be the value used to compare alternatives.

The definition and explanation of the cost structure has been a rather lengthy section. Since it will be the basis for comparing alternatives, however, it must be completely understood. Review of some of the elements necessary for calculation of the various costs reveals the need for the simulation model. Elements such as miles traveled and hours worked are determined through operation of the model. The model composition and operation are the subjects discussed in the next chapter.

5 Taylor, op. cit., pp. 22-27.
CHAPTER 5

THE SIMULATION MODEL

Simulation was defined in Chapter 1 as the duplication of system operations through the identification and manipulation of system activities. A description of any system consists of a definition of its inputs, outputs, processes, relationships, and feedback repetitions. The activities described in the definition of simulation represent the processes of a system. The relationships of the system represent the bonds between activities and thus, the flow from one activity to another. The activities are controlled by their beginning and ending events. In a sense, then, the simulation model is controlled by the beginning and ending events of system activities.

Simulation of the loading and hauling subsystems depends upon proper definition of the associated activities and events. The mere definition of these items, however, will not result in the equivalent annual cost described in the previous chapter. Realization of this cost requires manipulation of the model, collection of simulated data during the manipulation, and final cost calculations using the simulated data. Accomplishment of the first two items requires the facility to keep the simulation in operation and simultaneously collect the needed data. The facility used in this thesis takes the form of a simulation "language" called GASP II.
Simulation With GASP II by A. Alan B. Pritsker and Philip J. Kiviat outlines a simulation language which can be used to accomplish the two tasks just mentioned. The "language" takes the form of a series of computer subprograms used to keep track of simulation activities and statistics. These subprograms are written in FORTRAN IV computer language. Since nearly all computers accept programs written in FORTRAN IV language, GASP II can be used on almost any computer.

The simulation language was designed to free the user from the necessity of devising a way to keep track of simulated time, events, and statistics. Simulated time is accounted for in GASP II by the scheduled time of the next event. It does not increment time by a set unit and then check for the occurrence of particular events at that time. Rather, the language updates time at the occurrence of each event and skips the time when no events occur.

GASP II provides for storage and manipulation of all system elements and activities through use of a storage array and certain subprograms. Within the storage array, called NSET, several "files" can exist. A file contains all elements and events associated with a specific system function.

---

1 Pritsker, op. cit.
One file always present in GASP II is an event file. The file contains data about each future event. The data include the scheduled time of occurrence, the event code, and other information such as the equipment number and the time an activity began. Characteristics associated with an event are known as its attributes. Events in the event file are time ordered from lowest to highest. Events are placed into and removed from the file by two subprograms, FILEM and RMOVE.

Other files may exist concurrently with the event file. Typical uses of these files are storage areas for queues and buffer storage areas. The loading and hauling simulation utilizes six files within NSET. The first of course, is the event file. File two represents a queue of trucks awaiting service at the landing. File three is used as a buffer storage at the end of each simulated day. Files four and five store trucks waiting for prehaul trailers at the lock. File four contains highway trucks waiting for full prehaul trailers, while file five contains shuttle trucks waiting for empty trailers. Finally, file six acts as a buffer storage when breakdowns occur. Within each file the ordering code can be specified to allow either a first-in, first-out convention or a last-in, last-out convention. In this model the first-in, first-out convention is used exclusively. An example of the computer printout of NSET is shown in Figure 15.

System manipulation is controlled from an executive subroutine, appropriately called GASP. GASP causes the simulation to progress...
### GASP Job Storage Area Dump At 1235.0000 Time Units

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<tr>
<th>Scheduled Event Time</th>
<th>Event Code</th>
<th>Attributes</th>
<th>Succeeding Event</th>
<th>Preceeding Event</th>
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<td>50 00 30 40</td>
<td>5 00</td>
<td>8</td>
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</table>

**Figure 15:** Computer printout of the storage array NSET showing events in three files
in time by removing the first entry in the event file, noting the time that event is to occur, and directing control to an event subroutine, called EVNTS, from which the appropriate subprogram is called. As previously mentioned, each event of the simulation has an associated event code. Also associated with each event is a unique subroutine in which the activity signaled by the event is described and subsequent events are scheduled.

The subroutine, EVNTS, utilizes the event code to call the appropriate subroutine. Once control is returned to the executive subroutine, GASP, it automatically removes the next entry from the event file and subsequently processes it.

Statistics may be collected upon relevant data through use of statistical subroutines. These subroutines keep track of the minimum, maximum, and average values of any desired variable.

Utilization of the GASP II simulation language requires the definition, in terms of a computer subroutine, of each system event and activity. This requirement composed the largest portion of the development of the loading and hauling model.

LOADING AND HAULING SIMULATION EVENTS

Events and activities associated with the loading and hauling subsystems depend upon the type trailer used in the system. Use of a prehaul trailer requires definition of two additional system events.
A system utilizing standard trailers can briefly be described in terms of a loading activity and a hauling activity. The loading activity commences with a truck arrival at the landing and ends with an end-of-loading event. The hauling activity begins with this end-of-loading event and ends with an arrival of that truck at the landing. When prehaul trailers are used, the hauling activity must be modified by activities at the prehaul dock. These activities are described in terms of an arrival at the dock and an end of service at the dock.

The events mentioned above control normal operation in the loading and hauling subsystems. However, two special activities must also be acknowledged. Equipment breakdowns and their effect on the system are described in events marking the beginning and ending of a breakdown. The end of a working day requires special attention since all work will not come to an abrupt halt, but will continued until activities still in progress are completed.

As previously mentioned, each simulation event describes the activity to take place and schedules any subsequent events. The specific functions of the loading and hauling events will now be described in some detail.

**Arrivals at the Landing**

The subroutine called ARRVL signals the arrival of a truck at the landing. Subsequent processing will depend first upon the presence of other trucks at the landing and secondly upon the use of a preload bunk.
If a preload bunk is not being used and there are no other trucks at the landing, the current arrival receives immediate attention from the loader. The loader, previously idle, is set to a busy status. Statistics are collected on the idle time of the loader and on the number of trucks at the landing. After incrementing the number of trucks at the landing by one, an end-of-loading event is scheduled and filed into the event file.

If trucks are already at the landing, increment the number of trucks at the landing by one and store the attributes of the truck in file two, the queue of trucks waiting for loading.

Use of a preload bunk requires a further test of the loader status. Even if there are no other trucks at the landing, processing of a current arrival will be delayed if the loader is still filling the bunk. When this situation exists, the attributes of the truck are again stored in file two.

The chief functions of subroutine ARRVL are to test the status of the loader and either file and end-of-loading event or store the attributes of the truck in a queue.

End of Loading at the Landing

An end-of-loading event, described in subroutine ENDSV, signals completion of the loading activity. Subsequent actions depend upon the type of trailer in use, the presence of a preload bunk, and the equipment type just loaded.
In the system using standard trailers and having no preload bunk, scheduling of the arrival time at the landing for this particular truck takes place. This implies filing an arrival event in the event file. Since this truck now leaves the landing the number of trucks at the landing is decreased by one. If the departure of this truck leaves no truck at the landing, the loader status will be set to idle. If trucks are waiting in the queue, the loader will immediately process the truck with the longest time in the queue. This implies scheduling and end-of-loading event for the first entry in file two.

Prehaul trailers are processed in the same manner as standard trailers with one exception. The event subsequent to end-of-loading is now the arrival of the trucks at the prehaul dock rather than the landing.

When a preload bunk is utilized, an end-of-loading event can signal either the end-of-loading of the bunk or the end-of-transfer of the load from the bunk to the truck. The first case, an end-of-loading of the bunk, means that the bunk is now filled and that the logs in the bunk can be transferred to the truck. If a truck is waiting at the landing, it is removed from the queue of waiting trucks stored in file two as has an end-of-transfer time scheduled. If several trucks are waiting for service, the truck that has been waiting the longest is serviced first.

The end-of-loading event has also forced the loader to become idle. It remains idle until the bunk is emptied. Therefore, an end-
of-transfer event implies that the loader will again be set to a busy status. An end-of-loading event is now scheduled for the time when the loader will again finish filling the bunk. Since a truck has just been loaded, the next arrival of this truck is also scheduled. The presence of a preload bunk implies use of standard trailers. The combination of a preload bunk with prehaul trailers was not tested in this model.

For a system with standard trailers subroutines ARRVL and ENDSV represent the two events associated with normal operations. Use of prehaul trailers requires definition of two additional events; namely, the arrival of trucks at the prehaul dock and end-of-service at the dock. Subroutine ARRVL is listed in Appendix 5 and ENDSV in Appendix 6.

Arrival of Trucks at the Dock

Subroutine ARDOK processes arrivals at the prehaul dock. An arrival may come from either the landing or the mill. If a truck arrives from the landing, it is assumed to be a shuttle truck. A truck arriving from the mill is assumed to be a highway truck. The primary function of ARDOK is the scheduling of an end-of-unhooking time for the truck. End-of-unhooking implies the unloading or unhooking of the prehaul trailer in preparation for a hook-up with a new trailer. Most of the processes occurring at the dock are accounted for in the end-of-service subroutine. The ARDOK subroutine is listed in Appendix 7.
End-of-Service at the Dock

The subroutine concerned with end-of-service at the dock, ESVDK, is subdivided into four distinct areas. Highway and shuttle trucks are processed differently. Both of these truck types are further divided into end-of-unhooking activities and end-of-hooking activities.

Consider first a shuttle truck which has just unhooked its pre-haul trailer. Occurrence of this event causes the addition of a full trailer to the number of trailers at the dock. Since a highway truck might be forced to wait at the dock for full trailers, the addition of this full trailer could allow removal of a highway truck from its queue in file four. An end-of-unhooking event also makes the shuttle truck available for a hook-up and return trip to the landing. If empty trailers are available for hook-up with a shuttle truck, an end-of-hooking event is scheduled and filed in the event file. Absence of empty trailers results in storage of the shuttle truck in a queue of those waiting for trailers, file five.

The procedure involved when a highway truck finishes unhooking an empty trailer consists of the same routine used when shuttle trucks unhook full trailers. In this case the number of empty trailers is incremented, a check is made for any shuttle trucks awaiting an empty trailer, and the highway truck is either placed in a queue or scheduled for an end-of-hooking event.

Completion of a hook-up of a shuttle truck and empty trailer results in the departure of the truck from the dock. An arrival at the
landing is filed as the next event for this truck.

When a highway truck completes hook-up with a full trailer, scheduling of the next arrival of this truck at the dock occurs. Thus, highway trucks travel only between the dock and the mill and shuttle trucks between the dock and the landing.

The four events just mentioned describe the normal operations of a loading and hauling combination utilizing prehaul trailers. However, three other events exist for all loading and hauling combinations. These deal with equipment breakdowns and the activities occurring at the end of a day. Subroutine ENDSV is listed as a computer printout in Appendix 8.

Equipment Breakdowns

Subroutine BKDWN processes all equipment breakdowns. However, it is subdivided to allow separate processing of loader and truck breakdowns. A truck breakdown generally will not cause the entire system to become idle. Its occurrence results in a decrease in the number of trucks available for work. When a truck breakdown occurs, several items must be adjusted. All other events associated with this particular truck must either be eliminated from consideration or stored in buffer storage for later adjustment. All other breakdowns of this truck are stored in buffer storage. These consist of breakdowns of the "other two" severity levels.
Any other events, such as an arrival or end-of-service are removed from the event file without processing the actual event. The location of the breakdown is saved, however, to allow calculation of the towing distance.

When the towing distance, the cost of parts, and the duration and repair time are known, the cost of the breakdown can be determined.

Finally, using the duration of the breakdown, and end-of-breakdown event is scheduled. The end-of-breakdown event marks the time the truck can rejoin system operations.

Truck breakdowns force the system to be idle only if all trucks incur breakdowns during the same time period. A single loader breakdown, however, will force all trucks to cease operations. When a loader breakdown occurs, all truck arrivals at the landing and any end-of-service activities must be eliminated from the event file. This requires a review of all events in the file, eliminating those which can no longer be considered and storing those which need to be adjusted. This review includes the removal from the queue in file two of any trucks waiting at the landing for service. The cost of the breakdown is determined using the same type factors that affected truck breakdowns. Finally, an end-of-breakdown event will be scheduled at a time equal to the present time plus the duration of the breakdown. The computer printout of this subroutine is listed in Appendix 9.
Repair of Equipment Breakdowns

An end-of-breakdown event signals the return of repaired equipment to productive activity. The specific activities resulting from this event will depend upon whether a loader or truck has been repaired. Since a loader breakdown forces the entire system to become idle, its repair will result in a rescheduling of system events. This is accomplished by calling subroutine SCHTK to schedule initial arrivals of all trucks. Then the next breakdown of this severity level is scheduled and filed in the event file. Events associated with the loader and stored in buffer storage, file six, can now be removed and refilled in the event file.

When a truck becomes operational, it can be rescheduled to its original task in the system. Once this event is scheduled, truck breakdowns, which had been stored in file six, are transferred to the event file. Finally, the next breakdown of this truck for the particular severity level is scheduled and filed in the event file. The computer listing of ESVBK is shown in Appendix 10.

Effects of the End of a Day

An end of the scheduled work day does not necessarily imply an abrupt halt to all system activities. Those activities still in progress will be completed before the day officially ends. Subroutine ENDAY accounts for the special circumstances surrounding events completed after the end of a scheduled day. Some scheduled events will
be eliminated, acknowledging assumptions that in reality the activity would not have been started so late in the day. Such is the case with truck arrivals at the landing and arrivals at the prehaul dock of highway trucks.

End of service at the landing receives normal processing, reflecting a desire to maximize productive truck miles. The same is true with processing at the prehaul docks. Since highway trucks return to the mill at the end of each day, an effort is made to make the final trip productive.

Breakdowns are processed only if the equipment under consideration is functioning in the system. If it has already ended its work day, the breakdown will be stored in buffer storage, file three. Otherwise, processing takes place in the normal manner.

Repair work on breakdowns never continues past the scheduled end of day. Therefore, all end-of-breakdown events are stored in buffer storage.

After accounting for all system events, the ENDAY subroutine transfers the events from buffer storage back to the event file. Another function performed in ENDAY regards the determination of the next day's weather and terrain slope. If weather prevents normal operations, no normal work activities occur. Breakdown repair can continue in spite of bad weather, but loading and hauling activities cannot. The slope of the terrain affects the need for excavated landings.
Before scheduling the end of the next simulated day, the subroutine makes a check of the day, month, and year. When an end-of-year or end-of-simulation are indicated, ENDAY directs control to the appropriate subroutines. A listing of subroutine ENDAY is shown in Appendix 11.

**Scheduling Initial Truck Arrivals**

A uniform system for scheduling initial truck arrivals exists in subroutine SCHTK. The subroutine considers two distinct cases. When standard trailers are used, all trucks go directly to the landing. They are scheduled to arrive at different times. The second truck should arrive just as the first completes processing. The truck scheduled first is varied each day to balance the number of loads among the trucks.

If prehaul trailers are used, some truck arrivals are scheduled at the landing and some at the dock. The rotation technique used with standard trailers also applies here. Scheduling trucks with prehaul trailers involves concern for several other factors such as the number of full trailers at the dock, the number of shuttle trucks, and the time required by a shuttle truck to deliver a full trailer to the dock.

Variations in the scheduling technique employed here might result in increased productivity. However, implementation of these variations requires modification of a rather complex computer program. The
MODIFICATION OF SIMULATION ELEMENTS

Elements of the system thought subject to the most frequent modification were placed in function subprograms where they could be easily accessed. Consider the assumptions concerning breakdowns. Here, data collected regarding any of the breakdown items would probably result in a modification of some assumptions and therefore, in the subprogram concerned with breakdowns.

The cost of repair parts was found from the subprogram CPRT. Here, normal distributions described the cost of repair parts for each severity level and equipment type. A change in the distribution of the cost of parts would require changing a few of the statements in CPRT.

Determination of the time between breakdowns presently utilizes a negative exponential distribution. BKDTK depicts the function subprogram used to determine times between truck breakdowns. BKDLR is the name of the subprogram used to determine time between loader breakdowns. Modification of the negative exponential distribution requires changing a few statements present in these subprograms. The same modifications could be made to RPT and DBK. RPT finds repair time of a specific breakdown, and DBK finds the duration of the breakdown. Both subprograms use a negative exponential distribution, which could
be easily modified or changed. The subprograms just mentioned concerning breakdowns are listed in Appendix 13.

The element most critical to loader productivity is the loading time of a truck. The present values of loading time consist of data derived from estimates of lifting capacity and speed. An example of the method used is presented in Appendix 1. However, as future research makes data available, the values currently fed in as data should be replaced by values obtained from some valid relationship. Subprogram XDTM allows for this future expansion. Its current use simply represents recognition of the existence of the subroutine.

Other subprograms related to productivity include XDTMB and ULTDK. XDTMB determines the time required to transfer a load from a preload bunk to a truck. Since the value is fairly constant, an average value is supplied by XDTMB. In the subprogram ULTDK the unhooking and hooking times at the dock are determined. Currently ULTDK supplies an average value for these two times. The subprograms concerned with productivity are listed in Appendix 14.

Subprogram TRIPT furnishes the other subroutines the time in minutes required for a certain trip. Presently TRIPT solves for travel time using average speeds on each of the three road types. A modification could provide for a travel time determined from some distribution. Development of the modification depends largely upon the availability of relevant data. Ten types of trips can occur within generalized loading and hauling system. These are described as:
1. A round trip from the landing to the mill,
2. A one way trip from the landing through the processing mill,
3. A one way trip from the mill to the landing,
4. A one way trip from the landing to the prehaul dock,
5. A one way trip from the prehaul dock to the landing,
6. A one way trip from the prehaul dock through the processing mill,
7. A one way trip from the mill to the dock,
8. A round trip from the dock to the mill,
9. A one way trip from the landing to, but not through the mill,
10. A one way trip from the dock to, but not through the mill.

In addition to travel time, subroutine TRIPT includes an average value for unloading time at the mill and a personal allowance time proportional to the length of the trip. Subprogram TRIPT is listed in Appendix 15.

AREAS OF COST CALCULATIONS

Cost associated with the system simulation are calculated in three subroutines. Determination of breakdown cost occurs in subroutine BKDWN. It is calculated as the breakdown occurs. Calculations in the two other areas depend on whether the calculation needs simulation information or can be determined from just input data.

Cost factors needing only input data are calculated in the main program. The costs consist of owning costs of equipment and the decking
cost, COST 1. These cost totals are retained and used in yearly calculations. These calculations occur in subroutine OTPUT. Calculations of OTPUT require values determined in the simulation run.

Subroutine OTPUT not only makes the necessary calculations, but also prints out the information just obtained. Subroutine OTPUT is listed in Appendix 17.

USE OF THE SIMULATION MODEL

Proper use of the simulation model requires only the input of correct data. As previously mentioned, this data must depict a particular logging site. Any data transferred from this model to that of a user must be carefully studied.

Data used by the model are controlled by input statements in the main program and a GASP II subroutine, called DATAN. DATAN is concerned with data of the GASP II simulation language. Except for one variable, PARAM(I,J), the GASP II data should never need modification. PARAM(I,J) represents an array of data used by various distribution functions. In its present state, the model utilizes the values in PARAM(I,J) only in normal distributions. The subscript "I" specifies a particular normal distribution. PARAM(I,1) contains the mean of distribution "I": PARAM(I,2) contains the minimum value; PARAM(I,3) contains the maximum value; PARAM(I,4) contains the standard deviation. Modification of the distribution used would require modification of the parameter values.
CONTROL ELEMENTS

The main program contains all other input statements used in the model. The first three input statements contain the variables that control the number of cases tested. Figure 16 represents the input portion of the main program and contains the exact form of the input statements. The first data card will contain seven values. ICASE indicates the number assigned to the first case tested. MNVR1 represents the initial skidding system being tested. MNVR2 represents the final skidding system tested. The simulation will test every skidding combination from MNVR1 to MNVR2. If the two values are equal, the skidding system will be a constant. MNVR, the skidding system identification can take one of four values.

The loader category in a particular simulation run will vary from LCAT1 to LCAT2. LCAT1 represents the initial loader category and LCAT2, the final category. Within each loader category four size classes of the loader exist. They will vary from ISV1 to ISV2. The codes associated with loader category LCAT are listed below.

1. LCAT=1 implies a fully articulated hydraulic loader.
2. LCAT=2 implies a loader with air or hydraulic pinchers.
3. LCAT=3 implies a heelboom with grapple.
4. LCAT=4 implies a heelboom with tongs.
5. LCAT=5 implies a front-end loader.
6. LCAT=6 implies a long-boom loader.
CONMN DDNTK, CDIT, CDBIT, CDNIT, TRNT(20), PTML
CONMN BKFUL, CDBLR

C*****NUMBERS OF CARD READER AND CARD PUNCH
C
NCRDR=105
NPRNT=108

C*****INITIALIZE TOTAL COST AT SOME HIGH VALUE
C
CSTMN=99999*

C*****INITIALIZE THE NUMBER OF MINIMUM COST COMBINATIONS AT ZERO.
C
NEGA=0

C*****FIRST READ IN NECESSARY INPUT ASSOCIATED WITH THE SYSTEM VARIABLES
C
C
C*****READ IN DATA TO CONTROL THE TYPE CASES CONSIDERED
C
READ(NCRDR,150) ICASE, MNVR1, MNVR2, LCAT1, LCAT2, ISV1, ISV2
150 FORMAT(7I5)
READ(NCRDR,151) KSYS1, KSYS2, ITCA1, ITCA2, ITK1, ITK2
151 FORMAT(6I5)
READ(NCRDR,152) SUTK1, SUTK2, EXTR1, EXTR2, XMDK1, SCIN1
152 FORMAT(6F10.3)

C*****READ IN VALUES ASSOCIATED WITH THE SKIDDING OPERATION
C
READ(NCRDR,1) WGS8, RTS8, C68S, SCPH, SVPC, TQ1, TQ2
1 FORMAT(7F10.3)

C*****READ IN VALUES ASSOCIATED WITH THE LOADING OPERATION
C
DO 2 LCAT=1,8

Figure 16: Computer Listing of Input Portion of the Main Program
READ(NCRDR,3) TSV(LCAT),USL(LCAT),SVL(LCAT)

3 FORMAT(2F4.1,F5.4)
READ(NCRDR,60) (CSDL(LCAT,ISV),ISV=1,4)
READ(NCRDR,60) (CAPL(LCAT,ISV),ISV=1,4)
READ(NCRDR,60) (BHP(LCAT,ISV),ISV=1,4)

60 FORMAT(4F10.3)
NYEAR=USL(LCAT)
DO 70 ISV=1,4
READ(NCRDR,5) ((OPDV(LCAT,J,ISV,ICLAS),ICLAS=1,4),J=1,NYEAR)
70 CONTINUE
5 FORMAT(4F5.1)
READ(NCRDR,6) VDFL(LCAT),VGL(LCAT),CLMSC(LCAT)
6 FORMAT(3F10.3)
CONTINUE
READ(NCRDR,7) P9LR,AVMBF,CGT,WGLB,RTL6,WTGS,RTTS
7 FORMAT(7F10.3)

C*****READ IN VALUES ASSOCIATED WITH THE TRUCK CATEGORIES
C
DO 8 ITCA=1,6
READ(NCRDR,9) CSTK(ITCA),USTK(ITCA),SVLT(1TCA),VDFT(ITCA),VGT(ITC)
8 CONTINUE
9 FORMAT(5F10.3)
READ(NCRDR,10) WGTD, (P6TK(ISEVL),ISEVL=1,3)
10 FORMAT(4F10.3)
READ(NCRDR,11) (RTTD(ITKN),ITKN=2,11)
11 FORMAT(10F5.3)
C
C*****READ IN VALUES ASSOCIATED WITH THE BUNK AND PREHAUL SYSTEMS
C
DO 12 KSYS=1,3
READ(NCRDR,13) CSTR(KSYS),CSBK(KSYS),CSMSC(KSYS)
12 CONTINUE
13 FORMAT(3F10.4)

Figure 16: (continued)
C*****READ IN DISTANCE TO MILL AND AVERAGE SPEED

READ(NCRDR,14) XMIPA,XMIPR,XMIS,XPHPA,XPHPR,XPHS
14 FORMAT(6F10.3)

C*****READ IN DAYS AND WEATHER PROBABILITY FOR EACH MONTH

READ(NCRDR,15) (DAY(MONTH),MONTH=1,12)
READ(NCRDR,15) (WTHP(MONTH),MONTH=1,12)
READ(NCRDR,15) (TIDAY(MONTH),MONTH=1,12)
15 FORMAT(12F6.3)

C*****READ DATA CONCERNED WITH FUEL CONSUMPTION.

READ(NCRDR,16) FLCTD,FLCTG,FLCN,FLCN
16 FORMAT(4F10.3)

C*****READ IN DATA CONCERNED WITH INSURANCE AND INTEREST

READ(NCRDR,17) TIIPR,WCPPR,RR,ADMPR
17 FORMAT(4F10.5)

C*****READ IN DATA CONCERNED WITH MAINTENANCE AND BREAKDOWNS.

DO 19 ISEVL=1,3
19 READ(NCRDR,20) XMTBK(ISEVL),XMTTK(ISEVL),XMDBK(ISEVL),XMDTK(ISEVL)
1,XMRBK(ISEVL),XMRTK(ISEVL)
20 FORMAT(6F10.3)
READ(NCRDR,21) XMNCL,UFE,WGMP,WGMT
21 FORMAT(4F10.3)
READ(NCRDR,22) (XMNCT(ITKN),ITKN=2,11)
22 FORMAT(10F8.2)

C*****READ IN CONTROL VARIABLES

Figure 16: (continued)
**C*****READ IN THE NORMAL TIME IN A WORKING DAY AND THE TIME NEEDED IN A**
**C*****DAY TO SCHEDULE TRUCKS AFTER BREAKDOWNS. ALSO READ IN EXPECTED**
**C*****YEARY OPERATING HOURS**

```
READ(NCRDR,23) XNTDT,XNTDL,EY0H,DEFCT
23 FORMAT(4F10.2)
READ(NCRDR,970) ULEL9,ULTRK,ULETD,CST0W,(ULTDRI),I=1,3)
970 FORMAT(7F10.3)
```

**C*****READ IN THE AVERAGE TREE DIAMETER AND THE CLASS INTO WHICH IT FITS**

```
READ(NCRDR,960) AVDBH,ICLAS
960 FORMAT(F10.3,I4)
READ(NCRDR,71) XLAND,PTML
71 FORMAT(2F10.3)
SCINC=SCIN1
```

**C*****READ IN CONTROL VARIABLE REPRT FOR PRINTOUT OF YEARLY REPORTS**

```
C****REPT=0, NO PRINTOUT REPT=1, YEARLY PRINTOUT
C****REPT=1, NO END OF SIMULATION PRINTOUT
```

```
READ(NCRDR,24) REPRT
24 FORMAT(F10.4)
```

**C*****NOW READ IN THE GASPT DATA COMMON TO EVERY CASE**

```
NGT=0
CALL DATAN(NSET)
```

**C*****INITIALIZE THE CASE NUMBER AT ICASE**

```
NCASE=ICASE=1
```

**C*****NOW EITHER INITIALIZE OR VARY THE SKIDDING SYSTEM IN USE.**

```
C*****SKIDDING SYSTEMS HAVE THE FOLLOWING CODES:
C*****MNVR=1 IMPLIES A ROLLING STOCK SKIDDING SYSTEM
```

Figure 16: (continued)
Three combinations of trailers and bunks exist. Standard trailers may be used in either a "regular" system or one employing a preload bunk. Prehaul trailers are used only with prehaul docks and never, in this model, with a preload bunk. The combinations vary from KSYS1 to KSYS2. The three combinations are identified by KSYS in the following manner:

1. KSYS = 1 implies use of standard trailers;
2. KSYS = 2 implies use of prehaul trailers;
3. KSYS = 3 implies use of a preload bunk and standard trailers.

KSYS1 is the first value on the second data card, followed by KSYS2. Then the truck categories vary from ITCA1 to ITCA2. Trucks are classified, in terms of their original cost, into six categories. The final elements of data card two specify the number of trucks to be varied from ITK1 to ITK2.

The third data card contains five elements concerned only with prehaul trailers and one concerned with truck schedules. The number of shuttle trucks present when KSYS equals two varies from SUTK1 to SUTK2. EXTR1 represents the initial number of empty prehaul trailers at the dock, while EXTR2 depicts the initial number of full trailers. XMDKL represents the number of miles from the mill to the prehaul dock. Finally, SCIN1 consists of the number of minutes allowed between each truck arrival for unforeseen delays.

The number of combinations of the above variables approaches infinity. However, using some judgement and intuition, the number of
feasible combinations can be reduced to a reasonable number. However, this number of combinations will still involve a sizeable investment in computer time. Before simulating any combinations, note that variance of more than one variable results in a combinatorial number of cases. Thus, if the loader category varied from one to three and the number of trucks from six to seven, there would be six cases simulated. Figure 17 contains a complete listing of all input data.

GENERAL INPUT DATA

Following input of control variables, data concerned with the various elements of the loading and hauling subsystems are fed into the model. The first such input statement (actually associated with data card number four) concerns skidding information necessary for the calculation of the decking cost. The seven values contained on the fourth data card are defined as:

1. WGSO, the wage of the skidder operator;
2. RTSO, the skill rating of the skidder operator;
3. COOS, the cost to own and operate the skidder;
4. SCPH, skidding cycles per hour;
5. SVPC, skidding volume, in MBF, per cycle;
6. TQ1, the number of minutes required to build a class one log deck;
7. TQ2, the number of minutes required to build a class two log deck.
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</tr>
<tr>
<td></td>
<td></td>
<td>SCIN1 10.0</td>
</tr>
<tr>
<td>4</td>
<td>7F10.3</td>
<td>WGO 4.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RTSO 1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>COOS 5.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SCPH 7.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SVPC 0.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TQ1 0.383</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TQ2 0.383</td>
</tr>
<tr>
<td>5</td>
<td>2F4.1,F5.4</td>
<td>TSV(1) 0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>USL(1) 8.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SLV(1) 0.20</td>
</tr>
<tr>
<td>6</td>
<td>4F10.3</td>
<td>CSLD(1,1) (1,2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1,3) (1,4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>34000.0 37500.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40500.0 43000.0</td>
</tr>
<tr>
<td>7</td>
<td>4F10.3</td>
<td>CAPL(1,1) (1,2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1,3) (1,4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2000.0 3000.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4000.0 5000.0</td>
</tr>
<tr>
<td>8</td>
<td>4F10.3</td>
<td>BHP(1,1) (1,2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1,3) (1,4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>94.0 110.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120.0 130.0</td>
</tr>
<tr>
<td>9</td>
<td>4F5.1</td>
<td>OPDV(1,1,1,1) (1,1,1,2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1,1,1,3) (1,1,1,4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.2 25.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0 0.0</td>
</tr>
<tr>
<td>252</td>
<td>4F5.1</td>
<td>OPDV(6,8,4,1) (6,8,4,2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6,8,4,3) (6,8,4,3)</td>
</tr>
</tbody>
</table>

Figure 17: Listing of input data for present simulation model for non-GASP data (See Appendix 19 for listing of all loading times)
<table>
<thead>
<tr>
<th>Card Number</th>
<th>Format</th>
<th>Data Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>253</td>
<td>7F10.3</td>
<td>POLR 0.95 AVMBF 5.0 COT 120.0 WGLO 4.20 RTLO 1.00 WGETS 3.50 RTTS 1.00</td>
</tr>
<tr>
<td>254</td>
<td>5F10.3</td>
<td>CSTK(1) USTK(1) SVLTK(1) VDFT(1) VGT(1) 5000.0 5.0 0.06 1.0 0.0</td>
</tr>
<tr>
<td>255</td>
<td>5F10.3</td>
<td>CSTK(1) USTK(1) SVLTK(1) VDFT(1) VGT(1) 10000.0 3.6 0.33 1.0 0.0</td>
</tr>
<tr>
<td>256</td>
<td>5F10.3</td>
<td>CSTK(1) USTK(1) SVLTK(1) VDFT(1) VGT(1) 15000.0 6.0 0.20 1.0 0.0</td>
</tr>
<tr>
<td>257</td>
<td>5F10.3</td>
<td>CSTK(1) USTK(1) SVLTK(1) VDFT(1) VGT(1) 20000.0 10.0 0.12 1.0 0.0</td>
</tr>
<tr>
<td>258</td>
<td>5F10.3</td>
<td>CSTK(1) USTK(1) SVLTK(1) VDFT(1) VGT(1) 25000.0 17.0 0.075 1.0 0.0</td>
</tr>
<tr>
<td>259</td>
<td>5F10.3</td>
<td>CSTK(1) USTK(1) SVLTK(1) VDFT(1) VGT(1) 30000.0 20.0 0.06 1.0 0.0</td>
</tr>
<tr>
<td>260</td>
<td>4F10.3</td>
<td>WGETS 3.50 POTK(1) 0.10 POTK(2) 0.40 POTK(3) 0.90</td>
</tr>
<tr>
<td>261</td>
<td>10F5.3</td>
<td>RTTD(1) 1.0 (2) (3) (4) (10)</td>
</tr>
<tr>
<td>262</td>
<td>3F10.4</td>
<td>CSTR(1) 4418.0 CSBK(1) 0.0 CSMSC(1) 0.0</td>
</tr>
<tr>
<td>263</td>
<td>3F10.4</td>
<td>(2) (2) (2)</td>
</tr>
</tbody>
</table>

Figure 17: (continued)
<table>
<thead>
<tr>
<th>Card Number</th>
<th>Format</th>
<th>Data Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(3)</td>
<td>(3)</td>
</tr>
<tr>
<td>264</td>
<td>3F10.4</td>
<td>4418.0</td>
</tr>
<tr>
<td></td>
<td>XMIPA</td>
<td>XMIPR</td>
</tr>
<tr>
<td>265</td>
<td>6F10.3</td>
<td>40.0</td>
</tr>
<tr>
<td></td>
<td>DAY(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>266</td>
<td>12F6.3</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td>WTHP(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>267</td>
<td>12F6.3</td>
<td>0.60</td>
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<tr>
<td></td>
<td>TIDAY(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>268</td>
<td>12F6.3</td>
<td>300.0</td>
</tr>
<tr>
<td></td>
<td>FLCTD</td>
<td>FLCTD</td>
</tr>
<tr>
<td>269</td>
<td>4F10.3</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>TIIPR</td>
<td>WCPR</td>
</tr>
<tr>
<td>270</td>
<td>4F10.5</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>XMTBK(1)</td>
<td>XMTTK(1)</td>
</tr>
<tr>
<td>271</td>
<td>6F10.3</td>
<td>12000.0</td>
</tr>
<tr>
<td></td>
<td>XMTBK(2)</td>
<td>XMTTK(2)</td>
</tr>
<tr>
<td>272</td>
<td>4F10.3</td>
<td>122400.0</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>(3)</td>
</tr>
<tr>
<td>273</td>
<td>4F10.3</td>
<td>367200.0</td>
</tr>
</tbody>
</table>

Figure 17: (continued)
<table>
<thead>
<tr>
<th>Card Number</th>
<th>Format</th>
<th>Data Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>XMNCL</td>
</tr>
<tr>
<td>274</td>
<td>4F10.3</td>
<td>200.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>XMNCT(1)</td>
</tr>
<tr>
<td>275</td>
<td>10F8.2</td>
<td>350.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>XNTDT</td>
</tr>
<tr>
<td>276</td>
<td>4F10.2</td>
<td>755.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ULELO</td>
</tr>
<tr>
<td>277</td>
<td>7F10.3</td>
<td>0.70</td>
</tr>
<tr>
<td>278</td>
<td>F1013,14</td>
<td>14.0</td>
</tr>
<tr>
<td>279</td>
<td>2F10.3</td>
<td>0.40</td>
</tr>
<tr>
<td>280</td>
<td>F10.3</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Figure 17: (continued)
Information concerning variables associated with loader categories compose the largest block of data. Presently this information requires 249 data cards, with card numbers from 5 to 253. The final data card of this series contains elements common to all loader categories. The other elements vary for each loader category and some for each size class. All values common to a certain loader category are submitted to the model together. Thus, a block of data exists for each of the six categories. Cards pertaining to each category are listed below.

Cards 5 - 42 - a fully articulated hydraulic loader
Cards 43 - 72 - a loader with air or hydraulic pinchers
Cards 73 - 110 - a heelboom loader with grapple
Cards 111 - 148 - a heelboom loader with tongs
Cards 149 - 214 - a front-end loader
Cards 215 - 252 - a long-boom loader

Input of these 249 cards is accomplished through use of seven computer statements and several computer "do-loops." A do-loop simply causes a statement or series of statements to be repeated after incrementing a counter. Thus, the seven statements are repeated six times, incrementing the loader category, LCAT, each time. The values submitted to the computer in these seven statements are defined as:

1. $T_{SV(LCAT)}$, a variable that is one if a loader in category LCAT needs a tongsetter and zero if it does not;
2. USL\textsubscript{(LCAT)}, the economic life of a loader in category LCAT;
3. SVL\textsubscript{(LCAT)}, the salvage value expressed as a percent of the original cost;
4. CSLD\textsubscript{(LCAT,ISV)}, the original cost of a loader in category LCAT and size class ISV;
5. CAPL\textsubscript{(LCAT,ISV)}, the lifting capacity of a loader in category LCAT and size class ISV;
6. BHP\textsubscript{(LCAT,ISV)}, the brake-horsepower of the loader;
7. OPDV\textsubscript{(LCAT,NYEAR,ISV,ICLAS)}, the time in minutes required to load a truck by a loader in category LCAT, of age NYEAR, in size class ISV, when the timber loaded is in timber class ICLAS;
8. XLDMN\textsubscript{(LCAT,ICLAS)}, the smallest size class, ISV, in loader category LCAT that can lift a single log in timber class ICLAS;
9. VDFL\textsubscript{(LCAT)}, a variable that is one if diesel fuel is used to power the loader and zero if it is not;
10. VGL\textsubscript{(LCAT)}, a variable that is one if gasoline is used to power the loader and zero if it is not;
11. CLMSC\textsubscript{(LCAT)}, the cost per extra landing if one must be built for loaders in category LCAT.

The items 1, 2, and 3 in the above list are read into the computer on a single data card. Items 4, 5, and 6 each require a single data card. Each card contains four values, however, since ISV varies from
one to four. Item 7 requires a number of data cards equal to four multiplied by the economic life. This accounts for each combination of size class, ISV, and age, NYEAR. Each of the data cards contains four values representing the four timber classes. Item 8 is contained on a single data card having four values. The final three items 9, 10, and 11 are contained on the final data card of the data block. The card numbers mentioned in this discussion can be cross referenced with Figure 17.

Values constant for all loader categories, contained on data card number 253, are defined as:

1. POLR, the probability that outside help will be needed to repair a loader breakdown of the second severity level;
2. AVMBF, the average timber volume per truck load;
3. COT, the maximum time trucks remain at the landing after a loader breakdown;
4. WGLO, the wage of the loader operator;
5. RTLO, the skill rating of the loader operator;
6. WGTS, the wage of the tongsetter;
7. RTTS, the skill rating of the tongsetter.

Following input of loader data, information concerned with log carriers is read into the computer. These data again consist of some elements which vary with truck category and some which remain constant. Data which vary with the truck category are contained on card numbers 254 to 259. Each of the six cards contain the following values:
1. \( \text{CSTK}^\text{(ITCA)} \), the original cost of a truck in category ITCA;
2. \( \text{USTK}^\text{(ITCA)} \), the economic life of a truck in category ITCA;
3. \( \text{SVLTK}^\text{(ITCA)} \), salvage value of the truck expressed as a percent of the original cost;
4. \( \text{VDFT}^\text{(ITCA)} \), a variable that is one if a truck in category ITCA is powered by diesel fuel and zero if not.
5. \( \text{VGT}^\text{(ITCA)} \), a variable that is one if a truck is powered by gasoline and zero if not.

Two other data cards, numbers 260 and 261, contain truck data that are constant for all truck categories. These values are defined as:

1. \( \text{WGTD} \), the wage paid all truck drivers;
2. \( \text{POTK}^\text{(ISEVL)} \), the probability that outside help will be needed to repair a truck breakdown of severity level ISEVL;
3. \( \text{RTTD}^\text{(ITKN)} \), the skill rating of the driver of truck number ITKN.

Truck categories are defined in terms of the original cost of the truck-tractor. Each category has an associated cost and economic life. The category definitions used in this model are shown in Figure 18.
<table>
<thead>
<tr>
<th>Truck Category</th>
<th>Original Tractor Cost</th>
<th>Economic Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$ 5,000 (used)</td>
<td>3 years</td>
</tr>
<tr>
<td>2</td>
<td>10,000</td>
<td>3.6</td>
</tr>
<tr>
<td>3</td>
<td>15,000</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>20,000</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>25,000</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>30,000</td>
<td>20</td>
</tr>
</tbody>
</table>

Figure 18: Truck categories defined in terms of their original cost and economic life.

Input of trailer and bunk costs follow the truck data. This section consists of three cards, numbered 262, 263, and 264 for the three types of trailer-bunk combinations. The values read into the computer are defined as:

1. $CSTR_{(KSYS)}$, the original cost of the trailer used in trailer-bunk combination $KSYS$;
2. $CSBK_{(KSYS)}$, the original cost of the bunk;
3. $CSMSC_{(KSYS)}$, the cost per landing of extra landings.

Card number 265 contains information regarding the miles and average truck speed for each type road. The values are defined as:

1. $XMIPA$, miles of pavement;
2. $XMIPR$, miles of primary road;
3. $XMIS$, miles of spur road;
4. $XPHPA$, average truck speed on pavement;
5. XPHPR, average truck speed on primary road;
6. XPHS, average truck speed on spur road.

Data concerning the days in each month, the probability of good weather in a particular month, and the scheduled working time in a day during a particular month are read into the computer on card numbers 266, 267, and 268. The values are respectively called DAY(MONTH), WTHP(MONTH), and TIDAY(MONTH).

The cost of fuel and the fuel consumption rate are read into the computer on data card 269. The values concern the cost of both diesel fuel and gasoline, respectively called FLCTD and FLCTG; and the fuel consumption rate of both the loader and the trucks, respectively called FLCNL and TFLCN.

Insurance, interest, taxes and the desired rate-of-return are all expressed as a percent of equipment value. They are contained on data card 270. Insurance, interest, and tax cost is expressed as a percent called TIIPR. Workmen's compensation, expressed as a percent of wages is called WCPPR. RR, denoting the rate-of-return, expresses the minimum required return on investment. Administrative costs are expressed as ADMPR, a percent of equipment value.

Card numbers 271 to 275 express values concerned with breakdowns. The first three cards contain data specifying average values of the duration, repair time, and time between breakdowns for each piece of equipment and severity level. The values are defined as:
1. $X_{MTBK}(ISEVL)$, the mean time between loader breakdowns of severity level $ISEVL$;
2. $X_{MTTK}(ISEVL)$, the mean time between truck breakdowns of severity level $ISEVL$;
3. $X_{MDBK}(ISEVL)$, the mean duration of loader breakdowns;
4. $X_{MDTK}(ISEVL)$, the mean duration of truck breakdowns;
5. $X_{MRBK}(ISEVL)$, the mean repair time of loader breakdowns;
6. $X_{MRTK}(ISEVL)$, the mean repair time of truck breakdowns.

Card number 274 contains the values of the yearly expenditure for loader preventive maintenance, $XMGL$; percent utilization of truck drivers and tongsetters during loader breakdowns, $UFE$; and the wage of repair personnel for loader breakdowns and truck breakdowns, respectively called $WGMP$ and $WGMT$. Card 275 contains the yearly expenditure for preventive maintenance on each truck. It is defined as $X_{MNCT}(ITKN)$ where $ITKN$ is the truck number.

Following repair of a breakdown, scheduling of productive activity for the equipment depends upon the time remaining in the day. $X_{NTDT}$ is the time necessary before truck activity can be scheduled, and $X_{NTDL}$ is the time necessary before loader activity can begin. These items represent the first two values on data card 276. Also contained on this card are the expected yearly operating hours, $EYOH$ and the average amount of defect, called $DEFCT$, in the timber being processed.
Data card 277 contains information necessary for calculation of breakdown costs. These values include percent utilization of the loader operator and truck drivers while certain equipment is "down" and the cost of towing a truck in dollars per mile. Specifically, they are defined as:

1. ULELO, the percent utilization of the loader operator while waiting for parts;
2. ULTRK, the percent utilization of the truck unit during a loader breakdown;
3. ULETD, the percent utilization of a truck driver while waiting for truck repair parts;
4. CSTOW, the cost of towing a truck in dollars per mile;
5. ULTDR (ISEVL), the percent utilization of a truck driver during repair of a breakdown of severity level ISEVL.

The average size of the timber being processed is contained on data card 278. Two values describe the size of timber. AVDBH represents the average diameter and IGLAS specifies the size classification. Timber is classified into one of four categories depending upon its average diameter. Class one contains trees with a diameter under 12 inches; class two contains trees with a diameter between 12 and 16 inches; class three, diameters between 16 and 20 inches; and class four, diameters above 20 inches.

Data card 278 specifies the slope limit above which excavated landings require extra building costs. This limit is defined as XLAND.
The card also contains the average time required to position trucks at the landing. This variable is known as PTML.

The final non-GASP data card contains the variable known as REPRT. This variable is set to one if an end-of-year report is desired and to zero if it is not desired.

The GASP variables are read into the computer in a subroutine called DATAN. The only data of concern to the user are the values stored in the array, PARAM\(_{(I,J)}\). The four values of "J" have already been identified as the mean, minimum, maximum, and standard deviation of a normal distribution. The subscript "I" represents a code identifying the particular normal distribution. Identifications of the code numbers are listed below.

1. \(I = 1\) indicates a distribution of the cost of parts for a loader breakdown of severity level one.
2. \(I = 2\) indicates a distribution of the cost of parts for a loader breakdown of severity level two.
3. \(I = 3\) indicates a distribution of the cost of parts for a loader breakdown of severity level three.
4. \(I = 4\) indicates a distribution of the cost of parts for a truck breakdown of severity level one.
5. \(I = 5\) indicates a distribution of the cost of parts for a truck breakdown of severity level two.
6. \(I = 6\) indicates a distribution of the cost of parts for a truck breakdown of severity level three.
7. $I = 7$ indicates a distribution of the slope of the terrain at the logging area.

**SUMMARY**

Knowledge of the input data just mentioned facilitates simulation of the loading and hauling subsystems. These data should be largely supplied by the user. In cases where some data are unavailable, the data used in this model may be substituted for actual data. However, before using any data presented in this model, it should be carefully investigated in terms of the particular system under study.

As previously mentioned, the user may utilize some of this data for his particular logging situation. These data would probably include the loading time of a loader, information regarding the various loader and truck categories, and data pertaining to breakdowns. However, there are some data that must be researched and supplied by the user. These include the wage rates for all employees and their skill ratings. The user must also specify the loader and trucks as either diesel or gasoline powered. The logging site must be described in terms of the distance from the mill, the timber size, and the distribution of the slope. The cost of fuel, insurance, interest, taxes, and administration must be defined for the particular situation under study. Finally, the yearly amount for preventive maintenance must be specified.
This does not represent an exclusive list of the data a user needs to supply, but it does define the minimum amount of data to be supplied.

The data pictured in Figure 17 was used to test several variable combinations which could exist. The results are presented in the three case studies described in chapter six. A complete listing of all variables used in the computer model is contained in Appendix 20.
CHAPTER 6

SIMULATION RESULTS: THREE EXAMPLES

Simulation of all possible combinations of variables would require a great deal of time and expense. Since the data currently used in the model represent a hypothetical logging site, total enumeration of all variables was not deemed worthwhile. However, certain selected variables were varied in three case studies to show some uses of the simulation model.

CASE I: THE BEST LOADER TYPE

Suppose a logging contractor wished to purchase a new loader. He is not interested in any of the other factors at present and assumes that they remain constant. He is therefore only interested in varying the loader type and selecting the loader that operates for the minimum equivalent annual cost.

All control elements except LCAT1 and LCAT2 are set to their constant values. LCAT1 is set equal to one and LCAT2 is six. The simulation run is now completed and a comparison among the six results is made. These are shown for the six cases in Table 1. An example of the computer printout of one year's results is shown in Figure 19. A complete computer printout of one simulation run is listed in Appendix 18.
CASE STUDY I: THE BEST LOADER

Constant Factors:

- Skidding system - 1 Rolling Stock Skidders
- Loader size class - 2
- Truck Cost - $25,000
- Number of trucks - 7
- Trailer - bunk combination - 1 - standard trailers

SIMULATION RESULTS:

<table>
<thead>
<tr>
<th>Loader Category</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent busy time</td>
<td>33%</td>
<td>-</td>
<td>36%</td>
<td>65%</td>
<td>54%</td>
<td>34%</td>
</tr>
<tr>
<td>Percent down time</td>
<td>9%</td>
<td>-</td>
<td>9%</td>
<td>8%</td>
<td>9%</td>
<td>9%</td>
</tr>
<tr>
<td>COST 1 in $/MBF</td>
<td>$0.011</td>
<td>-</td>
<td>$0.011</td>
<td>$0.011</td>
<td>$0.011</td>
<td>$0.011</td>
</tr>
<tr>
<td>COST 2 in $/MBF</td>
<td>.929</td>
<td>-</td>
<td>1.939</td>
<td>3.107</td>
<td>2.316</td>
<td>.962</td>
</tr>
<tr>
<td>COST 3 in $/MBF</td>
<td>2.665</td>
<td>-</td>
<td>3.093</td>
<td>4.061</td>
<td>2.693</td>
<td>2.734</td>
</tr>
<tr>
<td>COST 4 in $/MBF</td>
<td>.636</td>
<td>-</td>
<td>.792</td>
<td>.134</td>
<td>.300</td>
<td>.591</td>
</tr>
</tbody>
</table>

TOTAL AVERAGE COST IN DOLLARS PER MBF

| 15.828 | - | 16.484 | 21.970 | 17.700 | 16.046 |

EQUIVALENT ANNUAL COST IN DOLLARS PER MBF


Table 1: Results of simulation for Case Study 1
**NON-CUMULATIVE COST SUMMARY FOR YEAR 1 CASE 1**

**PRODUCTIVITY** = 6574.496 MBF

**COST 1** — COST TO DECK LOGS AT LANDING

COST 1 = $0.011 PER MBF

**COST 2** — ACTUAL LOADING COST

COST TO OPERATE = CSOPL = $12496.504 PER YEAR
COST TO OWN = CSOWL = $4.139 PER HOUR
ACTUAL OPERATING HOURS = 1455.553 HOURS
LOADING COST = COST2 = $3.065 PER MBF

**COST 3** — COST OF LOADER BREAKDOWN

Figure 19: Example of cost printout of first year's operation
YEARLY COST TO REPAIR BREAKDOWNS = $ 28417.441
COST OF IDLE TIME = $ 5361.051
BREAKDOWN TIME AS PERCENT OF TOTAL = 10.1923 %
TOTAL BREAKDOWN COST = COST3 = $ 4.322 PER MBF

COST4 --- COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING
AVERAGE NUMBER OF TRUCKS AT THE LANDING = 0.8528
TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = 34.3083 %
COST OF UNPRODUCTIVE TIME = COST4 = $ 0.076 PER MBF

COST5 --- COST TO OWN AND OPERATE TRUCKS
TOTAL NUMBER OF TRUCKS = 7.0
AVERAGE TRUCK TIME AT LANDING = 76.995 MINUTES
AVERAGE TIME WAITING TO BEGIN LOADING = 17.237 MINUTES
AVERAGE NUMBER OF TRUCKS NOT BROKEN DOWN = 6.511
COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $ 14.824 PER MBF

TOTAL COST OF THE SYSTEM
TOTAL COST = COST8T = $ 22.298 PER MBF

Figure 19: (continued)
The identification codes of the loader categories were listed previously in the thesis. The results presented in Table 1 indicate the best loader to use under the circumstances described in the data. The data indicate that the timber being processed is in the second class, with an average diameter between 12 and 16 inches, and that the loader size being tested is in size class two. This combination of variables results in the elimination of the second loader category from consideration. Since a loader with air or hydraulic pinchers in size class two cannot lift a log in timber class two, the category can be eliminated from consideration.

The five remaining loader categories are compared by their total costs. The equivalent annual costs of the fully articulated loader (category one) and the long-boom loader (category six) are nearly equal. Although the long-boom loader operates at the lowest equivalent annual cost, it is so close to the cost of the fully articulated loader that the costs might be assumed equivalent. The basis for decision would then be intangible factors dealing with personal preference for one loader type over another. In this case, the contractor might believe that the fully articulated loader would be easier to maneuver throughout the logging site and base his decision between the equivalent alternatives on this factor.
Suppose the operator of this study was interested only in purchasing new logging trucks. His present fleet consists of five trucks, and he believes he is financially able to add up to three additional logging trucks. Thus, he will use the simulation to test the total system cost with six, seven, and eight trucks. The loader used in his system is a fully articulated hydraulic loader. The other system variables are the same as those used in the first case study. Varying the number of trucks from six to eight implies that ITK1 will be six and ITK2 will be eight. The results of the three simulation runs are shown in Table 2.

The combination yielding the minimum equivalent annual cost is the one utilizing eight trucks. The contractor should, therefore, purchase three additional trucks. This does not imply that eight trucks are the optimal number for the system, but only the best of the three numbers tested. Observation of the costs for all three combinations indicates the possibility of an optimal number of trucks at nine or ten trucks. This is indicated by the downtrend in cost between seven and eight trucks.
CASE STUDY II: THE BEST NUMBER OF TRUCKS

Constant Factors:
- Skidding system: Rolling Stock Skidders
- Loader category: Fully Articulated Hydraulic Loader
- Loader size class: 2
- Truck cost: $25,000
- Trailer-bunk combination: Standard trailers

SIMULATION RESULTS:

<table>
<thead>
<tr>
<th>Number of Trucks</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Busy Time</td>
<td>29%</td>
<td>33%</td>
<td>42%</td>
</tr>
<tr>
<td>COST 1 in $/MBF</td>
<td>$0.011</td>
<td>$0.011</td>
<td>$0.011</td>
</tr>
<tr>
<td>COST 2 in $/MBF</td>
<td>1.544</td>
<td>0.929</td>
<td>0.894</td>
</tr>
<tr>
<td>COST 3 in $/MBF</td>
<td>2.268</td>
<td>2.665</td>
<td>2.146</td>
</tr>
<tr>
<td>COST 4 in $/MBF</td>
<td>.791</td>
<td>.636</td>
<td>.517</td>
</tr>
<tr>
<td>COST 5 in $/MBF</td>
<td>9.949</td>
<td>11.587</td>
<td>11.433</td>
</tr>
<tr>
<td>TOTAL AVERAGE COST IN DOLLARS PER MBF</td>
<td>14.563</td>
<td>15.828</td>
<td>15.001</td>
</tr>
<tr>
<td>EQUIVALENT ANNUAL COST IN DOLLARS PER MBF</td>
<td>15.190</td>
<td>16.108</td>
<td>15.051</td>
</tr>
</tbody>
</table>

Table 2: Results of simulation for Case Study 2
The final case presents a study of the best trailer-bunk combination. Suppose a contractor decided to investigate the use of prehaul trailers and preload bunks. His current system consists of a fully articulated loader and eight trucks with standard trailers. He wishes to investigate the results of a modification of this system by use of either prehaul trailers or the additions of a preload bunk. Since a system utilizing prehaul trailers introduces two additional variables to the logging system, the contractor will test the prehaul system using both two and three shuttle trucks. Thus, four cases are simulated with the results shown in Table 3 on the following page. The control variables for this case are set with KSYS1 as one, KSYS2 as 2, SUTK1 as two, and SUTK2 as three.

Simulation results in Table 3 indicate that the existing system is most economical. However, reflection on the cases which were tested will reveal that the testing technique used here is very incomplete. The expected result of using prehaul trailers or a preload bunk is greater utilization of the loader with fewer logging trucks. Therefore, for system three, utilization of a preload bunk, the number of trucks should again be varied. For system two, utilization of prehaul trailers, the number of trucks should also be varied. In addition, a more complete analysis of the best number of shuttle
CASE STUDY III: USE OF PREHAUL TRAILERS AND BUNKS

Constant Factors:

- Skidding System: Rolling Stock Skidders
- Loader Category: Fully Articulated Hydraulic Loader
- Loader Size Class: 2
- Truck Cost: $25,000
- Number of Trucks: 8

SIMULATION RESULTS:

<table>
<thead>
<tr>
<th>Type combination:</th>
<th>Standard</th>
<th>Prehaul 2 sh tk</th>
<th>Prehaul 3 sh tk</th>
<th>Bunk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Busy Time</td>
<td>42%</td>
<td>25%</td>
<td>34%</td>
<td>32%</td>
</tr>
<tr>
<td>COST 1 in $/MBF</td>
<td>$0.011</td>
<td>$0.011</td>
<td>$0.011</td>
<td>$0.011</td>
</tr>
<tr>
<td>COST 2 in $/MBF</td>
<td>.894</td>
<td>.980</td>
<td>.912</td>
<td>.817</td>
</tr>
<tr>
<td>COST 3 in $/MBF</td>
<td>2.146</td>
<td>4.690</td>
<td>2.479</td>
<td>1.970</td>
</tr>
<tr>
<td>COST 4 in $/MBF</td>
<td>.517</td>
<td>1.070</td>
<td>.763</td>
<td>.691</td>
</tr>
<tr>
<td>COST 5 in $/MBF</td>
<td>11.433</td>
<td>15.623</td>
<td>13.443</td>
<td>12.623</td>
</tr>
<tr>
<td>TOTAL AVERAGE COST IN DOLLARS PER MBF</td>
<td>15.001</td>
<td>22.374</td>
<td>17.608</td>
<td>16.412</td>
</tr>
<tr>
<td>EQUIVALENT ANNUAL COST IN DOLLARS PER MBF</td>
<td>15.051</td>
<td>22.294</td>
<td>17.670</td>
<td>16.587</td>
</tr>
</tbody>
</table>

Table 3: Results of simulation for Case Study 3
trucks and the dock location should be made. The best results for systems two and three should be compared with the result for the existing system.

SUMMARY

The examples presented in this chapter represent a small part of the total number of combinations existing among loading and hauling variables. General conclusions regarding the best combination of variables are not possible at this time. Conclusions greatly depend upon the particular location of the logging site. This will vary for each contractor.

The result of this thesis investigation is not, therefore, an ideal combination of loading and hauling variables. Rather, the result presents a simulation model adaptable to the many logging situations in existence. It allows the determination of a single variable of the system or of the best combination of all variables. As more data become available and more simulation tests are made, knowledge of the most sensitive system variables should allow a reduction in the number of test runs that need to be made in any particular case.
CHAPTER 7

THESIS SUMMARY

The logging industry consists of five subsystems that first convert a tree to a log and subsequently transport the log to a conversion mill. Logmaking comprises two of the subsystems. Since work in these subsystems is generally performed by one or more men with chainsaws, the productivity of the logmaking subsystems greatly depends upon the skill of the worker. An intermediate transportation subsystem, called the skidding subsystem, transports logs from the stump area to a landing. The skidding subsystem has been subjected to considerable analysis and research to determine the best types of equipment to use. Loading consists of the movement of logs from log decks at the landing to the log carriers. The log carriers accomplish the long-distance transportation of logs from the landing to some processing point, either a mill or a prehaul dock. This final logging subsystem is known as the hauling subsystem.

Neither the loading nor hauling subsystems has been subjected to any substantial analysis. Since they are so closely related, any analysis of these subsystems should account for the effects of both. Both subsystems are analyzed in the simulation model developed in this thesis.
The simulation model developed duplicates the activities and events of the actual loading and hauling subsystems. Various combinations of system elements can then be tested to find the combination which operates for the least equivalent annual cost expressed in dollars per MBF.

The criterion used to test alternatives represents a ratio of investment to productivity. Calculation of this cost necessitates some cost structure where relevant costs may be established and calculated. The cost structure is composed of five sub-costs; namely the cost of decking, the actual loading cost, and cost of loader breakdowns, the cost of loader idle time when no trucks are at the landing, and the cost to own and operate a certain number of trucks. These are respectively called COST1, COST2, COST3, COST4, COST5. Each of the sub-costs are, in turn, affected by certain distinct factors. Some of these factors directly affect a specific sub-cost with the addition of a relevant cost. Some, however, have an indirect effect upon the sub-cost. Specification of the relationships among all cost factors and the five sub-costs results in a cost structure from which an equivalent annual operating cost can be determined.

Calculation of the five sub-costs requires some information determined from manipulation of the simulation model. The model is defined in terms of the events that can occur in the actual loading and
hauling subsystems. These events vary from the different truck-trailers used in the system. Systems with standard trailers are controlled primarily by two events, the arrival of a truck at the landing and the end of loading of the truck. Three additional events control system activities when a breakdown, end of repair of a breakdown, or an end of the working day occur. Systems with prehaul trailers must include two additional events, the arrival of a truck at the prehaul dock and an end of service at the dock. Recall that an event signals the beginning or ending of system activities. A computer subroutine describing an event must account for all activities caused by the occurrence of the event. This includes scheduling the time the next event is to occur.

A fully developed simulation model and its related cost structure combine to form a decision-making tool. The model, when manipulated, selects the variable combination with the minimum equivalent annual cost.

MODEL ASSUMPTIONS AND FUTURE RESEARCH

As in most models, certain assumptions were made to simplify the model and to account for the present lack of valid loading and hauling data. Two assumptions concern the relationships of the loading and hauling subsystems with other subsystems of the logging industry. These assumptions are as follows:
1. The loading subsystem will never have to wait for the skidding subsystem, but will always have logs available at the landing.

2. The logging contractor can sell as much timber as he produces and is not restricted by the processing mill.

The first assumption represents the general situation in the logging system. The logmaking and skidding subsystems work far enough ahead of the loading subsystem that the loader will seldom run out of logs. The second assumption, however, presents an area open to future research. There are many situations where a logging contractor can sell as much as he produces. But in some instances the processing mill will buy only a certain amount. Elimination of this assumption could be accomplished by modification of certain sections of the existing model.

Other model assumptions relate to operations and situations within the loading and hauling subsystems. The third model assumption relates to the area of operation as follows:

3. Logging operations take place in the Northern Rocky Mountain region.

Several assumptions relate to the design of the loading and hauling subsystems in terms of logging site location, equipment types used, and variable combinations. These assumptions are listed as:

4. Logging takes place at a single site the entire length of the simulation.
5. The number of miles of spur road is assumed to be a constant equal to the distance from the primary road to the middle of the logging site.

6. Logging trucks with trailers are used as log carriers.

7. The combination of prehaul trailers and a preload bunk will not be tested in this thesis.

Assumptions 4 and 7 represent areas of possible modification. Modifications for assumption 4 would consist of allowing variable distances from the mill to the landing and variable terrain characteristics to occur at certain points of simulated time. Modifications for assumption 7 would entail definition of any special events and activities associated with a combination of the preload bunk and pre­haul trailers. These modifications were not pursued in the present model because of a lack of time to develop them properly.

Certain assumptions regarding loader productivity reflect a lack of the real data necessary to derive valid relationships. These assumptions are listed as:

8. The relationship between logging deck quality and loader productivity is recognized but assumed to be negligible.

9. The type landing is assumed to have no effect upon loader productivity for all categories but the front-end loader.

Other assumptions reflect lack of necessary data for development of relationships between equipment age and other system elements. These are listed as:
10. Fuel consumption remains constant during the equipment life.
11. Preventive maintenance expenditures remain constant during the equipment life.

All assumptions contingent upon the availability of real data should be investigated and modified when the data becomes available. The greatest number of assumptions pertain to equipment breakdowns. These assumptions are generally caused by lack of real data. The assumptions are listed as follows:

12. Equipment operators help with the repair of all breakdowns.
13. Outside help will be needed a certain percent of the time.
14. Trucks are towed to a repair point only following the occurrence of second and third severity level breakdowns.
15. Frequency, duration, and repair time of breakdowns are described by negative exponential distributions.
16. A loader that is down will not be replaced by a reserve loader.
17. Breakdown repair occurs only during originally scheduled working time.
18. The intangible cost of system delay caused by a loader breakdown is recognized, but is assumed to be the same for all variable combinations.

Finally, four assumptions regarding landings, arrivals to the landing, and the priority scheme in waiting lines are listed as follows:
21. Truck arrivals to the landing or prehaul dock are scheduled only if enough time remains in a working day for the truck to arrive before the scheduled end of day.

22. All queues are processed on a first-in, first-out basis.

All assumptions of this model introduce areas that could be subjected to further research. The user should investigate these assumptions, and if any strongly contradict his specific situation, he should attempt to modify the model and eliminate the invalid assumption.

PRESENT USES OF THE MODEL:

The present model, when supplied with data regarding a particular logging site, represents a decision tool which the contractor can use in equipment purchases and system design. Although the costs found in the simulation may vary somewhat from actual operating costs, their comparative value should still be valid.

The user should remember, however, that this is only a decision tool, and that the simulation model has been restricted by certain assumptions. When these factors are kept in focus, the model user should find the results of this model to be of great assistance in decision making.
Simulation models do not exist without certain disadvantages. A simulation model will not solve for an optimal result but only the "best" result in terms of the alternatives tested. Use of a simulation model of this size also involves an expense in the computer time required to test different combinations. However, in a system containing the many variables existing in the loading and hauling subsystems, simulation may be the only decision-making tool available.

Simulation also implies several advantages over other decision-making tools. Major system changes can be tested in the simulation model before they are tried in the actual system. Usually this can be done with a minimum number of model changes. Simulation usually requires a minimum number of assumptions. The assumptions made in the loading and hauling model were generally caused by a lack of real data and could be modified with relatively little effort.

Simulation of several loading and hauling cases revealed several unique conclusions regarding the loading and hauling subsystems. The cost of decking was found to be very small in proportion to the total cost. This implies that once a relationship between deck quality and loader productivity can be established, the extra cost required to build a class one deck might be greatly compensated by the increased productivity.
The relationships between each of the costs and system productivity led to some interesting observations. The actual loading cost, COST2, decreases at a fairly constant rate as productivity increases. The cost of loader breakdowns, COST3, is affected by productivity in two ways. The total yearly breakdown cost stays fairly constant in spite of increased utilization of the loader. Hence, COST3, in dollars per MBF, will vary inversely with productivity. Increased loader breakdowns will have a two-fold effect on COST3. Breakdown costs will increase; and because of decreased loader productive time, the productivity will decrease. This will have a two-fold effect on increasing COST3. The cost of idle time in dollars per MBF caused by a loader waiting for trucks will decrease with an increase in the number of trucks. This cost will decrease in a two-fold manner. The increased number of trucks will cause increased productivity of the system and will also cause a decrease in the total cost of idle time. The cost to own and operate trucks will remain fairly constant with an increase in the number of trucks if the increase in owning and operating costs is just balanced by increased productivity.

The model developed in this thesis has, of course, limitations. These limitations are reflected in the model assumptions and are largely caused by the lack of real data. The model provides a basis, however, for further development and research in the loading and hauling areas.
It provides guidelines for future research investigations and still permits useful and beneficial testing of the current loading and hauling variables. If used properly, with valid input data, the results obtained from this model can assist the logging contractor in his decision making process.
APPENDICES
APPENDIX I

DERIVATION OF LOADER PRODUCTIVITY

Loader productivity in this thesis is expressed as minutes of loading time per truck. Since each truck holds an equal volume of timber, in this case five MBF, differences in loading times depend upon the loader type and timber size. Loader types vary in the number of logs that can be handled per loading cycle and the speed in handling and lifting logs. Lifting a greater number of logs per cycle will cause a decrease in total loading time.

The number of logs that can be handled depends also upon the size of the logs. Large logs require more lifting capacity, thus decreasing the number that can be lifted. However, larger logs will also fill a truck more quickly.

The loading time per truck was determined for each loader category, size class, and timber classification. Four timber classifications exist. Class one contains logs with diameters under 12 inches. Class two contains logs with diameters between 12 and 16 inches; class three, between 16 and 20 inches; and class four, above 20 inches. The loading times were found by first making estimates of the average weight of a log in each timber class and the number of logs required to make a truck load. Then an estimate was made of the number of logs per cycle. Cycle time in minutes per log resulted from division of
the total cycle time by the number of logs per cycle. Loading time was found by multiplying the number of logs per truck by the average time per log. The results of these calculations are shown for each loader type on the following pages.
Fully Articulated Hydraulic Loader
Cycle time-.562 min.

<table>
<thead>
<tr>
<th>Cost</th>
<th>34,000</th>
<th>37,500</th>
<th>40,500</th>
<th>43,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHP</td>
<td>94</td>
<td>110</td>
<td>120</td>
<td>130</td>
</tr>
<tr>
<td>Category(Cap)</td>
<td>2000</td>
<td>3000</td>
<td>4000</td>
<td>5000</td>
</tr>
<tr>
<td>Log Class</td>
<td>1  2  3  4</td>
<td>1  2  3  4</td>
<td>1  2  3  4</td>
<td>1  2  3  4</td>
</tr>
<tr>
<td>Pounds/Log</td>
<td>648 1300 2920 4100</td>
<td>648 1300 2920 4100</td>
<td>648 1300 2920 4100</td>
<td>648 1300 2920 4100</td>
</tr>
<tr>
<td>Av # logs per cycle</td>
<td>1.7 1.0 0 0</td>
<td>2.5 1.6 1.0 0</td>
<td>3.0 1.9 1.0 0</td>
<td>3.2 2.1 1.0 1.0</td>
</tr>
<tr>
<td>Cycle time min/log</td>
<td>.331 .562 0 0</td>
<td>.225 .351 .562 0</td>
<td>.187 .296 .562 0</td>
<td>.176 .268 .562 .562</td>
</tr>
<tr>
<td>#Logs per truck</td>
<td>70 45 20 13</td>
<td>70 45 20 13</td>
<td>70 45 20 13</td>
<td>70 45 20 13</td>
</tr>
<tr>
<td>Avg log length</td>
<td>16' 17' 20' 22'</td>
<td>16' 17' 20' 22'</td>
<td>16' 17' 20' 22'</td>
<td>16' 17' 20' 22'</td>
</tr>
<tr>
<td>Time per truck(min)</td>
<td>23.5 25.3</td>
<td>15.7 15.8 11.2</td>
<td>13.1 13.3 11.2</td>
<td>12.3 12.0 11.2</td>
</tr>
</tbody>
</table>

Figure 20: Loading Times for a Fully Articulated Hydraulic Loader
<table>
<thead>
<tr>
<th>Cost</th>
<th>27,500</th>
<th>23,500</th>
<th>21,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHP</td>
<td>100</td>
<td>90</td>
<td>75</td>
</tr>
<tr>
<td>Category(Cap)</td>
<td>2000</td>
<td>1500</td>
<td>1000</td>
</tr>
<tr>
<td>Log Class</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Pounds/log</td>
<td>648</td>
<td>1300</td>
<td>2920</td>
</tr>
<tr>
<td>Avg # logs/ cycle</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cycle time min/log</td>
<td>.42</td>
<td>.42</td>
<td>.42</td>
</tr>
<tr>
<td>Logs per truck</td>
<td>70</td>
<td>45</td>
<td>20</td>
</tr>
<tr>
<td>Avg log length</td>
<td>16'</td>
<td>17'</td>
<td>20'</td>
</tr>
<tr>
<td>Time per truck (min)</td>
<td>29.4</td>
<td>18.0</td>
<td>29.4</td>
</tr>
</tbody>
</table>

Figure 21: Loading Times for a Loader With Air or Hydraulic Pinchers
<table>
<thead>
<tr>
<th>Cost</th>
<th>36,000</th>
<th>33,000</th>
<th>31,500</th>
<th>30,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHP</td>
<td>130</td>
<td>120</td>
<td>110</td>
<td>94</td>
</tr>
<tr>
<td>Category (Cap)</td>
<td>5000</td>
<td>4000</td>
<td>3000</td>
<td>2000</td>
</tr>
<tr>
<td>Log Class</td>
<td>1  2  3  4</td>
<td>1  2  3  4</td>
<td>1  2  3  4</td>
<td>1  2  3  4</td>
</tr>
<tr>
<td>Pounds/Log</td>
<td>648 1300 2920 4100</td>
<td>648 1300 2920 4100</td>
<td>648 1300 2920 4100</td>
<td>648 1300 2920 4100</td>
</tr>
<tr>
<td>Avg # logs/cycle</td>
<td>3.1 1.4 1 1</td>
<td>2.9 1.4 1 1</td>
<td>1.7 1.2 1 1</td>
<td>1.2 1 0 0</td>
</tr>
<tr>
<td>Cycle time min/log</td>
<td>0.242 .535 .750 .750</td>
<td>0.259 .535 .750 .750</td>
<td>0.441 .625 .750 .750</td>
<td>0.625 .750 0 0</td>
</tr>
<tr>
<td># Logs per truck</td>
<td>70 45 20 13</td>
<td>70 45 20 13</td>
<td>70 45 20 13</td>
<td>70 45 20 13</td>
</tr>
<tr>
<td>Avg log length</td>
<td>16' 17' 20' 22'</td>
<td>16' 17' 20' 22'</td>
<td>16' 17' 20' 22'</td>
<td>16' 17' 20' 22'</td>
</tr>
<tr>
<td>Time per truck (min)</td>
<td>17.0 24.1 15.0 9.75</td>
<td>18.2 24.1 15.0 0</td>
<td>30.9 28.1 15.0 0</td>
<td>43.8 33.8 0 0</td>
</tr>
</tbody>
</table>

Figure 22: Loading Time For a Heel Boom Loader With Gravity Grapple
<table>
<thead>
<tr>
<th>Cost</th>
<th>33,000</th>
<th>31,500</th>
<th>30,000</th>
<th>29,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHP</td>
<td>130</td>
<td>120</td>
<td>110</td>
<td>94</td>
</tr>
<tr>
<td>Category (Cap)</td>
<td>5000</td>
<td>4000</td>
<td>3000</td>
<td>2000</td>
</tr>
<tr>
<td>Log Class</td>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>Pounds/log</td>
<td>648 1300 2920 4100</td>
<td>648 1300 2920 4100</td>
<td>648 1300 2920 4100</td>
<td>648 1300 2920 4100</td>
</tr>
<tr>
<td>Avg # logs/cycle</td>
<td>1 1 1 1</td>
<td>1 1 1 1</td>
<td>1 1 1 1</td>
<td>1 1 0 0</td>
</tr>
<tr>
<td>Cycle time min/log</td>
<td>1.25 1.25 1.25 1.25</td>
<td>1.25 1.25 1.25 1.25</td>
<td>0 1.25 1.25 1.25 0</td>
<td>1.25 1.25 0 0</td>
</tr>
<tr>
<td>#Logs per truck</td>
<td>70 45 20 13</td>
<td>70 45 20 13</td>
<td>70 45 20 13</td>
<td>70 45 20 13</td>
</tr>
<tr>
<td>Avg log length</td>
<td>16' 17' 20' 22'</td>
<td>16' 17' 20' 22'</td>
<td>16' 17' 20' 22'</td>
<td>16' 17' 20' 22'</td>
</tr>
<tr>
<td>Time per truck (min)</td>
<td>87.5 57.2 25.0 16.3</td>
<td>87.5 57.2 25.0 16.3</td>
<td>87.5 57.2 25.0 0</td>
<td>87.5 57.2 0 0</td>
</tr>
</tbody>
</table>

Figure 23: Loading Times for a Heel Boom Loader With Tongs
## Front-end Loader

**Cycle time**: 1.60 min.

<table>
<thead>
<tr>
<th>Cost</th>
<th>60,000</th>
<th>50,000</th>
<th>40,000</th>
<th>30,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHP</td>
<td>150</td>
<td>135</td>
<td>120</td>
<td>85</td>
</tr>
<tr>
<td>Category (Cap)</td>
<td>6000</td>
<td>5000</td>
<td>4000</td>
<td>3000</td>
</tr>
<tr>
<td>Log Class</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Pounds/log</td>
<td>648 1300 2920 4100</td>
<td>648 1300 2920 4100</td>
<td>648 1300 2920 4100</td>
<td>648 1300 2920 4100</td>
</tr>
<tr>
<td>Avg # logs/cycle</td>
<td>8.2 4 2 1</td>
<td>6.2 3 1 1</td>
<td>5.0 2 1 0</td>
<td>3.8 2 1 0</td>
</tr>
<tr>
<td>Cycle time min/log</td>
<td>0.195 0.400 0.80 1.60</td>
<td>0.258 0.524 1.60 1.60</td>
<td>0.321 0.80 1.60 0</td>
<td>0.422 0.80 1.60 0</td>
</tr>
<tr>
<td># Logs per truck</td>
<td>70 45 20 13</td>
<td>70 45 20 13</td>
<td>70 45 20 13</td>
<td>70 45 20 13</td>
</tr>
<tr>
<td>Avg log length</td>
<td>16' 17' 20' 22'</td>
<td>16' 17' 20' 22'</td>
<td>16' 17' 20' 22'</td>
<td>16' 17' 20' 22'</td>
</tr>
<tr>
<td>Time per truck (min)</td>
<td>13.7 18.0 16.0 20.9</td>
<td>18.2 23.6 32.0 20.8</td>
<td>22.5 36.0 32.0 0</td>
<td>29.5 36.0 32.0 0</td>
</tr>
</tbody>
</table>

**Figure 24**: Loading Times for a Front-end Loader
### Long-boom Loader With Gravity Grapple

Cycle time—.85 min.

<table>
<thead>
<tr>
<th>Cost</th>
<th>44,000</th>
<th>41,000</th>
<th>35,000</th>
<th>31,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHP</td>
<td>170</td>
<td>153</td>
<td>120</td>
<td>94</td>
</tr>
<tr>
<td>Category(Cap)</td>
<td>8000</td>
<td>6000</td>
<td>4000</td>
<td>2000</td>
</tr>
<tr>
<td>Log Class</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Pounds/log</td>
<td>648</td>
<td>1300</td>
<td>2920</td>
<td>4100</td>
</tr>
<tr>
<td>Avg # logs/cycle</td>
<td>3.3</td>
<td>2.3</td>
<td>1.9</td>
<td>1</td>
</tr>
<tr>
<td>Cycle time min/log</td>
<td>.248</td>
<td>.370</td>
<td>.448</td>
<td>.85</td>
</tr>
<tr>
<td>#Logs per truck</td>
<td>70</td>
<td>45</td>
<td>20</td>
<td>13</td>
</tr>
<tr>
<td>Avg log length</td>
<td>16'</td>
<td>17'</td>
<td>20'</td>
<td>22'</td>
</tr>
<tr>
<td>Time per truck (min)</td>
<td>17.4</td>
<td>16.7</td>
<td>8.97</td>
<td>11.1</td>
</tr>
</tbody>
</table>

Figure 25: Loading Times for a Long-boom Loader With Gravity Grapple
Two theoretical distributions were used to describe some of the situations in the simulation model. Various normal distributions described the cost of repair parts and the slope of the terrain. Negative exponential distributions describe the time between breakdowns and the duration and repair time of breakdowns.

The normal distribution describes the data of many real world situations. As such, it is one of the most frequently used theoretical distributions. The distributions used in this thesis were described by their mean, maximum, and minimum values and the standard deviation from the mean. The normal distribution of the cost of parts for a loader breakdown of the first severity level is shown in Figure 26.

![Figure 26: Normal distribution of cost of parts for a loader breakdown of severity level one](image)
The area under the curve represents a probability. Since the "tails" of the curve never touch the horizontal axis, there is always some chance that a value could exist beyond the maximum and minimum values. However, the probability of this happening is very small. Nearly all values lie within the maximum and minimum. The midpoint of the distribution represents the average or mean of the distribution. The curve of the distribution approaches the horizontal axis symmetrically on both sides of the mean.

Simulation distributions function as sources of various values needed in a simulation run. For instance, the normal distributions are used to generate the cost of repair parts. Each value in a distribution has a certain probability of occurrence. If the distribution is plotted as a cumulative distribution, a random number, representing a cumulative probability, can be used to find a random deviate from the distribution. If this cumulative distribution was related to the normal distribution shown in Figure 26, the random deviate would represent cost of parts for a particular situation. The procedure for finding random deviates is shown in Figure 27.
Steps Involved

a. Plot the cumulative probability function

b. Choose a random decimal between 0 and 1

c. Project horizontally from y-axis to \( y = F(x) \)

d. Find corresponding value of \( x \)

Figure 27: Method used to generate random deviates

Six normal distributions were used to describe the cost of parts for truck and loader breakdowns of each severity level. A seventh normal distribution described the slope of the terrain. The values describing these distributions were stored under the name \( \text{PARAM}(I,J) \) and had the values shown below.

<table>
<thead>
<tr>
<th>&quot;I&quot;</th>
<th>PARAM(1,1)</th>
<th>PARAM(1,2)</th>
<th>PARAM(1,3)</th>
<th>PARAM(1,4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Minimum</td>
<td>Maximum</td>
<td>Standard Deviations</td>
</tr>
<tr>
<td>1</td>
<td>1000</td>
<td>0</td>
<td>2000</td>
<td>333</td>
</tr>
<tr>
<td>2</td>
<td>3500</td>
<td>2000</td>
<td>5000</td>
<td>500</td>
</tr>
<tr>
<td>3</td>
<td>8000</td>
<td>5000</td>
<td>20000</td>
<td>4000</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>5</td>
<td>19</td>
<td>2.33</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>25</td>
<td>75</td>
<td>8.33</td>
</tr>
<tr>
<td>6</td>
<td>800</td>
<td>100</td>
<td>2000</td>
<td>400</td>
</tr>
<tr>
<td>7</td>
<td>30</td>
<td>0</td>
<td>134</td>
<td>35</td>
</tr>
</tbody>
</table>

Figure 28: Values stored in array \( \text{PARAM} \)

The conditions specified by code "I" are described earlier in the thesis.
Negative exponential distributions describe the mean time between breakdowns and the duration and repair time of breakdowns. The only data needed for negative exponential distributions are the means of the distributions. A negative exponential distribution has the form

\[ f(x) = \alpha e^{-\alpha x} \text{ for } x > 0 \]

where \( \alpha \) is the mean rate. A negative exponential distribution is shown in Figure 29.

Figure 29: Graph of a negative exponential distribution

Generating a random deviate from a negative exponential distribution is done by taking the product of the negative of the mean of the distribution and the logarithm of a random number. A discussion of this procedure appears on page 100 of reference number one in the bibliography.²

²Pritsker, op. cit., p. 100.
APPENDIX 3

MAIN PROGRAM

The main program in the simulation model functions in four distinct areas.

1. It facilitates input of necessary data.
2. It regulates variable combinations.
3. It contains calculations of costs not dependent upon simulation data.
4. It compares costs and prints the minimum cost combination.

The main program is listed in Figure 30. This figure is continued for several pages and will be referenced in the description which follows. References are made to the statement number printed to the right of each statement.

The input and output devices of each computer are described with different numbers. In statements 53 and 54 the value of the "card reader" and "line printer" are set equal to their respective values. For the XDS Sigma 7 computer at Montana State University the card reader, NCRDR, has code number 105 and the line printer, NPRNT, has code number 108.

Statements 56D through 56I input the control elements of the simulation. Each of the variables, as described earlier, control the minimum and maximum category number of a particular variable.
The remaining data input begins with statement 57 and continues through statement 152. The definition of each of the variables was presented in Chapter 5. Comment cards interspersed throughout this section of the program should identify the particular items.

Following data input, the main program initializes the first case to be simulated and sets up the procedure whereby different combinations can be tested. This continues from statement 156 to statement 245. The comment cards located in this region should again clarify the items being varied.

One cost calculation does occur in this section. The decking cost, COST 1, is found directly after the skidding system is specified. Statements 170 through 176 contain this series of calculations.

Once the variable combination for a particular case is specified, other variables necessary for data collection or system control are initialized. These variables have either been defined earlier or may be found in Appendix 19. Statements 253 through 293 contain the elements being initialized.

Calculations of the owning costs for both the loader and the trucks follow the initialization of variables. First calculated is the cost to own the loader. The technique used was described in Chapter 4. Statements involved in the calculation range from number 299 through number 320. The comment cards should again assist the reader in following the procedure.
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Calculation of the cost to own the trucks includes calculations of the owning costs of trailers and the preload bunk. This series of calculations continues from statement 320 through statement 387.

In statement 390A the fuel consumption in gallons per hour per brake-horsepower is converted to consumption in gallons per hour. Following this the out-of-sequence numbers 901 through 962 print the system variables specifically related to a certain case number.

Before the actual simulation can begin, initial simulation events must be specified, and statistical collection areas must be initialized. Initial events common to every case include the scheduling of initial truck arrivals and the determination of the initial breakdown at each severity level for each piece of equipment. This is accomplished in statements 395 through 397M.

Statement 398 marks the beginning of the simulation. The statement calls GASP, the executive subroutine which controls the simulation. It does not return control to the main program until simulation of a particular case is complete.

Once control returns to the main program, a cost comparison between the equivalent annual cost for this case and the previous minimum takes place. If the value for the current case is less, a new minimum-cost combination is defined. If it is greater, no change occurs. If more than one combination share the same minimum cost, both combinations are stored. The statements used to accomplish this task range from number 400 through number 450.
After the cost comparison, the next case is distinguished. Control returns to earlier sections of the main program to reinitialize variables and recalculate costs. This becomes another case, and a complete simulation takes place. Statements used to vary the cases range from number 451 through 489.

Finally, when all cases have been tested, the combination with the minimum annual cost is printed. Printed with the minimum cost are the variables that combined to yield the cost. The statements causing the printout range from number 491 through 588.
C
C*****SIMULATION OF LOADING AND HAULING OPERATIONS
C
C*****MAIN PROGRAM
C
DIMENSION NSET(7, 50), PERST(4), SVL(12), USTK(6), SVLTK(6), CSTR(3)
DIMENSION MNSVE(5), LCSVE(5), CDVSE(5), CPDSE(5), KSSVE(5)
DIMENSION ITSVE(5), NTSVE(5), NSTSE(5), XMSVE(5), EXTSVE(5), BHP(12, 4)
DIMENSION CSBK(3), CSLD(12, 4), CAPL(12, 4), XMLMN(12, 4)
DIMENSION SULTR(3), SULBK(3), USTR(3), USBK(3)
C
C*****GASP COMMON STATEMENTS
C
COMMON ID, IM, INIT, JENV, JMN, MFA, MSTDP, MX, MXC, NCLCT, NHIST, 1NOQ, NDRPT, NQT, NPRMS, NRUNS, NSTAT, OUT, SCALE, ISEED, TNT, 2TBEQ, TFIN, MXX, NPNRM, NCNDP, NEDQ, VNC(6)
COMMON ATRIB(5), ENG(6), INN(6), JCELS(1, 2), KXANK(6), MAXNQ(6), M 1FE(6), NLC(6), MLE(6), ACELS(1), NQ(6), PARAM(12, 4), QTIME(6), SSUMA 2(10, 5), SUMA(10, 5), NAME(6), NFRS, MN, NDAY, NRY, JCLR
COMMON KOF, KLE, KOL
C
C*****NON-GASP COMMON VARIABLES
C
COMMON LCAT, TSV(12), USL(12), VDFL(12), VGL(12), POQ, AVMBF, C 16T, WGLR, RTLB, WGT, RTTS, ITCA, CTSK(6), VFT(6), VGT(6), WGT, RDTR(2 20, KSYS, XMPIA, XMIPPA, XMIS, XPHPA, XPHPP, XPHS, DefC, DAY(12), WTHP(12)
COMMON MBOH, FLCTD, FLCGT, FLCN, FLCN, RR, XMTBK(3), XMTTK(3)
1, XMDBK(3), XMRTK(3), XMRSBK(3), XMRTT(3), XMNC, UFE, WGMX, XMNCT(20)
2, XNTD, XNIDL, XYOD, SCINC, SUTK, XPRRT, MVR, CST, CDV, CPD, TK, TKS 3
COMMON XMIDK, LBAQ, NBKTE, NBLR, DSID, DSB, DAT, TENYR, YEAR, CCRBK, C 30, XDBK, XTLT, XWLTK, XVSL(20), XSV, TENDY, LSY, CDBK, TID, TID8
1, WETHR, SLOPE, XLAND, CLN, NCASE, LGMX
COMMON ULEL, LUL, ULDK, ULDTR(3), ULETD, CSTOW, TIDAY(12), CLN
COMMON CLMSC(12), ICLAS, CST, PDTK(3), OVP(12, 25, 4), CSMSC(3)

Figure 30: Computer Listing of the Main Program
COMMON DDNTK,CIDIT,CBDIT,CDNIT,TRNT(20),PTML
COMMON BKFUL,CDBLR

C*****NUMBERS OF CARD READER AND CARD PUNCH
C
    NCRDR=105
    NPRNT=108
C
C*****INITIALIZE TOTAL COST AT SOME HIGH VALUE
C
    CSTMN=99999.
C
C*****INITIALIZE THE NUMBER OF MINIMUM COST COMBINATIONS AT ZERO.
C
    NEQA=0
C
C*****FIRST READ IN NECESSARY INPUT ASSOCIATED WITH THE SYSTEM VARIABLES
C
C
C*****READ IN DATA TO CONTROL THE TYPE CASES CONSIDERED
C
    READ(NCRDR,150) ICASE,MNVR1,MNVR2,LCAT1,LCAT2,ISV1,ISV2
    150 FORMAT(7I5)
    READ(NCRDR,151) KSYS1,KSYS2,ITCA1,ITCA2,ITK1,ITK2
    151 FORMAT(6I5)
    READ(NCRDR,152) SUTK1,SUTK2,EXTR1,EXTR2,XMDK1,SCIN1
    152 FORMAT(6F10.3)
C
C*****READ IN VALUES ASSOCIATED WITH THE SKIDDING OPERATION.
C
    READ(NCRDR,1) WGS6,RTS6,C06S,SCPH,SVPC,TQ1,TQ2
    1 FORMAT(7F10.3)
C
C*****READ IN VALUES ASSOCIATED WITH THE LOADING OPERATION
C
    DO 2 LCAT=1,6

Figure 30:  (continued)
READ(NCRDR,3) TSV(LCAT),USL(LCAT),SVL(LCAT)
3 FORMAT(2F4.1,F5.4) MAIN065
READ(NCRDR,60) (CSDL(LCAT,ISV),ISV=1,4) MAIN066
READ(NCRDR,60) (CAPL(LCAT,ISV),ISV=1,4) MAIN067
READ(NCRDR,60) (BHP(LCAT,ISV),ISV=1,4) MAIN068
60 FORMAT(4F10.3) MAIN069
NYEAR=USL(LCAT) MAIN070
DB 70 ISV=1,4 MAIN071
READ(NCRDR,5) ((BPDV(LCAT,J,ISV,ICLAS),ICLAS=1,4),J=1,NYEAR) MAIN072
70 CONTINUE MAIN073
5 FORMAT(4F5.1) MAIN074
READ(NCRDR,60) (XLDMN(LCAT,ICLAS),ICLAS=1,4) MAIN075
READ(NCRDR,6) VDFL(LCAT),VGL(LCAT),CLMSC(LCAT) MAIN076
6 FORMAT(3F10.3) MAIN077
2 CONTINUE MAIN078
READ(NCRDR,7) PDLR,AVMBF,COT,WGL8,RTL0,WGTS,RTTS MAIN079
7 FORMAT(7F10.3) MAIN080
C
C*****READ IN VALUES ASSOCIATED WITH THE TRUCK CATEGORIES
C
DB 8 ITCA=1,6 MAIN081
READ(NCRDR,9) CSTK(ITCA),USTK(ITCA),SVLTK(ITCA),VDFT(ITCA),VGT(ITC) MAIN082
1A CONTINUE MAIN083
9 FORMAT(5F10.3) MAIN084
READ(NCRDR,10) WGTD,(P6TK(ISEVL),ISEVL=1,3) MAIN085
10 FORMAT(4F10.3) MAIN086
READ(NCRDR,11) (RTTD(ITKN),ITKN=2,11) MAIN087
11 FORMAT(10F5.3) MAIN088
C
C*****READ IN VALUES ASSOCIATED WITH THE BUNK AND PREHAUL SYSTEMS
C
DB 12 KSYS=1,3 MAIN089
READ(NCRDR,13) CSTR(KSYS),CSBK(KSYS),CSMSC(KSYS) MAIN090
12 CONTINUE MAIN091
13 FORMAT(3F10.4) MAIN092

Figure 30: (continued)
C ******READ IN DISTANCE TO MILL AND AVERAGE SPEED
C   READ(NCRDR, 14) XMIPA, XMIPR, XMIS, XPHPA, XPHPR, XPHS
   14 FORMAT(6F10.3)
C ******READ IN DAYS AND WEATHER PROBABILITY FOR EACH MONTH
C   READ(NCRDR, 15) (DAY(MONTH), MONTH=1, 12)
   READ(NCRDR, 15) (WTHP(MONTH), MONTH=1, 12)
   READ(NCRDR, 15) (TIDAY(MONTH), MONTH=1, 12)
   15 FORMAT(12F6.3)
C ******READ DATA CONCERNED WITH FUEL CONSUMPTION.
C   READ(NCRDR, 16) FLCTD, FLCTG, FLCNL, TFLCN
   16 FORMAT(4F10.3)
C ******READ IN DATA CONCERNED WITH INSURANCE AND INTEREST
C   READ(NCRDR, 17) TIIPR, WCPPR, RR, ADMPR
   17 FORMAT(4F10.5)
C ******READ IN DATA CONCERNED WITH MAINTENANCE AND BREAKDOWNS.
C   DO 19 ISEVL=1, 3
   19 READ(NCRDR, 20) XMTBK(ISEVL), XMTTK(ISEVL), XMDBK(ISEVL), XMDTK(ISEVL)
      XMRSBK(ISEVL), XMRTK(ISEVL)
   20 FORMAT(6F10.3)
   READ(NCRDR, 21) XMNCL, UFE, WGMP, WGMT
   21 FORMAT(4F10.3)
   READ(NCRDR, 22) (XMNCT(ITKN), ITKN=2, 11)
   22 FORMAT(10F8.2)
C ******READ IN CONTROL VARIABLES
C
Figure 30: (continued)
****READ IN THE NORMAL TIME IN A WORKING DAY AND THE TIME NEEDED IN A DAY TO SCHEDULE TRUCKS AFTER BREAKDOWNS. ALSO READ IN EXPECTED YEARLY OPERATING HOURS

READ(NCRDR,23) XNTDT,XNTDL,EY6H,DEFCT
23 FORMAT(4F10.2)
READ(NCRDR,970) ULEL6,ULTRK,ULETD,CST6W,(ULTDR(I),I=1,3)
970 FORMAT(7F10.3)

****READ IN THE AVERAGE TREE DIAMETER AND THE CLASS INTO WHICH IT FITS

READ(NCRDR,960) AVDBH,ICLAS
960 FORMAT(F10.3,I4)
READ(NCRDR,71) XLAND,PML
71 FORMAT(2F10.3)
SCINC=SCIN1

****READ IN CONTROL VARIABLE REPRT FOR PRINTOUT OF YEARLY REPORTS

****REPRT=0, NO PRINTOUT

****REPRT=1, YEARLY PRINTOUT

****REPRT=-1, NO END OF SIMULATION PRINTOUT

READ(NCRDR,24) REPRT
24 FORMAT(F10.4)

****NOW READ IN THE GASP DATA COMMON TO EVERY CASE

NSET=0
CALL DATAN(NSET)

****INITIALIZE THE CASE NUMBER AT ICASE

NCASE=ICASE-1

****NOW EITHER INITIATE OR VARY THE SKIDDING SYSTEM IN USE. THE SKIDDING SYSTEMS HAVE THE FOLLOWING CODES,

MNVR=1 IMPLIES A ROLLING STOCK SKIDDING SYSTEM

Figure 30: (continued)
C*****MNVR#2 IMPLIES AN IDAHO-JAMMER SKIDDING SYSTEM
C*****MNVR#3 IMPLIES A SHOVEL SKIDDING SYSTEM
C*****MNVR#4 IMPLIES A SKY-LINE SKIDDING SYSTEM
C
    MNVR=MNVR1
    100 CONTINUE
C
C*****NOW DETERMINE COST1, THE COST TO DECK LOGS TO A CERTAIN QUALITY
C*****DECK:
C
    G0 TO (25,26,26,26)*MNVR
    25 PDS11=(SVPC/(TQ1/60.0))*RTS6
    PDS12=(SVPC/(TQ2/60.0))*RTS6
    CBST1=((WGS8+C88S)/(SCP*((0*10*PDS12)+(0*90*PDS11))))
    PERST(1)=SCP*(((TQ1*0.9)+(TQ2*0.1))/60.0)
    G0 TO 27
    26 CBST1*0.0
    PERST(MNVR)=0.0
    27 CONTINUE
C
C*****NOW INITIALIZE OR VARY THE LOADER CATEGORY. THE VARIABLE LCAT
C*****IDENTIFIES THE LOADER CATEGORIES USING THE FOLLOWING CODES.
C*****LCAT=1 IMPLIES A FULLY ARTICULATED HYDRAULIC LOADER
C*****LCAT=2 IMPLIES A LOADER WITH AIR OR HYDRAULIC PINCHER
C*****LCAT=3 IMPLIES A HEELBOOM LOADER WITH GRAPPLE
C*****LCAT=4 IMPLIES A LOADER WITH TONGS AND A TONGSETTER
C*****LCAT=5 IMPLIES A FRONT-END LOADER
C*****LCAT=6 IMPLIES A LONG-BOOM LOADER WITH GRAPPLE
C
    LCAT=LCAT1
    200 CONTINUE
C
C*****FOR EACH CATEGORY OF LOADER VARY THE COST DIVISIONS
C
    ISV=ISV1=1
    300 CONTINUE

Figure 30: (continued)
$ISV = ISV + 1$

IF(ISV = ISV2) 302,302,50

302 $XISV = ISV$

IF(XLDMN(LCAT, ICLAS) = XISV) 301,301,300

301 CDV = CSLD(LCAT, ISV)

CPD = CAPL(LCAT, ISV)

C

C*****NBW INITIALIZE OR VARY THE TYPE LOADING TRAILERS OR BUNKS IN USE.

C*****THE TYPE SUBSYSTEM IS IDENTIFIED BY KSYS ACCORDING TO THE CODE:

C*****KSYS=1 IMPLIES USE OF STANDARD LOGGING TRAILERS, THE REGULAR SYSTEM

C*****KSYS=2 IMPLIES USE OF PREHAUL TRAILERS, THE PREHAUL SYSTEM

C*****KSYS=3 IMPLIES USE OF A LOADING BUNK, THE PRELOAD SYSTEM.

C

KSYS = KSYS1

400 CONTINUE

C

C*****NBW INITIALIZE OR VARY THE TRUCK CATEGORY FOR THE SIX POSSIBLE

C*****CATEGORIES RANGING FROM USED TO THE MOST EXPENSIVE.

C

ITCA = ITCA1

500 CONTINUE

C

C*****NBW INITIALIZE AND VARY THE NUMBER OF TRUCKS BEING USED IN THE

C*****SYSTEM.

C

ITK = ITK1

600 CONTINUE

TK = ITK

TKSYS = TK

C

C*****NBW, IF DESIRED THE NUMBER OF SHUTTLE TRUCKS MAY BE VARIED, BUT

C*****ONLY IF KSYS=2.

C

IF(KSYS=2) 750,751,750

751 SUTK = SUTK1

700 CONTINUE

Figure 30: (continued)
C***** THE DISTANCE OF THE Dock FROM THE MILL MAY ALSO BE VARIED FOR
C***** PREHAUL SYSTEMS
C XMDK=XMDK1
    750 CONTINUE
C***** NOW INCREMENT THE NUMBER OF CASES TESTED,
C NCASE=NCASE+1
C***** NOW INITIALIZE ALL VARIABLES WHICH WILL EITHER BE CUMULATED
C***** THROUGHOUT THE PROGRAM OR WHICH SPECIFY INITIAL CONDITIONS OF THE
C***** SYSTEM.
C***** CUMULATIVE VARIABLES
C LOADS=0
WETHR=1.
SLOPE=30.0
NBKTK=0
NBKLR=0
DSIDL=0.
DSBD=0.
DDNTK=0.0
DATBT=0.
TENYR=0.
YEAR=1.
CCPBK=0.
CBKIT=0.
CTLIT=0.
CWTIT=0.
CIDIT=0.
CBDIT=0.
CDNIT=0.
CCTBK=0.

Figure 30: (continued)
CDBTK=0.0
CSV1=0.0
CSV2=0.0
CSV3=0.0
CSV4=0.0
CSV5=0.0
CSVTT=0.0
CL9AD=0.0
CDLR=0.0
M8NTH=1
DAYS=1
CLND=0.0
CSLND=0.0
ITKN=ITK+1
DB 28 K=2, ITKN
H9UR(K)=0.0
28 MILES(K)=0.0
XISYS=0.0

C
C*****STATE OF SYSTEM VARIABLES
C
BUS1=0.0
BUS2=0.1
BKFUL=0.0

C
C*****USE THE FOLLOWING VARIABLES TO VARY THE NUMBER OF PREHAUL TRAILERS
C*****IN EXCESS OF TRUCKS. ETADK IS EMPTY TRAILERS, LADBK = FULL.
C
ETADK=EXTR1
FADBK=EXTR2
DB 29 K=2, ITKN
TRNT(K)=1.0
29 BUSTK(K)=1.0
SCHBD=0.0
SVLTR(KSYS)=SVLTK(ITCA)
SVLBK(KSYS)=SVL(LCAT)

Figure 30: (continued)
USTR(KSYS)=USTK(ITCA)
USBK(KSYS)=USL(LCAT)

C
C*****NOW CALCULATE YEARLY MAINTENANCE COSTS IF THEY ARE MODIFIED FROM
C*****INPUT.
C
C*****NOW CALCULATE THE TOTAL OWNING COST OF THE LOADER.
C
DEPR=(CDV-(SVL(LCAT)*CDV))/USL(LCAT)
ILIFE=USL(LCAT)
VALUE=CDV
ADMC=0
CINS=0

C*****CALCULATE WORKMAN’S COMPENSATION
C
WCOMP=(WGL@+(WGTS*TSV(LCAT)))*WCPPR
C
C*****TIME VALUE OF MONEY IS ACCOUNTED FOR IN OUTPUT.
C*****NOW DETERMINE INSURANCE, TAX, INTEREST, AND ADMINISTRATIVE COSTS.
C
DOB 30 L=1, ILIFE
CINS=CINS+(TIPR*VALUE)
ADMC=ADMC+(ADMPR*VALUE)
30 VALUE=VALUE-DEPR
C
C*****NOW DETERMINE OWNING COSTS IN $/HR.
C
CS@WL=WCOMP+(CDV+CINS+ADMC-(SVL(LCAT)*CDV))/(EYH*USL(LCAT))
C
C*****NOW ROUND THE COST TO OWN TO THREE DECIMAL PLACES
C
ICL@=CS@WL*1000
ICL@=ICL@*10
ICL=CS@WL*1000
ICL1=ICL*5

Figure 30: (continued)
IF (ICL1=ICLA) 850,851,851
850 CSWL=ICLA/10000:
851 CSWL=(ICLA+10)/10000:
852 CONTINUE

C C*****NOW DETERMINE THE OWNING COST OF THE TRUCK IN $/HOUR FOR EACH
C C*****TRUCK. THIS COST INCLUDES THE OWNING COST OF REGULAR OR PRE-HAUL
C C*****TRAILERS AND OF THE BUNK:
C
C C*****FIRST DETERMINE THE WORKMAN'S COMPENSATION COST PER TRUCK IN $/HR
C
C WCOMP=WGTD*WCPPR

C C*****NOW DETERMINE THE COST TO OWN A PRELOAD BUNK IF ONE IS IN USE:
C
C IF (KSYS=2) 32,32,33
33 DEPBK=(CSBK(KSYS)-SVLBK(KSYS)*CSBK(KSYS))/USBK(KSYS)
VALBK=CSBK(KSYS)
CINS=0:
ADMC=0:
ILIFE=USBK(KSYS)
DO 31 L=1,ILIFE
CINS=CINS+(VALBK*TIPR)
ADMC=ADMC+(VALBK*ADMPR)
31 VALBK=VALBK*DEPBK
XCSBK=(CSBK(KSYS)+CINS+ADMC-(SVLBK(KSYS)*CSBK(KSYS)))/(Ey6H*USBK(KSYS))
G0 TO 34
32 XCSBK=0.0
34 XCSBK=XCSBK/TK

C C*****NOW DETERMINE THE COST TO OWN A TRAILER IN $/HR
C
C DEPTR=(CSTR(KSYS)-SVLTR(KSYS)*CSTR(KSYS))/USTR(KSYS)
VALTR=CSTR(KSYS)

Figure 30: (continued)
CINS=0;
ADMC=0;
ILIFE=USTR(KSYS)
D0 35 L=1,ILIFE
CINS=CINS+(VALTR*TTIPR)
ADMC=ADMC+(VALTR*ADMPR)
35 VALTR=VALTR-DEPTR
XCSTR=(CSTR(KSYS)+CINS+ADMC+(SVLTR(KSYS)*CSTR(KSYS)))/EY0H=USTR(KSYS)
C
C*****NOW DETERMINE WHETHER THERE ARE MORE TRAILERS THAN TRUCKS. IF
C*****THERE ARE, THE COST TO OWN THE EXTRA TRAILERS MUST BE DISTRIBUTED
C*****EQUALLY TO THE TRUCKS;
C
IF(KSYS=2) 38,39,38
39 XLADK=FADBK
EXTRK=XLADK+ETADK
IF(EXTRK) 38,38,40
40 EXTRC=(XCSTR*EXTRK)/TK
G0 TO 41
38 EXTRC=0.0
C
C*****NOW DETERMINE THE COST TO OWN THE TRACTOR AND THE TOTAL OWNING
C*****COST OF THE TRUCK;
C
41 DEPTK=(CSTK(ITCA)-(SVLTK(ITCA)*CSTK(ITCA)))/USTK(ITCA)
ITKN=ITK+1
D0 36 K=2,ITKN
VALTK=CSTK(ITCA)
CINS=0,
ADMC=0,
ILIFE=USTK(ITCA)
D0 37 L=1,ILIFE
CINS=CINS+(VALTK*TIIPR)
ADMC=ADMC+(VALTK*ADMPR)
37 VALTK=VALTK-DEPTK

Figure 30: (continued)
36 C8WTK(K) = ((CSTK(ITCA) + CINS + ADMC) * (SVLTK(ITCA) + CSTK(ITCA))) / (EY8H * US 1TK(ITCA)) * WC8MP * XCSBK + XCSTR * EXTRC

C

C*****NOW ROUND THE COST TO 8WN TO THREE DECIMAL PLACES
C

DO 853 K = 2, IGTK
ICLA = C8WTK(K) * 1000.
ICLA = ICLA + 10
ICL = C8WTK(K) * 10000.
ICL1 = ICL + 5
IF (ICLI = ICLA) 854, 855, 855
854 C8WTK(K) = ICLA / 10000.
G0 TO 853
855 C8WTK(K) = (ICLA + 10) / 10000.
853 CONTINUE
C

C*****DETERMINE THE LOADER FUEL CONSUMPTION IN GAL/HR BASED ON THE
C*****BRAKE HORSEPOWER = (BHP)
C
FLCN = FLCNL * BHP (LCAT, ISV)
IF (REPRT) 937, 901, 901
C

C*****NOW PRINT VARIABLES CONNECTED WITH THIS CASE
C
901 WRITE (NPRNT, 902)
902 FORMAT (1X)
WRITE (NPRNT, 903) NCASE
903 FORMAT (30X, 'IDENTIFICATION OF SYSTEM VARIABLES === CASE1, I4//')
G0 TO (904, 906, 908, 910), MNVR
904 WRITE (NPRNT, 905)
905 FORMAT (20X, 'SKIDDING SYSTEM 1 === ROLLING STOCK//')
G0 TO 912
906 WRITE (NPRNT, 907)
907 FORMAT (20X, 'SKIDDING SYSTEM 2 === IDAHO JAMMER//')
G0 TO 912
908 WRITE (NPRNT, 909)

Figure 30: (continued)
909 FORMAT(20X,'SKIDDING SYSTEM 3 --- SHOVEL SKIDING!/)
GO TO 912
910 WRITE(NPRNT,911)
911 FORMAT(20X,'SKIDDING SYSTEM 4 --- HIGH LEAD!/)
912 CONTINUE
GO TO(913,915,917,919,921,923),LCAT
913 WRITE(NPRNT,914)
914 FORMAT(20X,'LOADER CATEGORY 1 --- FULLY ARTICULATED HYDRAULIC!/)
GO TO 925
915 WRITE(NPRNT,916)
916 FORMAT(20X,'LOADER CATEGORY 2 --- AIR OR HYDRAULIC PINCHER!/)
GO TO 925
917 WRITE(NPRNT,918)
918 FORMAT(20X,'LOADER CATEGORY 3 --- HEELBOOM WITH GRAPPL!/)
GO TO 925
919 WRITE(NPRNT,920)
920 FORMAT(20X,'LOADER CATEGORY 4 --- TONGS WITH TONGSETTER!/)
GO TO 925
921 WRITE(NPRNT,922)
922 FORMAT(20X,'LOADER CATEGORY 5 --- FRONT-END LOADER!/)
GO TO 925
923 WRITE(NPRNT,924)
924 FORMAT(20X,'LOADER CATEGORY 6 --- LONG BOOM WITH GRAPPL!/)
925 WRITE(NPRNT,926) CDV
926 FORMAT(20X,'LOADER COST CDV = ',F10.3/
WRITE(NPRNT,927) CPD
927 FORMAT(20X,'LOADER CAPACITY CPD = ',F10.3, ' POUNDS!/)
WRITE(NPRNT,928) ITCA,CSTK(ITCA)
928 FORMAT(20X,'TRUCK CATEGORY I,12,1 COST = ',F10.3/
WRITE(NPRNT,929) ITK
929 FORMAT(20X,'NUMBER OF TRUCKS = ',I3/
GO TO(930,932,934),KSYS
930 WRITE(NPRNT,931)
931 FORMAT(20X,'TYPE TRAILER SYSTEM 1 --- REGULAR OR NORMAL TRAILERS 1/
GO TO 936

Figure 30: (continued)
932 WRITE(NPRNT,933)
933 FORMAT(20X,'TYPE TRAILER SYSTEM 2 --- PREHAUL TRAILERS!/) GO TO 936
934 WRITE(NPRNT,935)
935 FORMAT(20X,'TYPE TRAILER SYSTEM 3 --- PRELOAD OR BUNK!/) IF(KSYS=2)937,938,937
936 WRITE(NPRNT,939) SU TK
939 FORMAT(20X,'NUMBER OF SHUTTLE TRUCKS = ',F10.2)
WRITE(NPRNT,940) XMIDK
940 FORMAT(20X,'DISTANCE FROM MILL TO DOCK = XMIDK = ',F10.3)
WRITE(NPRNT,941) EXTRK
941 FORMAT(20X,'NUMBER OF EXTRA PREHAUL TRAILERS = EXTRK = ',F10.3)
937 CONTINUE

Figure 30: (continued)
ATRIB(3) = 0.0
ATRIB(4) = 1
ATRIB(5) = 1.0
CALL FILEM(1, NSET)
75 CONTINUE
ITKN = TK + 1
DO 76 J = 2, ITKN
DO 77 I = 1, 3
ATRIB(I) = 0.0 + BKDTK(I, NSET)
ATRIB(1) = 0.0
ATRIB(2) = 5.0
ATRIB(3) = 0.0
ATRIB(4) = 1.
ATRIB(5) = J
CALL FILEM(1, NSET)
77 CONTINUE
76 CONTINUE
ATRIB(1) = 0.0
ATRIB(2) = 101.0
CALL FILEM(1, NSET)
N8T = 1
JCLR = 1
NEP = 9
CALL DATAN(NSET)
CALL GASP(NSET)

C****NOW COMPARE THE TOTAL COST IN $/MBF WITH THE MINIMUM COST TO THIS
C****POINT AND IF THE COST FOR THE CURRENT CASE IS LESS, REPLACE THE
C****VARIABLES OF THE PREVIOUS MINIMUM WITH VARIABLES OF THIS CASE.

C IF(CSTMN = CSVTT) 42, 43, 44
44 CSTMN = CSVTT
MNSV = MNYR
LCSV = LCAT
CDVS = CDV
CPDS = CPD
KSSV = KSYS

Figure 30: (continued)
ITSV=ITCA
NTSV=TK
NSTS=SUTK
XMDS=XMIDK
EXTS=EXTRK
IF(NEQA) 42,42,45
45 CONTINUE
DB 46 I=1,NEQA
MNSVE(I)=0
LCSVE(I)=0
CDVSE(I)=0
CPDSE(I)=0
KSSVE(I)=0
ITSVE(I)=0
NTSVE(I)=0
NSTSE(I)=0
XMDSV(I)=0
46 EXTSV(I)=0
NEQA=0
G0 TO 42
C
C*****IF TWO OR MORE ALTERNATIVES HAVE THE SAME TOTAL COST, SAVE THE
C*****CHARACTERISTICS OF ALL THE ALTERNATIVES,
C
43 IF(NEQA) 47,47,48
47 NEQA=1
MNSVE(NEQA)=MNSV
LCSVE(NEQA)=LCSV
CDVSE(NEQA)=CDVS
CPDSE(NEQA)=CPDS
KSSVE(NEQA)=KSSV
ITSVE(NEQA)=ITSV
NTSVE(NEQA)=NTSV
NSTSE(NEQA)=NSTS
XMDSV(NEQA)=XMIDK
EXTSV(NEQA)=EXTRK

Figure 30: (continued)
48 NEQA=NEQA+1
MNSVE(NEQA)=MNVR
LCSVE(NEQA)=LCAT
CDVSE(NEQA)=CDV
CPDSE(NEQA)=CPD
KSSVE(NEQA)=KSYS
ITSVE(NEQA)=ITCA
NTSVE(NEQA)=TK
NSTSE(NEQA)=SUTK
XMDSV(NEQA)=XMDS
EXTSV(NEQA)=EXTS
42 CONTINUE

C*****NOW BEGIN CHANGING THE PARAMETERS AND CHARACTERISTICS OF THE
C*****SYSTEM:
C
C*****IF KSYS=2, THE DISTANCE FROM THE DOCK TO THE MILL MAY BE VARIED
C
C*****IF KSYS=2, THE NUMBER OF EXTRA TRAILERS MAY BE VARIED
C
C*****FIRST, IF KSYS=2, VARY THE NUMBER OF SHUTTLE TRUCKS IF DESIRED.
C
IF(KSYS=2) 602,701,602
701 SUTK=SUTK+1.
IF(SUTK=SUTKE) 700,700,602
C
C*****NOW VARY THE NUMBER OF TRUCKS IN THE SYSTEM:
C
602 CONTINUE
ITK=ITK+1.
IF(ITK=ITKa) 600,600,601
601 CONTINUE
C
C*****NOW VARY THE TRUCK CATEGORY

Figure 30: (continued)
C ITCA=ITCA+1
   IF (ITCA=ITCA2) 500,500,49
C
C*****NEW VARY THE LOADING SYSTEM BETWEEN BUNK, PREHAUL, AND NORMAL
C*****TRAILERS:
C
49 KSYS=KSYS+1
   IF (KSYS=KSYS2) 400,400,401
   401 CONTINUE
C
C*****NEW VARY THE COST-CAPACITY CATEGORY
C
   IF (ISV=ISV2) 300,50,50
C
C*****NEW VARY THE LOADER CATEGORY
C
50 LCAT=LCAT+1
   IF (LCAT=LCAT2) 200,200,102
C
C*****NEW VARY THE SKIDDING SYSTEM
C
   102 CONTINUE
   MNVR=MNVR+1
   IF (MNVR=MNVR2) 100,100,101
   101 CONTINUE
C
C*****WHEN ALL DESIRED ALTERNATIVES HAVE BEEN CHECKED PRINT THE COST AND
C*****CHARACTERISTICS OF THE COMBINATION OR COMBINATIONS WITH MINIMUM
C*****COST.
C
   IF (NEQA) 51,51,52
   51 NEQA=1
   MNSVE(NEQA)=MNSV
   LCSVE(NEQA)=LCSV
   CDVSE(NEQA)=CDVS

Figure 30: (continued)
CPnSE(NEQA)=CPDS
KSSVE(NEQA)=KSSV
ITSVE(NEQA)=ITSV
NTSVE(NEQA)=NTSV
NSTSE(NEQA)=NSTS
XMDSV(NEQA)=XMDS
EXTSV(NEQA)=EXTS
52 CONTINUE
WRITE(NPRNT,800)
800 FORMAT(1H1)
WRITE(NPRNT,799)
WRITE(NPRNT,799)
WRITE(NPRNT,799)
799 FORMAT(20X,'************************************************************************************')
WRITE(NPRNT,798)
798 FORMAT(/)
WRITE(NPRNT,801)
801 FORMAT(30X,'COMBINATION YIELDING MINIMUM COST!/////')
WRITE(NPRNT,802) CSTMN,NEQA,NCASE
802 FORMAT(20X,'A MINIMUM COST OF $1,7103.5 PER MBF WAS FOUND!//')
WRITE(NPRNT,803) 1,IN 'I5' COMBINATIONS OF THE 'I8' COMBINATIONS WHICH WERE TES
2TED'//)
WRITE(NPRNT,804) 1
803 FORMAT(30X,'EQUIPMENT SPECIFICATIONS OF MINIMUM COST COMBINATIONS!/////')
DS 53 1=#1,NEQA
WRITE(NPRNT,804) 1
804 FORMAT(40X,'COMBINATION ',I5//)
MM=MNSVE(I)
805 WRITE(NPRNT,806) MM
805 WRITE(NPRNT,806) MM
806 FORMAT(25X,'SKIDDING SYSTEM ',I2,' --- ROLLING STOCK!//')
806 WRITE(NPRNT,806) MM
807 WRITE(NPRNT,808) MM
807 WRITE(NPRNT,808) MM
808 FORMAT(25X,'SKIDDING SYSTEM ',I2,' --- IDAHO JAMMER!//')
808 WRITE(NPRNT,808) MM

Figure 30: (continued)
Figure 30: (continued)
KK=KSSVE(I)
G0 TO(827,829,831),KK
827 WRITE(NPRNT,828) KK
828 FORMAT(25X,'LOADING TRAILER SYSTEM I,I2,' NORMAL OR REGULAR TRAILERS'/)
G0 TO 56
829 WRITE(NPRNT,830) KK
830 FORMAT(25X,'LOADING TRAILER SYSTEM I,I2,' PREHAUL TRAILERS'/)
G0 TO 56
831 WRITE(NPRNT,832) KK
832 FORMAT(25X,'LOADING TRAILER SYSTEM I,I2,' BUNK OR PRELOAD'/)
56 ITS=ITSVE(I)
WRITE(NPRNT,833) ITS,CSTK(ITS)
833 FORMAT(25X,'TRUCK CATEGORY I,I2, TRUCK COST OF $1,F10.3'/)
NTS=NTSVE(I)
WRITE(NPRNT,834) NTS
834 FORMAT(25X,'TOTAL NUMBER OF TRUCKS IN SYSTEM = ',I4'/)
IF(KSSVE(I) .LT. 2) 837,835,837
835 WRITE(NPRNT,836) NSTSE(I)
836 FORMAT(25X,'NUMBER OF SHUTTLE TRUCKS IN PREHAUL SYSTEM = ',I4'/)
WRITE(NPRNT,838) XMIDK
838 FORMAT(25X,'LOCATION OF THE LOADING DECK FOR PREHAUL SYSTEM = ',1F10.3,' MILES FROM THE MILL'/)
NEXTR=EXTSV(I)
WRITE(NPRNT,840) NEXTR
840 FORMAT(25X,'NUMBER OF EXTRA PREHAUL TRAILERS = ',I4'/)
837 WRITE(NPRNT,839)
839 FORMAT(/)
53 CONTINUE
END

Figure 30: (continued)
Subroutine EVNTS is the primary subroutine called by the executive subroutine, GASP. Using an event code, control is directed to one of eight statements. The statements, in turn call the subroutine by its particular event code. The EVNTS subroutine is shown in Figure 31.
SUBROUTINE EVNTS(IX,NSET)
DIMENSION NSET(7,1)

C

C***GASP COMMON STATEMENTS

COMMON ID,IM,INIT,JEVT,JMNIT,MFA,MSTP,MX,MXC,NCLCT,NHIST,
1NRQ,NNRPT,NST,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,
2TBEG,TFIN,MMX,NPRNT,NCRDR,NEP,VPN(6)
COMMON ATRIB(5),ENG(6),INN(6),JCELS(1,2),KRANK(6),MAXNO(6),M
1FE(6),MLC(6),MLE(6),NCELS(1),NO(6),PARAM(12,4),QTIME(6),SSUMA
2(10,5),SUMA(10,5),NAME(6),NPROJ,MON,NDAY,NYR,JCLR

COMMON KOF,KLE,KGL
G0 T0(1,2,3,4,5,6,7,8),IX
1 CALL ARRVL(NSET)
RETURN
2 CALL ENDSV(NSET)
RETURN
3 CALL ARDK(NSET)
RETURN
4 CALL ESVDK(NSET)
RETURN
5 CALL BKDWN(NSET)
RETURN
6 CALL ESVBK(NSET)
RETURN
7 CALL SCHTK(NSET)
RETURN
8 CALL ENDAY(NSET)
RETURN
END

Figure 31: Computer Listing of Subroutine EVNTS
APPENDIX 5

SUBROUTINE ARRVL

The arrival of a truck at the landing is processed in subroutine ARRVL. This arrival signals the beginning of the loading activity. However, if the loader is busy at the time a truck arrives, the truck will be placed in a queue of those waiting for service. The computer listing of this subroutine is contained in Figure 32. Reference to the comment cards placed throughout the listing should enable the reader to follow the logic easily.
SUBROUTINE ARRVL(NSET)
DIMENSION NSET(7,1)

C*****GASP COMMON STATEMENTS

COMMON ID, IM, INIT, JEVNT, JMNIT, MFA, MSTOP, MX, MXC, NCLCT, NHIST,
1N90, N9RT, N9T, N9RMS, N9RUN, N9RUNS, N9STAT, BUT, SCALE, I9EED, TNOW,
2TBE9, TFIN, M9X, N9RNT, NCRDR, NEP, VNG(6)

COMMON ATRIB(5), ENG(6), INN(6), JCELS(1,2), KRANK(6), MAXNQ(6), M1F(6), MLC(6), MLE(6), NCELS(1), NQ(6), PARAM(12,4), QTIME(6), SSUMA
2(10,5), SUMA(10,5), NAME(6), N9R9J, M9N, NDAY, N9R, JC1LR

COMMON KBF, KLE, KBL

C*****NON-GASP COMMON VARIABLES

COMMON LCAT, TSV(12), USL(12), VDFL(12), VGL(12), PG9L, AVMBF, C107, W9LB, RTL9, W9T(2), ITCA, CSTK(6), VDF9T(6), V9T(6), W9TD, RTTD(2)
20, KSYS, X9IPA, XM9P, X9S, XPHPA, X9PR, X9PS, DE9CP, D9AY(12), W9HP(12)

COMMON M9NTH, F9CTD, F9CTG, F9CN, FFLCN, RR, XM9TBK(3), XM9TK(3)
1, XM9DK(3), XM9DTK(3), XM9BK(3), XM9TK(3), XM9NCL, UPE, W9MP, XM9NCT(20)
2, X9NTD, X9NTDL, ET9H, S9INC, SUTK, REPRT, MV9R, C9ST, CD9, CP9D, TK, TK9SYS

COMMON XM9DK, L9ADS, NBKTK, N9BLR, D9IDL, D9BD, DAT9T, T9NYR, YEAR, C9RBK, C9K
1BK9, C9T9IT, C9T9IT, C9CT9K, CS9V1, CS9V2, CS9V3, CS9V4, CS9V5, CS9TT, CL9AD, D9YS, H
29UR(20), MILES(20), XISYS, Bus1, Bus2, E9A9D, F9D9K, B9STK(20), SCHBD

COMMON CS9WL, C9WTK(20), ISV, TENDY, TISYS, WT, CB9TK, T9D9L, T9D9K,
1WETHR, SL9PE, XLAND, NC9SE, W9GMT

COMMON U9EL9, UL9RK, UL9DR(3), ULE9T, CST9W, T9DAY(12), C9ND

COMMON CL9SC(12), ICL9AS, CST96T, P9TK(3), PDV(12,25,4,4), C9MSC(3)

COMMON D9NTK, CID9T, CB9IT, CD9NIT, TRNT(20), PT9ML

COMMON BKFUL, C9BLR

C*****NOW INCREMENT THE CUMULATIVE DISTANCE FOR THIS TRUCK BY THE EITHER
C*****THE DISTANCE FROM THE MILL OR FROM THE LANDING.

C

ITKN*ATR18(5)

Figure 32: Computer Listing of Subroutine ARRVL
G0 TO (3,4,3),KSYS
3 MILES(ITKN)+MILES(ITKN)+XMIPR+XMIPA+XMIS
G0 TO 5
4 MILES(ITKN)+MILES(ITKN)+XMIPR+XMIS+XMIPA+XMIDK
IF(TRNT(ITKN)) 20,20,5
20 CALL ERROR(82,NSET)
5 CONTINUE
C
C*****SINCE A TRUCK ARRIVAL INCREASES THE NUMBER OF TRUCKS AT THE
C^>*»*LANDING COLLECT STATISTICS ON THE NUMBER OF TRUCKS AT THE LANDING,
C
CALL TMST(XISYS,TNOW,J,NSET)
IF(XISYS) 7,8,9
7 CALL ERROR(31,NSET)
RETURN
C
C*****SINCE THE NUMBER OF TRUCKS IN THE SYSTEM WAS ZERO, THE TRUCK NEED
C*****NOT WAIT FOR OTHER TRUCKS FOR SERVICE, IF NORMAL OR PREHAUL
C*****TRAILERS ARE BEING USED CONTROL IS TRANSFERRED TO STATEMENT 1 AND
C*****LOADING CAN BEGIN IMMEDIATELY. IF THE BUNK SYSTEM IS IN USE
C*****CONTROL IS TRANSFERRED TO STATEMENT 2 AND A CHECK MUST BE MADE TO
C*****DETERMINE WHETHER THE LOADER IS STILL LOADING THE BUNK.
C
8 G0 TO(1,1,2),KSYS
C
C*****FOR THE NORMAL AND PREHAUL TRAILER SYSTEMS INCREMENT THE NUMBER OF
C*****TRUCKS AT THE LANDING BY ONE, COLLECT STATISTICS ON THE IDLE TIME
C*****OF THE LOADER AND WAITING TIME OF THE TRUCK, AND SCHEDULE AN END
C*****OF LOADING TIME FOR THE TRUCK.
C
1 XISYS=XISYS+1.
CALL TMST(BUS1,TNOW,2,NSET)
BUS1=1.0
CALL COLCT(0,2,TNOW)
ATRIB(1)=TNOW+XDTM(LCAT,NSET)
ATRIB(2)=2.

Figure 32: (continued)
ATRIB(3)=TNBW
ATRIB(4)=0.0
CALL FILEM(1,NSET)
RETURN

C*****IF THE BUNK LOADING SYSTEM IS IN USE CHECK WHETHER THE LOADER IS
C*****BUSY. IF THE LOADER IS BUSY THE LOADER IS STILL LOADING THE BUNK
C*****AND THE TRUCK MUST BE PLACED IN A QUEUE AS SHOWN WHEN DIRECTED TO
C*****STATEMENT 9. IF THE LOADER IS IDLE THE BUNK IS LOADED AND READY
C*****TO BE TRANSFERRED TO THE TRUCK AS IS DONE WHEN CONTROL IS
C*****TRANSFERRED TO STATEMENT 11.

2 ITKN=ATRIB(5)
   IF(BKFUL) 10,9,11
10 CALL ERROR(32,NSET)
   RETURN
11 ATRIB(1)=TN8W*XDTSB(KSYS)
   ATRIB(2)=2.0
   ATRIB(3)=TN8W
   ATRIB(4)=2.0
   CALL FILEM(1,NSET)
   XISYS=XISYS+1.
   CALL C6LCT(0.0,2,NSET)
   RETURN

C*****IF BUNK IS STILL BEING LOADED PLACE TRUCK IN QUEUE.

9 ATRIB(3)=TN8W
   CALL FILEM(2,NSET)
   XISYS=XISYS+1.
   RETURN
END

Figure 32: (continued)
APPENDIX 6

SUBROUTINE ENDSV

Completion of loading at the landing is signalled by an end-of-loading event. This event is processed in subroutine ENDSV. Action taken in this subroutine depends upon the trailer-bunk combination being used. Generally, however, the next arrival of the truck is scheduled to either the landing or the prehaul dock. The computer listing of subroutine ENDSV is contained in Figure 33.
SUBROUTINE ENDSV(NSET)
DIMENSION NSET(7,1)

C*****GASP COMMON STATEMENTS
C
COMMON ID, IM, INIT, JEVNT, JMNIT, MFA, MST0P, MX, MXC, NCLCT, NHIST,
1NQ, NBRPT, N8T, NPRMS, NRUN, NRUNS, NSTAT, OUT, SCALE, ISEED, TNOW,
2TBEG, TFIN, MX, NPRNT, NCRDR, NEP, VNG(6)
COMMON ATRIB(5), ENG(6), INN(6), JCELS(1,2), KRANK(6), MAXNG(6), M
1FE(6), MLC(6), MLE(6), NCELS(1), NQ(6), PARAM(12,4), QTIME(6), SSUMA
2(10,5), SUMA(10,5), NAME(6), NBRUJ, M8N, NDAY, NYR, JCLR
COMMON K8F, KLE, KBL

C*****NON-GASP COMMON VARIABLES
C
COMMON LCAT, TSV(12), USL(12), VDFL(12), VGL(12), P8LR, AVMBF, C
16T, WGLB, RTL9, WGTS, RTTS, ITCA, CSTK(6), VDF(6), VGT(6), WGT, RTTD(2)
20), KSYS, XMIPA, XMIPR, XMIS, XPHPA, XPHPR, XPHS, DEMP, DAY(12), WTP(12)
COMMON MNTH, FLCST, FLCND, TFCN, TNMBK(3), TNMTK(3)
1, XMDBK(3), XMVTXK(3), XMRTK(3), XMNL, UFE, WMGP, XMNCT(20)
2, XNDT, XNDT1, EY0H, SCINC, SUTK, REPR, MNVR, CBST1, CDV, CPD, TKSYS
COMMON XMDK, LADS, NBKTK, NBKLR, DSIDL, DSBD, DAT6T, TENYR, YEAR, CCR8K, C
1BKIT, CBLT, CNTT, CTOBK, CSV1, CSV2, CSV3, CSV4, CSV5, CSVT, CL8AD, DAYS, H
26UR(20), MILES(20), XISYS, BUS1, BUS2, ETADK, FAD06, BUSTK(20), SCHBD
COMMON CSWL, CWPTK(20), ISV, TENDY, TISYS, WT, CDBT, TDKD, TDKK,
1WETH, SLORX, XLAND, CSLND, NCASE, WMG
COMMON ULELB, ULRK, ULD, CST0W, TIDAY(12), CLND
COMMON CLMSC(12), IC3, CSM(3), P07K(3), DPV(12,25,4,4), CSMSC(3)
COMMON DONIT, CDRIT, CBDIT, CDNIT, TRNT(20), PTHM
COMMON BKL, CDBL

C*****DEPENDING ON WHETHER TRAILER OR BUNK SYSTEMS ARE IN USE, TRANSFER
C*****CONTROL TO EITHER STATEMENT 1 OR 2.
C
GO TO(1,1,2), KSYS

Figure 33: Computer Listing of Subroutine ENDSV
C FOR NORMAL AND PREHAUL TRAILER SYSTEMS CALCULATE AND COMPUTE
C STATISTICS ON THE TIME AT THE LANDING, THE NUMBER OF TRUCKS AT THE
C LANDING, AND THE CUMULATIVE NUMBER OF LOADS COMPLETED.

C
1 TISYS=TNOW=ATTRIB(3)
   CALL CBLCT(TISYS,1,NSET)
   CALL TMST(XISYS, TNOW, 1, NSET)
   XISYS=XISYS+1
   LOADS=LOADS+1

C GENERATE THE NEXT ARRIVAL OF THIS PARTICULAR TRUCK, FOR THE
C NORMAL TRAILER SYSTEM THIS IS THE NEXT ARRIVAL AT THE LANDING.
C FOR THE PREHAUL TRAILER SYSTEM THIS IS THE ARRIVAL AT THE LOADING
C DECK.

C
G0 TO (5,6,2)*KSYS

C FOR THE NORMAL TRAILER SYSTEM SCHEDULE THE NEXT ARRIVAL ONLY IF
C IT IS NOT THE END OF THE DAY

C
5 LL=ATTRIB(4)+1
   G0 TO (31,32,32,32,LL)
32 ITKN=ATTRIB(5)
   HRSV=TRIPT(2,ITKN,NSET)
   HOUR(ITKn)=HOUR(ITKn)+HRSV
   MILES(ITKn)=MILES(ITKn)+XMIPA+XMIPR+XMIS
   G0 TO 7
31 ITKN=ATTRIB(5)
   HRSV=TRIPT(1,ITKN,NSET)
   HOUR(ITKn)=HRSV+HOUR(ITKn)
   MILES(ITKn)=MILES(ITKn)+XMIPA+XMIPR+XMIS
   ATTRIB(1)=TNOW+HRSV
   ATTRIB(2)=1.0
   ATTRIB(3)=0.0
   ATTRIB(4)=0.0

Figure 33: (continued)
CALL FILEM(1,NSET)
GO TO 7

C*****FOR PREHAUL TRAILER SYSTEM
C
6 ITKN=ATRIB(5)
HRSV=TRIP(4,ITKN,NSET)
HOUR(ITKN)=HOUR(ITKN)+HRSV
MILES(ITKN)=MILES(ITKN)+XMIPA+XMIPR+XMIS-XMIDK
ATRIB(1)=TNBW+HRSV
ATRIB(2)=3.0
ATRIB(3)=0.0
ATRIB(4)=1.0
ATRIB(5)=ITKN
CALL FILEM(1,NSET)
TRNT(ITKN)=1.0

C*****CHECK WHETHER ANY TRUCKS ARE IN THE QUEUE OF THOSE WAITING FOR
C*****SERVICE. IF THERE ARE NONE SET THE STATUS OF THE LOADER TO IDLE
C*****AFTER COLLECTING STATISTICS. DECREASE NUMBER OF TRUCKS BY ONE.
C
7 IF (NG(2)) 8,9,10
8 CALL ERRBR(33,NSET)
RETURN
9 CALL TMST(BUS1,TN BW,2,NSET)
BUS1=0.0
RETURN

C*****IF TRUCKS ARE WAITING FOR LOADING REMOVE THE TRUCK WHICH HAS BEEN
C*****WAITING THE LONGEST, COLLECT STATISTICS ON ITS WAITING TIME, AND
C*****SCHEDULE AN END-OF-LOADING TIME.
C
10 CALL RMBVE(MFE(2),2,NSET)
WT=TNBW-ATRIB(3)
CALL COLCT(WT,2,NSET)
ATRIB(1)=TNBW+XDTM(LCAT,NSET)

Figure 33: (continued)
ATRIB(2) = 2,0
ATRIB(4) = 0,0
CALL FILEM(1,NSET)
RETURN

C****FOR THE BUNK SYSTEM FIRST DETERMINE WHETHER THIS END-OF-SERVICE
C****MEANS THE LOADER FINISHES LOADING THE BUNK OR A TRUCK FINISHES
C****GETTING A LOAD FROM THE BUNK:
C
  2 II = ATRIB(4)
  G0 TO (3, 4, 3, 4), II
C
C****WHEN THE LOADER FINISHES LOADING A BUNK INCREMENT THE NUMBER OF
C****LOADS THE LOADER HAS COMPLETED, COLLECT STATISTICS ON THE BUSY
C****TIME OF THE LOADER, SET ITS STATUS TO IDLE, AND CHECK FOR ANY
C****TRUCKS WAITING FOR THE LOADER TO FINISH:
C
  3 LOADS = LOADS + 1
  CALL TMST(BUS1, TN0W, 2, NSET)
  BUS1 = 0, 0
  IF(NQ(2)) 20, 21, 22
  20 CALL ERROR(34, NSET)
  RETURN
C
C****IF TRUCKS ARE WAITING REMOVE THE ONE WHICH HAS BEEN WAITING THE
C****LONGEST, CALCULATE AND COLLECT STATISTICS ON ITS WAITING TIME, AND
C****SCHEDULE AN END-OF-TRANSFER TIME FROM THE BUNK TO THE TRUCK:
C
  22 CALL RMOVE(MFE(2), 2, NSET)
  WT = TN0W + ATRIB(3)
  CALL C6LCT(WT, 2, NSET)
  ATRIB(1) = TN0W + XDTMB(KSYS)
  ATRIB(2) = 2, 0
  ATRIB(4) = 2, 0
  CALL FILEM(1, NSET)

Figure 33: (continued)
C*****IF NO TRUCKS ARE WAITING CONTROL MAY BE RETURNED TO THE EXECUTIVE
C*****ROUTINE
C
21 BKFUL=1.0
RETURN
C
C*****FOR AN END OF TRANSFER OF A LOAD FROM THE BUNK TO THE TRUCK
C*****CALCULATE AND COLLECT STATISTICS ON THE TIME IN THE SYSTEM AND
C*****GENERATE THE NEXT ARRIVAL OF THIS TRUCK TO THE SYSTEM.
C
4 TISYS=TN8W=ATRIB(3)
CALL C6LCT(TISYS,1,NSET)
LL=ATRIB(4)
BKFUL=0.0
GO TO (33,33,34,34), LL
34 ITKN=ATRIB(5)
HRSV=TRIPT(2,ITKN,NSET)
HOUR(ITKN)=HOUR(ITKN)+HRSV
MILES(ITKN)=MILES(ITKN)+XMIPA+XMIPR+XMIS
GO TO 35
33 ITKN=ATRIB(5)
HRSV=TRIPT(1,ITKN,NSET)
HOUR(ITKN)=HOUR(ITKN)+HRSV
MILES(ITKN)=MILES(ITKN)+XMIPA+XMIPR+XMIS
ATRIB(1)=TN8W+HRSV
ATRIB(2)=1.0
ATRIB(3)=0.0
ATRIB(4)=0.0
CALL FILEM(1,NSET)
C
C*****COLLECT STATISTICS ON THE NUMBER OF TRUCKS AND DECREASE THE NUMBER
C*****OF TRUCKS BY ONE, SINCE THE BUNK IS NOW EMPTY SET THE LOADER
C*****STATUS AND SCHEDULE AN END OF LOADING TIME.
C
35 CALL TMST(XISYS, TN8W, 1, NSET)
XISYS=XISYS-1.0

Figure 33: (continued)
IF(NQ(2)) 50,51,52
50 CALL ERROR(80,NSET)
RETURN
51 IF(TNW=TENDY) 52,52,53
52 CALL TMST(BUS1,TNW,2,NSET)
BUS1=1.0
ATRIB(1)=TNW+XDTM(LCAT,NSET)
ATRIB(2)=2.0
ATRIB(3)=TNW
ATRIB(4)=1.0
ATRIB(5)=1.0
CALL FILEM(1,NSET)
53 RETURN
END

Figure 33: (continued)
APPENDIX 7

SUBROUTINE ARDOK

When prehaul trailers are used with the hauling unit, the actions at the prehaul dock must be considered. The arrival of a truck at the prehaul dock is processed in subroutine ARDOK. Action in this subroutine consists of scheduling the time when the prehaul trailer will be unhooked. The computer listing of subroutine ARDOK is contained in Figure 34.
SUBROUTINE ARDOK(NSET)
DIMENSION NSET(7,1)

C

C*****GASP COMMON STATEMENTS
C
COMMON ID, IM, INIT, JEVNT, JMNIT, MFA, MSTKP, MX, MXC, NCLCT, NHIST,
1NG0, NQRTPT, NBT, NPRMS, NRUN, NRUNS, NSTAT, OUT, SCALE, ISEEDE, TNOW,
2TBEG, TFIN, MXX, NPRNT, NCNRD, NEP, VNO(6)
COMMON ATRIB(5), ENQ(6), INN(6), JCELS(1,2), KRAIN(6), MAXNO(6), M
1FE(6), MLC(6), MLE(6), NCELS(1), NQ(6), PARAM(12,4), QTIME(6), SSUMA
2(10,5), SUMA(10,5), NAME(6), NPROJ, M0N, NDAY, NVR, JCLR
COMMON KBF, KLE, KBL

C

C*****NON-GASP COMMON VARIABLES
C
COMMON LCAT, TSV(12), USL(12), VDFL(12), VGL(12), PBLR, AVMBF, C
16T, WGBL, RTL8, WGT3, RTTS, ITCA, CSTK(6), VDFT(6), VGT(6), WGT0, RRTD(2
20), KSYS, XMIPA, XMIPR, XMS, XPHPA, XPHPR, XPHS, DEPC, DAY(12), WTHP(12)
COMMON MONT, FLCTD, FLCTG, FLCN, TFLCN, RR, XMTBK(3), XMTTK(3)
1, XMDBK(3), XMRTK(3), XMRTK(3), XMNL, UFE, WGM, XMNCT(20)
2, XNMTD, XNMDL, EYBH, SCINC, SUTK, REPT, MNVR, CMST, CDV, CPDNT, TKSYS
COMMON XMIDK, LADS, NBLK, BNKLR, DSIDL, DSBD, DAT8T, TENYR, YEAR, CCRBK, C
BK1T, CTTT, CTTK, CSS1, CSS2, CSS3, CSS4, CSS5, CSS6, CLAD, DAVS, H
2BUP(20), MILES(20), XISYS, BUS1, BUS2, ETADK, FADOK, BUSTK(20), SCHR
COMMON CSWL, CBWTK(20), ISV, TENDY, TISYS, WT, CDBT, TID, TIDK,
1WETH, SL0PE, SL0PE, XLAND, CMLD, NCASE, WGMT
COMMON ULED, UTRK, ULDR(3), ULET, CST8W, TIDAY(12), CLND
COMMON CLMSC(12), ICLAS, CST8T, PSTK(3), 8PDV(12,25,4,4), CSMSC(3)
COMMON DONST, CDIT, CBIDT, CDNIT, TRNT(20), PTHL
COMMON BKFUL, CDBLR

C

C*****SCHEDULE AN END-OF-HOOKING TIME WHEN THE TRAILER WILL BE UNLOADED.
C
KK=ATRIB(5)
IF (TRNT(KK)) 10,10,11

Figure 34: Computer Listing of Subroutine ARDOK
10 IF(ATRIB(3)) 12, 13, 13
12 IF(ETADK) 15, 15, 16
15 ATRIB(3) = TSNW
   CALL FILEM(5, NSET)
   RETURN
16 ATRIB(2) = 4, 0
   ATRIB(3) = TSNW
   ATRIB(4) = 1, 0
   CALL ESVDK(NSET)
   RETURN
13 ATRIB(2) = 4, 0
   ATRIB(3) = TSNW
   CALL ESVDK(NSET)
   MILES(KK) = MILES(KK) + XMIDK
   RETURN
11 CONTINUE
   JJ = ATRIB(4)
   G0 T0(5, 6), JJ
5 ATRIB(1) = TSNW + ULTDK(1)
   ATRIB(2) = 4, 0
   ATRIB(3) = TSNW
   CALL FILEM(1, NSET)
   I茨V = ATRIB(5)
   G0 T0(3, 4), JJ
4 MILES(ITSV) = MILES(ITSV) + XMIDK
3 RETURN
6 IF(TSNW - TENDY) 5, 3, 3
END

Figure 34: (continued)
APPENDIX 8

SUBROUTINE ESVDK

Subroutine ESVDK signals the end of processing at the prehaul dock. Depending upon whether the truck is a shuttle truck or a highway truck, the next event scheduled will either be an arrival at the landing or the next arrival of the truck at the dock. The subroutine also processes events when a truck finishes unhooking a trailer. The normal activity following this event is a hooking-up of a new trailer. The different cases existing in subroutine ESVDK are outlined in the computer listing shown in Figure 35.
SUBROUTINE ESVDK(NSET)
DIMENSION NSET(7,1)

C*****GASP COMMON STATEMENTS

COMMON ID, IM, INIT, JEVNT, JMNIT, MFA, MST8P, MX, MXC, NCLCT, NHIST,
1NBD, NBRPT, NET, NPRMS, NRUN, NRUNS, NSTAT, OUT, SCALE, ISEED, TNOW,
2TBEG, TFIN, MX, NPRMS, NCRDR, NEP, VNO (6)
COMMON ATRIB(5), ENO(6), INN(6), JCELS(1,2), KRANK(6), MAXNQ(6), M
1FE(6), MLC(6), MLE(6), NCELS(1), NQ(6), PARAM(12,4), GTIME(6), SSUMA
2(10,5), SUMA(10,5), NAME(6), NPRBJ, MN0, NDAY, NYR, JCLR
COMMON K8F, KLE, K6L

C*****NON-GASP COMMON VARIABLES

COMMON LCAT, TSV(12), USL(12), VDFL(12), VGL(12), P0LR, AVMBF, C
10T, WGLL, RTLB, WCTS, RTTS, ITCA, CSTK(6), VDFT(6), VGT(6), WGT, RTTD(2
20), KSYS, XMIPA, XMIPR, XMIS, XPHPA, XPHPR, XPHP, DEFC, DAY(12), WTP(12)
COMMON MENT, FLCRD, FLCRT, FLCN, TFLCN, RR, XMBK(3), XMTK(3)
1, XMDBK(3), XMSTK(3), XMRLK(3), XMRTK(3), XMNC, UFE, WGMP, XMNCT(20)
COMMON XMTK(3), XMTK(3), XMRTK(3), XMRLK(3), XMRC, UFE, WGMP, XMNCT(20)
2, XNDDT, XNDDL, EYBH, SCINC, SUTK, REPR, MNVR, C8ST1, CDV, CPD, TK, TKS
COMMON XMIDK, LBADS, NBKKT, NBKLR, SDPL, SDSR, DAT0, TENYR, YEAR, CCRBK, C
1BKHT, CTRT, CTTH, CTK, CV1, CV2, CV3, CV4, CV5, CV6, CLGAD, DAIN, H
20U(20), XISYS, BUS1, BUS2, ETAK, FAD8K, BUSTH(20), SCHBD
COMMON CSW, CWSB, CWS(20), CVT, TENDY, TISIS, W, CDBK, TIDK, TIDK,
1WETHR, SLOPE, XLAND, CLEND, NCASE, WGMT
COMMON ULEL0, ULTRK, ULD(3), ULED, CSTE(4), TDAY(12), CLND
COMMON CLM(12), ICASL, C8T8T, P0TK(3), 0PDV(12,25,4,4), CSMSC(3)
COMMON DONTK, CIDT, CDBT, CDIT, DNS, TR(20), PTML
COMMON BKFUL, CDBLR

C*****TRANSFER CONTROL TO ONE OF FOUR STATEMENTS DEPENDING UPON WHETHER
C***** (1) A TRUCK FINISHES UNHOOKING A FULL TRAILER, (2) A TRUCK FROM THE
C***** MILL FINISHED UNHOOKING AN EMPTY TRAILER, (3) A TRUCK HAS HOOKED UP
C***** AN EMPTY TRAILER AND IS RETURNING TO THE LANDING, AND (4) A TRUCK

Figure 35: Computer Listing of Subroutine ESVDK
C*****HAS HOOKED UP A FULL TRAILER AND IS RETURNING TO THE MILL.
C
    II=ATRIB(5)
    JJ=ATRIB(4)
    TSAVE=ATRIB(3)
    GO TO(1,2,3,4),JJ

C*****FOR A FULL TRAILER FROM THE LANDING INCREASE THE NUMBER OF LOADS
C*****AT THE DOCK, CHECK FOR LOADER BREAKDOWNS, AND IF THE EVENT OCCURS
C*****BEFORE THE END OF THE DAY CHECK FOR ANY TRUCKS WAITING FOR THE
C*****AVAILABILITY OF A FULL TRAILER.
C
    1 IF(TRNT(II)) 14,14,91
    91 CALL TMST(FAD8K,TNOW,5,NSET)
        FAD8K=FAD8K+1.*
        IF(NQ(4)) 13,14,15
    13 CALL ERROR(52,NSET)
        RETURN

C*****IF A TRUCK IS WAITING, SCHEDULE THE TIME THIS TRUCK WILL FINISH
C*****HOOKING UP THE LOADED TRAILER.
C
    15 CALL RM8VE(MFE(4),4,NSET)
        IJK=ATRIB(5)
        ATRIB(1)=TNOW+ULTDK(4)
        ATRIB(2)=4.*
        ATRIB(4)=4.*
        CALL FLEMF(1,NSET)
        TRNT(IJK)=10
        CALL TMST(FAD8K,TNOW,5,NSET)
        FAD8K=FAD8K+1.
    14 IF(TNOW-TENDY) 31,30,30
    31 IF(BUSTK(II)) 60,30,62
    60 CALL ERROR(67,NSET)
        RETURN

Figure 35: (continued)
C****NOW CHECK FOR ANY EMPTY TRAILERS AT THE DOCK SO THAT THE SHUTTLE
C****TRUCK MAY HOOK UP AN EMPTY TRAILER AND RETURN TO THE LANDING.
C****FIRST, HOWEVER, CHECK THE OPERATIONAL STATUS OF THE LOADER.
C
62 IF(BUS2) 40, 30, 41
40 CALL ERROR(54, NSET)
RETURN
41 IF(ETADK) 10, 11, 12
10 CALL ERROR(53, NSET)
RETURN
C
C*****IF THERE ARE NO TRAILERS AVAILABLE PLACE THIS TRUCK IN A QUEUE OF
C*****THOSE WAITING FOR EMPTY TRAILERS.
C
11 ATRIB(3) = TSAVE
ATRIB(5) = II
CALL FILEM(5, NSET)
RETURN
C
C*****IF THERE IS AN EMPTY TRAILER AVAILABLE, SCHEDULE AN END-OF-HOOKING
C*****TIME FOR THIS TRUCK.
C
12 ATRIB(1) = TNOW + ULTDK(3)
ATRIB(2) = 4
ATRIB(3) = TSAVE
ATRIB(4) = 3
ATRIB(5) = II
CALL FILEM(1, NSET)
TRNT([II] = 1, 0
CALL TMST(ETADK, TNOW, 6, NSET)
ETADK = ETADK + 1
RETURN
C
C*****FOR A TRUCK FROM THE MILL WHICH HAS JUST FINISHED UNHOOKING AN
C*****EMPTY TRAILER, INCREMENT THE NUMBER OF EMPTY TRAILERS AT THE DOCK
C*****AND CHECK WHETHER ANY SHUTTLE TRUCKS ARE WAITING FOR EMPTY

Figure 35: (continued)
C*****TRAILERS.*

2 IF(TRNT(I)) 17,17,81
  81 CALL TMST(ETADK,TNBW,6,NSET)
    ETADK=ETADK+1.
  16 CALL ERR8R(55,NSET)
    RETURN

C*****IF A SHUTTLE TRUCK IS WAITING, CHECK FIRST FOR A LOADER BREAKDOWN
C*****AND IF THERE IS NONE, SCHEDULE THE END-OF-HOOKING TIME WHEN THIS
C*****TRUCK WILL FINISH LOADING THE EMPTY TRAILER.

13 IF(TNOW,TENDY) 32,17,17
  32 IF(BUS2) 40,17,42
  42 CALL RM6VE(MFE(5),5,NSET)
    IJK=ATRIB(5)
    ATRIB(1)=TN8W+ULTDK(3)
    ATRIB(2)=4.
    ATRIB(4)=3.
    CALL FILEM(1,NSET)
    TRNT(IJK)=1.0
    CALL TMST(ETADK,TNBW,6,NSET)
    ETADK=ETADK+1.

C

C*****NOW CHECK WHETHER THERE ARE ANY FULL TRAILERS WHICH THIS TRUCK CAN
C*****HAUL TO THE MILL. IF THERE ARE NONE CHECK THE OPERATIONAL STATUS
C*****OF THE LOADER AND IF THE LOADER IS UP FILE THE TRUCK IN A QUEUE OF
C*****THOSE WAITING FOR FULL LOADS.

17 IF(BUSTK(I)) 60,30,61
  61 IF(FADDK) 19,20,21
  19 CALL ERR8R(56,NSET)
    RETURN
  20 IF(BUS2) 40,30,43
  43 IF(TNBW=TENDY) 72,30,30

Figure 35: (continued)
72 ATLIB(3) = TSAVE
    ATLIB(5) = I
    CALL FILEM(4, NSET)
    RETURN

C
C*****IF A LOADED TRAILER IS AVAILABLE, SCHEDULE THE TIME AT WHICH THE
C*****TRUCK WILL FINISH HOOKING UP THE TRAILER.
C
21 ATLIB(1) = TNOW + ULDK(4)
    ATLIB(2) = 4
    ATLIB(3) = TSAVE
    ATLIB(4) = 4
    ATLIB(5) = I
    CALL FILEM(1, NSET)
    TRNT(I) = 1, 0
    CALL TMST(FAD0K, TNOW, 6, NSET)
    FAD0K = FAD0K + 1.
    RETURN

C
C*****WHEN A SHUTTLE TRUCK FINISHES HOOKING UP AN EMPTY TRAILER,
C*****STATISTICS ARE COLLECTED ON THE TIME AT THE DOCK, THEN, IF IT IS
C*****NOT PAST THE END OF THE DAY AND THE LOADER IS NOT DOWN, AND ARRIVAL
C*****AT THE LANDING WILL BE SCHEDULED.
C
3 TIDKL = TNOW - ATLIB(3)
    CALL CBLCT(TIDKL, 4, NSET)
    IF(TNOW = TENDY) 45, 50, 50
45 IF(BUS2) 40, 50, 46
46 HRSV = TRIP (5, I1, NSET)
    HOUR(I) = HOUR(I) + HRSV
    ATLIB(1) = TNOW + HRSV
    ATLIB(2) = 1
    ATLIB(3) = 0.0
    ATLIB(4) = 0.0
    ATLIB(5) = I
    CALL FILEM(1, NSET)

Figure 35: (continued)
TIDBK = TNOW - ATBK
CALL COLCT (TIDBK, 3, NSET)
MILES (II) = MILES (II) + XMIDK
IF (TNOW = TENDY) 47, 48, 49
IF (BUS2) 40, 48, 49
49 HRSV = TRIP (8, II, NSET)
HOUR (II) = HOUR (II) + HRSV
ATBK (1) = TNOW + HRSV
ATBK (2) = 3
ATBK (3) = 0.0
ATBK (4) = 2
ATBK (5) = II
CALL FILEM (1, NSET)
TRNT (II) = 1.0
RETURN

CALL COLCT (TIDQK, 4, NSET)
GO TO (51, 52, 51, 52), JJ
51 TIDKL = TNOW - TSAVE
CALL COLCT (TIDKL, 4, NSET)
GO TO 50
52 TIDBK = TNOW - TSAVE

RETURN

C
C*****IF IT IS THE END OF THE DAY OR THE LOADER IS DOWN, INCREMENT THE
C*****HOURS WORKED BY THE HOURS TO THE MILL AND RETURN.

48 HRSV = TRIP (6, II, NSET)
HOUR (II) = HOUR (II) + HRSV
50 RETURN

30 TRNT (II) = 0.0
G0 TO (51, 52, 51, 52), JJ
CALL COLCT(TIDSK,3,NSET)
GO TO 50
END

Figure 35: (continued)
APPENDIX 9

SUBROUTINE BKDWN

The occurrence of a breakdown is signaled by subroutine BKDWN. If the breakdown was incurred by the loader, the entire operation of the loading and hauling subsystems will be made idle. If a truck breaks down, the number of trucks servicing the loader will be divided into two sections. The listing is shown in Figure 36.
SUBROUTINE BKDWN(NSET)
DIMENSION NSET(7,1)
C
C*****GASP COMMON STATEMENTS
C
COMMON ID,IM,INIT,JEVT,JMNIT,MFA,MST8P,MX,MXC,NCLCT,NHIST,
1NEQ,NBRPT,NSI,NPRMS,NRUN,NRUNS,NSAT,OUT,SCALE,ISEED,TNW
2TBEG,TFIN,MMX,NPRNT,NEP,NN(6)
COMMON ATRIB(5),ENG(6),INN(6),JCELS(1,2),KRNK(6),MNAXNQ(6),M
1FE(6),MLE(6),MNCLELS(1),NG(6),PARAM(12,4),QTIME(6),SSUMA
2(10,5),SUMA(10,5),NAME(6),NPR0J,MON,NDAY,MYR,JCLR
COMMON K9F,KLE,K6L
C
C*****N&N-GASP COMMON VARIABLES
C
COMMON LCAT,TSV(12),USL(12),VDFL(12),VGL(12),POLR,AVMBF,C
10T,WGL0,RTL9,WGTS,RTTS,ITCA,CSTK(6),VDFT(6),VGT(6),WGT,RTTD(2
10),KSYS,XMIPA,XMIPR,XMIS,XPHPA,XPHPR,XPHS,DEFC,DAY(12),WTHP(12)
COMMON MNTH,FCT,FLCTD,FLCTG,FLCN,TFLCN,RR,XTBK(3),XTTK(3)
1,XMDBK(3),XMDTK(3),XMRBK(3),XMRTK(3),XMNCL,UFN,WMPP,WMNCT(20)
2,XNTDT,XNTDL,HE8H,SCINC,SUKE,REPRT,NNV,MST1,CDV,CPD,TK,TKSYS
COMMON XIDK,LOADS,GBK,NKLR,DSID,DSBD,DAT6T,TERY,YEAR,CCBRK,C
1BKIT,CIT,CTBT,CSTK,CV1,CV2,CV3,CSV5,CSVT,CL9AD,DAY,H
20UR(20),MILES(20),XISYS,BUS1,BUS2,ETADK,FADBK,BUSTK(20),SCHBD
COMMON CWSW,CTHTK(20),IV,TNDSY,TISYS,WTCDBK,TITKL,TL9K,
1WTHR,SLOPE,SLAND,SLN,NCASE,WG
COMMON ULELS,ULTRK,ULTRD(3),ULETD,CST6W,TIDAY(12),CLND
COMMON CLMSC(12),ICLAS,CST6T,P6T(3),BDV(12,25,4,4),CAVMSC(3)
COMMON DONK,CIDT,CDIT,CDNTR,TNT(20),PTML
COMMON BKFUL,CDBL
C
C*****FIRST DETERMINE WHETHER THE LOADER OR A TRUCK HAS BROKEN DOWN AND
C*****TRANSFER CONTROL TO THE APPROPRIATE STATEMENT.
C
II=ATRIB(4)

Figure 36: Computer Listing of Subroutine BKDWN
JJ=ATTRIB(5)
SMWS=(WGT*D TK)+(WGTS*TSV(LCAT))
FLD=0.0
LDLFT=0
IF(JJ=1) 21,22,23
21 CALL ERROR(35,NSET)
RETURN
C
C*****SINCE THIS TRUCK IS NO LONGER IN SERVICE, EVENTS ASSOCIATED WITH
C*****THIS TRUCK MUST BE REMOVED FROM THE EVENT FILE AND EITHER STORED
C*****IN FILE 6 OR ELIMINATED.
C
23 TKN8=JJ
BUSTK(JJ)=0.0
65 CALL FIND(TKN8,5,1,5,KCOL,NSET)
IF(KCOL)60,61,25
60 CALL ERROR(36,NSET)
RETURN
25 CALL RM0VE(KCOL,1,NSET)
LLL=ATTRIB(4)
KKK=ATTRIB(2)
G0 TO (62,63,62,64,302,302,65,65),KKK
63 CALL TMST(XISYS,TNOW,I,NSET)
XISYS=XISYS-1
62 SAVE=ATTRIB(2)
G0 TO 65
64 SAVE=ATTRIB(2)
G0 TO (303,303,304,305),LLL
303 CALL ESVDK(NSET)
TRNT(JJ)=0.0
G0 TO 65
304 TRNT(JJ)=1.0
ATTRIB(4)=2.0
CALL ESVDK(NSET)
TRNT(JJ)=0.0
G0 TO 65

Figure 36: (continued)
305 TRNT(JJ)=1.0
ATTRB(4)=1.0
CALL ESVDK(NSET)
TRNT(JJ)=0.0
G0 TO 65
302 CALL FILEM(6,NSET)
G0 TO 65
61 CALL FIND(TKN6,5,2,5,KCBL,NSET)
IF(KCBL)66,67,68
66 CALL ERROR(37,NSET)
RETURN
68 CALL RM9VE(KCBL,2,NSET)
SAVE=5.
CALL TMST(XISYS,TN0W,1,NSET)
XISYS=XISYS-1.
67 CALL FIND(TKN6,5,4,5,KCBL,NSET)
IF(KCBL)306,307,308
306 CALL ERROR(68,NSET)
RETURN
308 CALL RM9VE(KCBL,4,NSET)
SAVE=4.
TRNT(JJ)=0.0
G0 TO 309
307 CALL FIND(TKN6,5,5,5,KCBL,NSET)
IF(KCBL)306,309,310
310 CALL RM9VE(KCBL,5,NSET)
SAVE=4.
TRNT(JJ)=0.0
C
C*****FOR A TRUCK BREAKDOWN DETERMINE THE TOTAL DURATION OF THE
C*****BREAKDOWN AND THE REPAIR TIME.  ALSO INCREMENT THE NUMBER OF TRUCK
C*****BREAKDOWNS AND DECREASE THE NUMBER OF TRUCKS AVAILABLE FOR USE IN
C*****THE SYSTEM.
C
309 NBKTK=NBKTK+1
DBKTK=DBK(JJ,II,NSET)

Figure 36: (continued)
RPTTK = RPT(JJ, II, NSET)
IF (DBKTK = RPTTK) 80, 81, 81
80 DBKTK = RPTTK
81 ISAV = SAVE
   IF (ISAV = 2) 220, 221, 220
221 G0 TO (225, 225, 226), KSYS
226 IF (NQ(2)) 222, 220, 228
228 CALL RMOVE(MFE(2), 2, NSET)
   WT = TNBW * ATRIB(3)
   CALL CSLET(WT, 2, NSET)
   ATRIB(1) = TNBW * XDTMB(KSYS)
   ATRIB(2) = 2
   ATRIB(4) = 2
   CALL FILEM(1, NSET)
   G0 TO 220
225 IF (NQ(2)) 222, 223, 224
222 CALL ERROR(73, NSET)
RETURN
223 CALL TMST(BUS1, TN0W, 2, NSET)
   BUS1 = 0, 0
   G0 TO 220
224 CALL RMOVE(MFE(2), 2, NSET)
   WT = TNBW * ATRIB(3)
   CALL CSLET(WT, 2, NSET)
   ATRIB(1) = TNBW * XDTM(LCAT, NSET)
   ATRIB(2) = 2
   ATRIB(4) = 0
   CALL FILEM(1, NSET)
220 IF (II = 1) 200, 200, 201
200 MILTW = 0, 0
   G0 TO 107
201 CONTINUE
   G0 TO (100, 101, 102, 103, 104), ISAV
100 MILTW = (XMPA + XMPR + XMIS) / 2
   G0 TO 107
101 MILTW = XMPA + XMPR + XMIS

Figure 36: (continued)
G0 TO 107
102 G0 TO (311,312),LLL
311 MILTW=XMIDK+(XMIPA+XMIPR+XMIS/XMIDK)/2*
G0 TO 107
312 MILTW=XMIDK/2*
G0 TO 107
103 MILTW=XMIDK
G0 TO 107
104 MILTW=XMIPA+XMIPR+XMIS
107 CONTINUE
CALL DRAND(ISEED,RNUM)
IF(RNUM=PBTK(II)) 113,114,114
113 OUTSD=1.0
G0 TO 112
114 OUTSD=0.0
112 CPRTS=CPRT((JJ,II,NSET)
CBKTK=CPRTS+(DBKTK*C&WTK(JJ))/60.0)+(RPTTK*OUTSD*WGMT)/60.0)+(M1
1LTW*CSTMW)+(WGD*(DBKTK-RPTTK)*(1+ULETD))/60.0)+(WGD*RPTTK)/60
2.0)
CCTBK=CCTBK+CBKTK
CDTK=CDBTK+DBKTK
CALL TMST(TKSYS,TNOW,4,NSET)
TKSYS=TKSYS-1.
C
C******NEW SCHEDULE AN END-OF-BREAKDOWN FOR THIS TRUCK
C
ATRIB(1)=TNOW+DBKTK
ATRIB(2)=6*
ATRIB(3)=TNOW
ATRIB(4)=II
ATRIB(5)=TKNB
CALL FILEM(1,NSET)
RETURN
C
C******FOR A LOADER BREAKDOWN DETERMINE FIRST THE DURATION AND REPAIR
C******TIME OF THE BREAKDOWN, THEN DETERMINE WHETHER THIS DURATION IS

Figure 36: (continued)
C*****LONGER THAN SOME CUT-OFF TIME AFTER WHICH TRUCKS RETURN FROM THE
C*****LANDING EMPTY.

C
22 NBKLR = NBKLR + 1
   DBKLR = DBK(1, 1, NSET)
   RPTBK = RPT(1, 1, NSET)
   IF (DBKLR > RPTBK) 82, 83, 83
82 DBKLR > RPTBK
83 IF (BUS2) 355, 355, 356
355 CALL ERROR(72, NSET)
   RETURN
356 IF (DBKLR > DBK) 69, 69, 27
C
C*****IF THE BREAKDOWN IS OF SHORT DURATION, A CHECK MUST BE MADE TO SEE
C*****IF THE LOADER WAS BUSY AT THE TIME OF THE BREAKDOWN. IF IT WAS
C*****EXTEND THE END OF LOADING TIME OF THE TRUCK BY THE DURATION OF THE
C*****BREAKDOWN.

C
69 IF (BUS1) 30, 28, 29
30 CALL ERROR(38, NSET)
   RETURN
29 CALL FIND(2, 5, 1, 2, KCOL, NSET)
   CALL RMVE(KCOL, 1, NSET)
   ATRIB(1) = ATRIB(1) + DBKLR
   CALL FILEM(1, NSET)
C
C*****IF THE LOADER WAS BUSY RECORD THE NUMBER OF TRUCKS WAITING WHILE
C*****THE LOADER IS DOWN.

C
TKWTN = NQ(2) + 1
   CALL TMST(BUS1, TNOW, 2, NSET)
   BUS1 = 0.
   G0 TO 90
28 TKWTN = 0, 0
90 CALL TMST(BUS2, TNOW, 3, NSET)
   BUS2 = 0.

Figure 36: (continued)
\[\text{CWAIT} = \frac{(\text{WGTD}+\text{CBWT}(2) \times \text{DBKLR})}{60.0} \]
\[\text{G0 TO (121, 122, 123), II} \]

121 \text{OUTSD}=0.0
\[\text{G0 TO 124} \]

122 \text{CALL DRAND(ISIED,RNUM)}
\[\text{IF (RNUM \neq 0) 125, 126, 126} \]

126 \text{OUTSD}=1.0
\[\text{G0 TO 124} \]

125 \text{OUTSD}=0.0
\[\text{G0 TO 124} \]

123 \text{OUTSD}=1.0

124 \text{CPRTS} = \text{CPRT}(1, 11, \text{NSET})
\[\text{CBKLR} = \text{CBKLR} + \text{CBKLR} \]
\[\text{CCRBK} = \text{CCRBK} + \text{CCRBK} \]
\[\text{G0 TO 350} \]

C

C***** IF THE DURATION OF THE BREAKDOWN IS GREATER THAN THE CUT-OFF TIME, 
C***** THE TRUCKS WILL LEAVE THE LANDING AND WILL BE RESCHEDULED WHEN THE 
C***** BREAKDOWN IS REPAIRED. ALSO IF THE LOADER WAS BUSY AT THE TIME OF 
C***** THE BREAKDOWN THE TRUCK IT WAS LOADING WILL BE RETURNED TO THE 
C***** LANDING AND BE COUNTED AS A FULL LOAD. 

C

27 \text{CALL TMST(BUS2, TN8W, 3, NSET)}
\[\text{BUS2}=0.0 \]
\[\text{G0 TO (230, 230, 240), KSYS} \]

230 \text{IF(BUS1) 70, 31, 32}

70 \text{CALL ERROR(81, NSET)}
\[\text{RETURN} \]

32 \text{CALL FIND(2, 5, 1, 2, KC8L, NSET)}
\[\text{CALL RMBVE(KC8L, 1, NSET)} \]
\[\text{ITKN} = \text{ATRIB}(5) \]
\[\text{G0 TO (71, 72, 71), KSYS} \]

71 \text{MILES(ITKN)=MILES(ITKN)+XMIS+XMIPR+XMIPA}

Figure 36: (continued)
72 MILES(ITKN)=MILES(ITKN)+XMIS+XMIPR+XMIPA=XMIDK
HRSV=TRIPT(4,ITKN,NSET)
H8UR(ITKN)=H8UR(ITKN)+HRSV
ATRIB(1)=TN8W+HRSV
ATRIB(2)=3.
ATRIB(3)=0.0
ATRIB(4)=1.
ATRIB(5)=ITKN
CALL FILEM(1,NSET)
LOADS=LOADS+1
G0 TO 73
240 IF(BUS1) 70,360,361
361 CALL FIND(2,5,1,2,KCBL,NSET)
IF(KCBL) 370,371,372
370 CALL ERR0B(83,NSET)
RETURN
372 CALL RMVBE(KCBL,1,NSET)
371 IF(NG(2)) 241,241,242
242 CALL RMVBE(MFE(2),2,NSET)
ATRIB(1)=TN8W+XDTMB(KSYS)
ATRIB(2)=2.0
ATRIB(4)=2.0
CALL FILEM(1,NSET)
WT=TN8W+ATRIB(3)
CALL CBLCT(WT,2,NSET)
LOADS=LOADS+1
364 CALL TMST(XISYS,TN8W,1,NSET)
XISYS=1,
TKRTN=NG(2)
365 IF(NG(2)) 40,366,367
367 CALL RMVBE(MFE(2),2,NSET)
G0 TO 365
241 LOADS=LOADS+1
368 LDLFT=1
TKRTN=0.0

Figure 36: (continued)
GO TO 366
360 CALL FIND(2,5,1,2,KC8L,NSET)
IF(KC8L) 74,368,364
C
C*****NOW CHECK FOR ANY TRUCKS IN THE QUEUE OF THOSE WAITING FOR LOADING
C*****REMOVE THEM, RECORD THE NUMBER OF TRUCKS RETURNING TO THE MILL
C*****EMPTY, COLLECT STATISTICS ON THE TRUCKS AT THE LANDING, AND SET
C*****THE NUMBER TO ZERO.
C
73 CONTINUE
150 IF(NQ(2)) 40,41,42
40 CALL ERROR(39,NSET)
RETURN
42 CALL RMBVE(MFE(2),2,NSET)
GO TO 150
41 TKRTN=XISYS=1
CALL TMST(XISYS,TNOW,1,NSET)
XISYS=0
366 CALL TMST(BUS1,TNOW,2,NSET)
BUS1=0*0
GO TO 77
C
C*****NOW CANCEL ANY ARRIVALS WHICH ARE SCHEDULED AT THE LANDING EXCEPT
C*****ONES TO HANDLE A LOAD IN A BUNK SYSTEM
C
31 TKRTN=0*0
77 CALL FIND(1,5,1,2,KC8L,NSET)
IF(KC8L) 74,35,36
74 CALL ERROR(41,NSET)
RETURN
36 CALL RMBVE(KC8L,1,NSET)
IF(LDLFT) 77,77,244
244 ATR=ATRIB(1)
BATR=ATRIB(2)
CATR=ATRIB(3)
DATR=ATRIB(4)
Figure 36: (continued)


EATR = ATRIB(5)
LDLFT = 0
F1LD = 1
G0 TO 77
35 IF(F1LD) 245,245,246
246 ATRIB(1) = ATR
ATRIB(2) = BATR
ATRIB(3) = CATR
ATRIB(4) = DATR
ATRIB(5) = EATR
CALL FILEM(1, NSET)
F1LD = 0
245 CONTINUE
G0 TO (130, 131, 130), KSYS
130 TAF = TRIP(1, 2, NSET)
CEXT = ((TAF * (WGTD + C6WK(2))) / 60) + (TFLCN * (FLCTD * \(VDFT \))
1(ITCA)) + (FLCTG * VGT(ITCA)) * (XMIPA + XMIPR + XMIS) * 2
G0 TO 133
131 TAF = TRIP(4, 2, NSET)
CEXT = ((2 * TAF * (WGTD + C6WK(2))) / 60) + (TFLCN * (FLCTD * V
1DFT ITCA)) + (FLCTG * VGT ITCA)) * (XMIPA + XMIPR + XMIS = XMIDK) * 2
133 CONTINUE
G0 TO (141, 142, 143), II
141 OUTSD = 0
G0 TO 144
142 CALL DRARE(1, ISEED), RNUM
IF (RNUM = PBWR) 145, 146, 146
146 OUTSD = 1
G0 TO 144
145 OUTSD = 0
G0 TO 144
143 OUTSD = 1
144 CPRTS = CPRT(1, II, NSET)
CBKL = CPRTS * (TKRTN * CEXTP) + ((WGLB * (DBKL * RPTBK) * (1 = ULEL)) / 60) + ((DSBK * CSSWL) / 60) + ((RPTBK * WGM* OUTSD) / 60) + ((C6WK(2) * TK * (DBKL
2R = TAF)) * (1 = UTRK)) / 60) + ((SMWGS * DBKL * (1 = UFE)) / 60) + (WGLB = RPT)

Figure 36: (continued)
3BK)/60.0)
CCRBK=CCRBK+CBKLR
CDBLR=CDBLR+DBKLR
350 CALL FIND(1..5,1..5, KCBL,NSET)
IF(KCBL) 351,352,353
351 CALL ERROR(70,NSET)
RETURN
353 CALL RMOVE(KCBL,1,NSET)
CALL FILEM(6,NSET)
GO TO 350
352 CONTINUE
C
C*****NOW FILE AN END-OF-BREAKDOWN EVENT FOR THIS BREAKDOWN
C
ATRIB(1)=TNOW+DBKLR
ATRIB(2)=6
ATRIB(3)=TNOW
ATRIB(4)=II
ATRIB(5)=1.
CALL FILEM(1,NSET)
RETURN
END

Figure 36: (continued)
APPENDIX 10

SUBROUTINE ESVBK

When an inoperable piece of equipment is repaired, the event is signaled by subroutine ESVBK. The function of this subroutine is to schedule the equipment back into service and then schedule the next breakdown of a particular severity level. This subroutine is listed in Figure 37.
SUBROUTINE ESVBK(NSET)
DIMENSION NSET(7,1)
C
C*****GASP COMMON STATEMENTS
C
COMMON ID, IM, INIT, JEVNT, JMNIT, MFA, MST6P, MX, MXC, NCLCT, NHIST,
NBO, NFRPT, NBT, NPRMS, NRUN, NRUNS, NSTAT, BUT, SCALE, ISEED, TN8W,
2TBEG, TFIN, MX, NFRRT, NCRDR, NEP, VNO(6)
COMMON ATRIB(5), ENQ(6), INN(6), JCELS(1, 2), KRANK(6), MAXNQ(6), M
1E(6), MLC(6), MLE(6), NCELS(1), NQ(6), PARAM(12, 4), GTIME(6), SSUMA
2(10, 5), SUMA(10, 5), NAME(6), NPRBJ, MBO, NDAY, NFR, JCLR
COMMON ATRB, ENQ(6), INN(6), JCELS(1, 2), KRANK(6), MAXNQ(6), M
1E(6), MLC(6), MLE(6), NCELS(1), NQ(6), PARAM(12, 4), GTIME(6), SSUMA
2(10, 5), SUMA(10, 5), NAME(6), NPRBJ, MBO, NDAY, NFR, JCLR

C *****NON-GASP COMMON VARIABLES
C
COMMON LCAT, TSV(12), USL(12), VDFL(12), VGL(12), P8LR, AVMBF, C
18T, WLE, RTL0, WGT, RTTS, ITCA, CSTK(6), VDFT(6), VGT(6), WGT5, RTTD(2)
20), XSYS, XMIPA, XMIPR, XMIS, XHPA, XHPR, XPHS, DECT, DAY(12), WTHP(12)
COMMON MENTH, FLCTD, FLCTG, FLCN, TFLCN, RR, XMTBK(3), XMTTK(3)
1, XMDBK(3), XMDDK(3), XMREEK(3), XMRTK(3), XMNC, USE, WGM, XMNC(12)
2, XNTDT, XNTDL, EY6H, SCINC, SUTK, REPRT, MNVR, C8ST, CDV, CPD, TK, TKSYS
COMMON XMIDK, LADS, NTK, NBLK, DS1D, NBLD, DAT8T, TENYR, YEAR, CCRBK, C
1BK1, C1LE1, C1MT, C1TB, C1SV1, C1SV2, C1SV3, C1SV4, C1SV5, C1SVT, C1LO, C1AD, C1AYS, H
2BUR(20), MILES(20), XISYS, BUS1, BUS2, ETADK, FADOK, BUSTK(20), SCHBD
COMMON CSW, C0WTK(20), ISY, TENDY, XISY, WT, CDBT, TKDL, TIDOK,
WETHR, SLOPE, XLAND, C1SN, NCASE, WGMT
COMMON ULEL, ULTRK, ULTDK, CST8W, T0DAY(12), CLND
COMMON C1MSC(12), Cl1C1, CST8TK, P8TK(3), OPLV(12, 25, 4, 4), CS1MSC(3)
COMMON D0NTK, CIDIT, CBDIT, C0NIT, TRNT(20), PTHL
COMMON BKFUL, CDBLR
C
C*****FIRST DETERMINE WHETHER THE END OF BREAKDOWN IS FOR THE LOADER OR
C*****FOR A TRUCK.
C
II=ATRIB(4)

Figure 37: Computer Listing of Subroutine ESVBK
TDN=ATRIB(3)
JJ=ATRIB(5)
IF(JJ=1) 21 22 23
21 CALL ERROR(42,NSET)
RETURN

C
C
C*****NOW, DEPENDING UPON THE TIME OF DAY THE BREAKDOWN REPAIR WAS
C*****COMPLETED EITHER GENERATE TRUCK ARRIVALS TO THE SYSTEM THAT DAY OR
C*****WAIT UNTIL THE NEXT DAY. FIRST CHECK THE DAY’S WEATHER
C
22 IF(WETHR) 6,6,33
33 CALL FIND(8.,5,1,2,KC6L,NSET)
CALL RMOVE(KC6L,1,NSET)
TSAVE=ATRIB(1)
CALL FILEM(1,NSET)
IF(TSAVE-TN8W-XNTDL) 6,7,7
6 CALL TMST(BUS2,TN8W,3,NSET)
BUS2=1.0
G0 TO 8
7 CALL TMST(BUS2,TN8W,3,NSET)
SCHBD=1.
CALL SCHTK(NSET)
BUS2=1.0
C
C*****NOW SCHEDULE THE NEXT BREAKDOWN OF THE LOADER FOR THIS PARTICULAR
C*****SEVERITY LEVEL.
C
8 ATRIB(1)=TN8W+BKDLR(II,NSET)
ATRIB(2)=5.
ATRIB(3)=0.0
ATRIB(4)=II
ATRIB(5)=JJ
CALL FILEM(1,NSET)
C
C*****NOW ADJUST THE COST OF LOADER BREAKDOWNS BY ANY TRUCKS WHICH WERE

Figure 37: (continued)
C**#*#D0WN AT THE SAME TIME EBK1C4C

C EBK1C4D

IF(TK-TKSYS) 60,60,103 EBK1C4E

103 ITKN=TK+!. EBK1C4F

DB 104 J=2,ITKN EBK1C4G

IF (BUSTK(J)) 105, 106,104 EBK1C4H

105 CALL ERR6R(77,NSET) EBK1C4I

RETURN EBK1C4J

106 XJ=J EBK1C4K

CALL F I  N D (XJ,5,I,5,KCBLiNSET) EEK1C4L

CALL RMeVE(KC9L,l,NSET) EBK1C4M

TXX =  ATR TB(3 )  EBK1C4N

CALL F ILEM(I,NSET >  EB1C4N1

IF(TXX-TDN) 107,108,108 EBK1C48

107 CCRBK=CCRBK-(((CBWTK(J )»(TNBW-TDN))#(I.-ULTRK))/6Q.0> EBK1C4P

GA TB 104 EEK1C4Q

108 CCRBK=CCRBK.(((CBWTK(J )*(TNBW-TXX))*(I.-ULTRK))/60,0) EBK1C4R

104 CONTINUE EBK1C4S

Ge TB 60 ESBK1C5

C ESBK127

C*****CHECK WHETHER TH

E BADER IS DBWN AT THIS TIME SINCE THE ARRIVAL BF ESBK128

C*****THIS TRUCK CANNOT BE SCHEDULED UNLESS THE BADER IS OPERATING AND ESBK129

0#*#*THERE IS ENOUGH TIME LEFT IN THE DAY. REGARDLESS, INCREMENT THE ESBK130

C*****NUMBER OF TRUCKS AVAILABLE BY BNE , ESBK

23 BUSTK(J)=1. IF(TKSYS=TCSYS+1. 0,20 EBK1C4A

RETURN 53 CALL ERROR(53,NSET) ESBK133

16,16,14 Figure 37: (continued)

20 IF(WETHR)16,16,14

23 BUSTK(J)=1. IF(TKSYS=TCSYS+1. 0,20 EBK1C4A

RETURN 53 CALL ERROR(53,NSET) ESBK133

16,16,14 Figure 37: (continued)

107 G9 T9 104 CALL RMGE(KCBL,1,NSET)

108 IF(TXX=Xnx) 107,108,108 EBK1C4m

107 CALL RMeVE(KC9L,l,NSET) EBK1C4M

108 CALL F ILEM(I,NSET >  EB1C4N1

224
CALL FIND(8,5,1,2,KC6L,NSET)
CALL REMOVE(KC6L,1,NSET)
TSAVE=ATRIB(1)
CALL FILEM(1,NSET)
IF(TSAVE-TN8W-XNDT) 16,15,15

C*****IF THERE IS ENOUGH TIME TO SCHEDULE AN ARRIVAL OF THIS TRUCK, THE
C*****AREA OF ARRIVAL WILL DEPEND UPON WHAT TYPE TRAILER IS USED AND
C*****WHETHER A PREHAUL TRAILER IS A SHUTTLE OR HIGHWAY TRAILER.

15 G0 TO(17,18,17),KSYS
17 IF(TKSYS=.1.) 132,132,130
132 IF(KSYS=.1.) 130,130,131
131 ATRIB(1)=TN8W+XNDT(LCAT,NSET)
ATRIB(2)=2.0
ATRIB(3)=TN8W
ATRIB(4)=1.0
ATRIB(5)=1.0
CALL FILEM(1,NSET)
CALL TMST(BUS1,TN8W,2,NSET)
BUS1=1.0
130 HRSV=TRIPT(3,JJ,NSET)
HOUR(JJ)=HOUR(JJ)+HRSV
ATRIB(1)=TN8W+HRSV
ATRIB(2)=1.0
ATRIB(3)=0.0
ATRIB(4)=0.0
G0 TO 19
18 ISUTK=SUTK+1.
IF(JJ=.ISUTK) 31,31,35
31 IF(TRNNT(JJ)) 120,120,121
120 HRSV=TRIPT(7,JJ,NSET)
HOUR(JJ)=HOUR(JJ)+HRSV
ATRIB(1)=TN8W+HRSV
ATRIB(2)=3.0
ATRIB(3)=5.0

Figure 37: (continued)
ATRIB(4) = 1.0
GO TO 19

121 HRSV = TRIP(T(3, JJ, NSET))
HOUR(JJ) = HOUR(JJ) + HRSV
ATRIB(1) = TNBW + HRSV
ATRIB(2) = 1
ATRIB(3) = 0.0
ATRIB(4) = 0.0
GO TO 19

35 HRSV = TRIP(T(7, JJ, NSET))
HOUR(JJ) = HOUR(JJ) + HRSV
ATRIB(1) = TNBW + HRSV
ATRIB(2) = 3.0
ATRIB(3) = 2.0
ATRIB(4) = 2.0

19 ATRIB(5) = JJ
CALL FILEM(I, NSET)

C
C*** NEW SCHEDULE THE NEXT BREAKDOWN FOR THIS TRUCK FOR THIS SEVERITY
C*** LEVEL.

C

16 ATRIB(1) = TNBW + BKDTK(I, NSET)
ATRIB(2) = 5
ATRIB(3) = 0.0
ATRIB(4) = I1
ATRIB(5) = JJ
CALL FILEM(I, NSET)

C
C*** NEW FILE ENTRIES IN FILE SIX BACK INTO FILE ONE
C

60 XNB = JJ
43 CALL FIND(XNB, 5, 6, 5, KCBL, NSET)
IF(KCBL) 40, 61, 42
40 CALL ERROR(66, NSET)
RETURN
42 CALL RM6VE(KCBL, 6, NSET)

Figure 37: (continued)
IF(ATTRB(1) = TNSW) 44,44,45
44 ATTRB(1) = TNSW
45 CONTINUE
   CALL FILEM(1,NSET)
   GO TO 43
61 RETURN
END
APPENDIX 11

SUBROUTINE ENDAY

The end of a scheduled working day causes the occurrence of event ENDAY. The purpose of a special subroutine for the end of the day is to process all activities that are still in progress and cancel those which would, in a real situation, never have been scheduled. The subroutine further generates the weather for the next day and the slope of the terrain. This subroutine is listed in Figure 38.
SUBROUTINE ENDAY (NSET)
DIMENSION NSET (7,1)

C*****GASP COMMON STATEMENTS

COMMON ID, I,M, INIT, JEVT, JMNI, MFA, MSTD, MX, MXC, NCLCT, NHIST,
 1, NBO, NBRPT, NBT, NPRM5, NRUN, NRUNS, NSTAT, OUT, SCALE, ISEED, TNOW,
 2, TBEG, TFIN, MX, NPRNT, NCRD, NEP, VNQ (6)
COMMON ATRIB (5), END (6), INN (6), JCELS (1,2), KRANK (6), MAXNO (6), M
 1, FE (6), MLC (6), MLE (6), NCELS (1), Ng (6), PARAM (12,4), OTIME (6), SSUMA
 2, (10,5), SUMA (10,5), NAME (6), NPRE, M0N, NDAY, NFR, JCLR
COMMON KBB, KLE, KBL

C*****NON-GASP COMMON VARIABLES

COMMON LCAT, TSV (12), USL (12), VDFL (12), VGL (12), PBL, AVMBF, C
187, WGL, RTL, WSGS, RTS, ITCA, CSTK (6), VDFL (6), VGT (6), WGT, RTTD(2)
201, SYS, XMIPA, XMIPR, XMIS, XHP, XHP, XPS, DEFT, DAY (12), WTHP (12)
COMMON MONT, FLCTD, FLCTG, FCN, FLCN, RR, XMTK (3), XMTK (3)
1, XMDBK (3), XMCTK (3), XMRTK (3), XMCL, UFE, WGMP, XMN (20)
2, XMTDK, XMTD, XTS, Y6G, SCINC, SUTK, REPR, MNVR, COST, CDV, CPD, TK, TKSYS
COMMON XMIDK, LADS, NBKTK, NBKLR, DSIDL, DSBD, DAT, TENV, YEAR, CCRBK, C
178, CLIT, CTIT, CBTK, CSV1, CSV2, CSV3, CSV4, CVST, CLBAD, DAYS, H
29, UR (20), MILES (20), XSYS, BUS, BUS, ETADK, FADK, BUSTK (20), SCHB
COMMON CSWL, CBWL, (20), ISV, TENDY, TISYS, W, CDBK, TK, TIDK, TIDK
1, WERT, SLPE, XLAND, CSLN, NCASE, WM
COMMON ULEL, ULTR, ULTDR (3), ULET, CSTBW, TIDAY (12), CLN
COMMON CLMCS (12), ICLAS, CSTBK, POKT (3), OPDV (12, 25, 4, 4), CSMSC (3)
COMMON DONTK, CIDTK, CBDTK, CDNIT, TRNT (20), PTLML
COMMON BKFUL, CDBLR

C*****SAVE THE TIME SCHEDULED TO END THE DAY AND THE CURRENT TIME AND,
C*****SINCE A SCHEDULED END OF DAY HAS OCCURRED, PROCESS ALL TRUCKS
C*****OUT OF THE LANDING, ALSO UPDATE OR ELIMINATE OTHER EVENTS.

Figure 38: Computer Listing of Subroutine ENDAY
TSAVE=TNOW
TENDY=TNOW
7 IF(NQ(1)) 8,9,10
8 CALL ERROR(44,NSET)
RETURN

C*****REMOVE ALL ENTRIES FROM FILE ONE AND, DEPENDING ON THE TYPE OF
C*****EVENT, PROCESS EACH DIFFERENTLY.

C 10 CALL REMAP(MFE(1),1,NSET)
   TNOW=ATRIB(1)
   JJ=ATRIB(2)
   IF(JJ=101) 97,96,96
96 CALL FILEM(3,NSET)
   G0 TO 7
97 CONTINUE
   G0 TO (11,12,13,14,15,16,11)/JJ

C*****ALL TRUCK ARRIVALS FOR THIS DAY ARE ELIMINATED SINCE IN THE ACTUAL
C*****SYSTEM A TRIP TO THE LANDING WILL BE STARTED ONLY IF THERE IS
C*****TIME TO ARRIVE BEFORE THE END OF THE DAY.

C 11 G0 TO 7

C*****IF THE EVENT IS AN END-OF-LOADING EVENT, PROCESS IT IN THE NORMAL
C*****MANNER EXCEPT THAT NO ARRIVAL WILL BE SCHEDULED.

C 12 ATRIB(4)=ATRIB(4)+2.
   TSAVE=TNOW
   CALL ENDSV(NSET)
   G0 TO 7

C*****ARRIVALS AT THE LOADING DOCK FROM THE MILL WILL BE ELIMINATED
C*****WHILE THOSE FROM THE LANDING WILL BE PROCESSED NORMALLY.

C 13 IF(ATRIB(4)=1) 17,18,7

Figure 38: (continued)
17 CALL ERROR(45,NSET)
    RETURN
18 CALL ARDSK(NSET)
    G0 T0 7

C*****PROCESS AN END-OF-SERVICE AT THE DOCK NORMALLY BUT MODIFIED BY THE C*****FACT THAT THE SCHEDULED DAY IS OVER.

C 14 CALL ESVDK(NSET)
    G0 T0 7

C*****FOR A BREAKDOWN, TEST THE PIECE OF EQUIPMENT WHICH BROKE DOWN. IF C*****THE EVENT IS A LOADER BREAKDOWN, CHECK THE BUSY STATUS OF THE C*****LOADER. IF IT IS IDLE, STORE THE BREAKDOWN IN A STORAGE FILE. IF C*****IT IS BUSY, PROCESS THE BREAKDOWN NORMALLY.

C 15 IF(ATRIB(S).I.0)22,23,24
22 CALL ERROR(46,NSET)
    RETURN
23 IF(BUS1) 19,20,21
19 CALL ERROR(47,NSET)
    RETURN
20 CALL FILEM(3,NSET)
    G0 T0 7
21 CALL BKDWN(NSET)
    G0 T0 7

C

C*****IF A TRUCK HAS BROKEN DOWN TRACE THE PARTICULAR TRUCK TO SEE C*****WHETHER IT IS AT ONE OF THE FACILITIES OR IS FINISHED FOR THE DAY. C*****THIS CHECK MAY ALSO BE USED TO ELIMINATE ARRIVALS.

C 24 AATR=ATRIB(1)
    BATR=ATRIB(2)
    CATR=ATRIB(3)
    DATR=ATRIB(4)
    XN8=ATRIB(5)
Figure 38: (continued)
C*****WAS TO COME FROM THE LANDING OR THE MILL SINCE ARRIVALS FROM THE
C*****MILL WILL BE ELIMINATED AND ARRIVALS FROM THE LANDING WILL BE
C*****PROCESSED.

C
60 GO T0 (61,62) \\
61 CALL FILEM(1,NSET) \\
   ATRIB(1)=AATR \\
   ATRIB(2)=BATR \\
   ATRIB(3)=CATR \\
   ATRIB(4)=DATR \\
   ATRIB(5)=XN6 \\
   CALL BKDW(NSET) \\
   GO T0 7 \\
62 ATRIB(1)=AATR \\
   ATRIB(2)=BATR \\
   ATRIB(3)=CATR \\
   ATRIB(4)=DATR \\
   ATRIB(5)=XN6 \\
   CALL FILEM(3,NSET) \\
   GO T0 7 \\
C
C*****IF THE TRUCK HAS AN END-OF-HOOKING AT THE DOCK SCHEDULED, PROCESS
C*****THE BREAKDOWN IN A NORMAL MANNER.

C
31 GO T0 61 \\
C
C*****IF THE EVENT IS A BREAKDOWN OR AN END-OF-BREAKDOWN FILE IT IN THE
C*****STORAGE FILE AND CONTINUE CHECKING FOR THE TRUCK'S LOCATION.

C
32 CALL FILEM(3,NSET) \\
   GO T0 35 \\
C
C*****IF THE TRUCK CANNOT BE LOCATED IN THE EVENT FILE CHECK FOR THE
C*****TRUCK IN THE QUEUE OF TRUCKS WAITING TO BE LOADED. IF THE TRUCK
C*****IS IN THE QUEUE PROCESS THE BREAKDOWN NORMALLY.

Figure 38: (continued)
26 CALL FIND(XN0, 5, 2, 5, KCOL, NSET)
    IF(KCOL) 25, 99, 34
34 ATRIB(1) = AATR
    ATRIB(2) = BATR
    ATRIB(3) = CATR
    ATRIB(4) = DATR
    ATRIB(5) = XN0
    CALL BKDOWN(NSET)
    G0 TO 7
99 ATRIB(1) = AATR
    ATRIB(2) = BATR
    ATRIB(3) = CATR
    ATRIB(4) = DATR
    ATRIB(5) = XN0
    CALL FILEM(3, NSET)
    G0 TO 7
C*****FOR AN END-OF-REPAIR OF A BREAKDOWN, STORE IT IN A STORAGE FILE
C*****AND RETURN.
C
16 CALL FILEM(3, NSET)
    G0 TO 7
C
C*****SINCE ALL EVENTS IN FILE 1 HAVE BEEN PROCESSED THEY MAY NOW BE
C*****TRANSFERRED BACK FROM FILE 3. A BREAKDOWN WILL HAVE TO BE UPDATED
C*****IF ITS TIME OF OCCURRENCE IS LESS THAN THE CURRENT TNOW. END-OF-
C*****REPAIR OF BREAKDOWNS MUST BE UPDATED FROM THE SCHEDULED END-OF-DAY
C
9 TNOW = TSAVE
36 IF(NO(3)) 58, 41, 59
58 CALL ERROR(49, NSET)
    RETURN
59 CALL RM8VE(MFE(3), 3, NSET)
    JJ = ATRIB(2)
    IF(JJ=97) 98, 37, 37
98 CONTINUE

Figure 38: (continued)
C******NEW REMOVE ALL TRUCKS WAITING AT THE DOCK FROM THEIR RESPECTIVE QUEUES.

C

41 IF(NQ(4)) 70, 71, 72
42 CALL ERROR(57, NSET)
43 RETURN
44 CALL MOVE(MFE(4), 4, NSET)
45 TIDK = TNEW - ATRIB(3)
46 JK = ATRIB(5)
47 TRNT(JK) = 0.0
48 CALL COLCT(TIDK, 3, NSET)
49 G0 TO 41
50 IF(NQ(5)) 73, 74, 75
51 CALL ERROR(58, NSET)
52 RETURN
53 CALL MOVE(MFE(5), 5, NSET)
54 TIDK = TNEW - ATRIB(3)
55 CALL COLCT(TIDK, 4, NSET)
56 JK = ATRIB(5)
57 TRNT(JK) = 0.0
58 G0 TO 71

C******NEW DETERMINE THE WEATHER FOR THE NEXT DAY. IF BAD, WETHR=0, AND LOGGERS CAN ONLY WORK TO REPAIR BREAKDOWNS. IF WETHR=1, THE WEATHER IS GOOD AND NORMAL WORK CAN TAKE PLACE.

C

74 CALL DRAND(ISEED, RNUM)
IF (RNUM=WTHP(MONTH)) 42, 42, 65
65 WETHR=0.0
GO TO 43
42 WETHR=1.0
C
C******CHECK THE STATUS OF THE LOADER WITH REGARD TO BREAKDOWNS. REPAIRS
C******CAN BE MADE DURING BAD WEATHER SO THE WEATHER IS CHECKED:
C
43 IF (BUS2) 44, 45, 46
44 CALL ERROR(50, NSET)
RETURN
45 IF (WETHR) 47, 57, 49
47 CALL ERROR(51, NSET)
RETURN
46 IF (WETHR) 47, 48, 50
C
C******IF THE WEATHER IS BAD AND THE LOADER IS OPERATIONAL, INCREMENT THE
C******NUMBER OF DAYS WORK CANNOT BE DONE BECAUSE OF WEATHER AND COLLECT
C******STATISTICS:
C
48 CALL TMST(0.0, TNBW, 7, NSET)
DSIDL=DSIDL+1.
C
C*****ALSO COLLECT STATISTICS ON THE TOTAL NUMBER OF BAD WEATHER DAYS.
C
57 CALL TMST(0.0, TNBW, 8, NSET)
DSBD=DSBD+1.
GO TO 49
C
C******IF WEATHER IS GOOD AND LOADER IS UP, SCHEDULE TRUCK ARRIVALS.
C
50 CALL TMST(1.0, TNBW, 7, NSET)
CALL TMST(1.0, TNBW, 8, NSET)
SCHBD=0.0
CALL SCHTK(NSET)
C
Figure 38: (continued)
C*****NOW DETERMINE THE SLOPE FOR THE NEXT DAY
C
SLOPE=RNDRM(7)
IF(SLOPE=XLAND) 90,90,91
91 IF(LCAT=5) 93,94,93
94 IF(KSYS=2) 93,95,93
93 CSLND=CSLN+CSMSC(KSYS)
95 CLND=CLND+CLMSC(LCAT)
90 CONTINUE
C
C*****DETERMINE WHETHER THIS DAY MARKS THE END OF A MONTH.
C
49 IF(DAYS=DAY(MMONTH)) 51,66,66
66 DATBT=DATBT+DAYS
DAYS=1
MMONTH=MMONTH+1
C
C*****DETERMINE WHETHER THE END OF THIS MONTH MARKS THE END OF A YEAR.
C
IF(12=MMONTH) 53,52,52
53 MMONTH=1
CALL ENDYR(NSET)
YEAR=YEAR+1
C
C*****NOW DETERMINE WHETHER THE END OF THIS YEAR MARKS THE END OF THE
C*****USEFUL LIFE OF THIS LOADER AND THE END OF THIS SIMULATION RUN.
C
IF(YEAR=USL(LCAT)) 52,52,55
55 YEAR=YEAR+1
CALL ENDSM(NSET)
RETURN
C
C*****SCHEDULE THE END OF THE NEXT DAY.
C
51 DAYS=DAYS+1
52 ATRIB(1)=TNEW+TIDAY(MMONTH)

Figure 38: (continued)
ATRIB(2) = 8
ATRIB(3) = 0
ATRIB(4) = 0
ATRIB(5) = 0
CALL FILEM(1, NSET)
TENDY = ATRIB(1)
RETURN
END

Figure 38: (continued)
Scheduling the initial arrival of each truck requires a special subroutine. Here, the first truck arrival is scheduled at the beginning of the day and each subsequent truck is scheduled to arrive when the previous truck has finished processing. Scheduling can take place at the beginning of the day or after the repair of a loader breakdown. The scheduling technique also varies between systems using standard trailers and those using prehaul trailers. The computer listing of this scheduling process shown in Figure 39.
SUBROUTINE SCHTK(NSET)
DIMENSION NSET(Til)

C*****GASP COMMON STATEMENTS
COMMON ID, IM, INIT, JEVNT, JMNIT, MFA, MSTBP, MX, MXC, NCLCT, NHIST,
1NGC, NRBP, NBT, NRPMS, NRUN, NRUNS, NSTAT, OUT, SCALE, ISEEID, TNOW,
2TBEG, TFIN, TMIN, NPRNT, NCADR, NEF, VNG(6)
COMMON ATRIB(5), ENG(6), INN(6), JCELS(1, 2), KRANK(6), MAXNQ(6), M
1FE(6), MLC(6), MLE(6), NCELS(1), NQ(6), PARAM(12, 4), GTIME(6), SUMA
2(10, 5), SUMA(10, 5), NAME(6), NPROJ, MNO, NDAY, NYR, JCLR
COMMON KOF, KLE, KB

C*****NON-GASP COMMON VARIABLES
COMMON LCAT, TSV(12), USL(12), VDFL(12), VGL(12), PBLR, AVMBF, C
16T, WGLB, RTLB, WGT, RTTS, ITCA, CSTK(6), VDFT(6), VGT(6), WT, RTTD, RTTD(2)
20), KSYS, XMIPA, XMIPR, XMIS, XPHPA, XPHPR, XPHS, DEFC, DAY(12), WTHP(12)
COMMON MONT, FLCTD, FLCTG, FLCTN, TFN, RTR, XMTBK(3), XMTTK(3)
1, XMDBK(3), XMEDK(3), XMREK(3), XMRTK(3), XMNCL, UFE, WMP, XMNCT(20)
2, XNTDT, XNTDL, EV6H, SCINC, SUTK, REPRT, MNVR, CTS1, CDV, CPD, TK, TKSYS
COMMON XMIDK, LADS, NBKTK, NNLK, DSIDL, DSB, DATB, TENYR, YEAR, CCRBK, C
1BKT, CTTI, CTTI, CTTBK, CV1, CV2, CV3, CV4, CV5, CVTT, CLAD, DAY, H
28UR(20), MILE(20), XISYS, BUS1, BUS2, ETADK, FAD6K, BUSTK(20), SCHBD
COMMON CSBWL, CSWTK(20), IS, TENDY, TISYS, WT, CDBTK, DMDK, TIDK, TIDK
1, WETHR, SLOPE, XLAND, CCLND, NCASE, WMG
COMMON ULEL0, ULTRK, ULTD, CSTB, TIDAY(12), CLND
COMMON CLMSC(12), ICCLS, CSTG, P0TK(3), PDV(12, 25, 4, 4), CSMSC(3)
COMMON DNTP, CIDTP, CIDTP, CDNIT, TRNT(20), PTL
COMMON BKFUL, CDBLR

C*****THE SCHEDULING TECHNIQUES ARE DIFFERENT FOR NORMAL AND PREHAUL
C*****TRAILERS. SO TRANSFER CONTROL TO THE APPROPRIATE STATEMENT.
C*****FIRST CHECK WHETHER ALL TRUCKS ARE DOWN WITH BREAKDOWNS.

Figure 39: Computer Listing of Subroutine SCHTK
IF(TKSYS) 200,201,202
   CALL ERROR(71,NSET)
   RETURN
   G0 TO (4,5,4),KSYS
C
C*****FOR NORMAL TRAILER SYSTEMS ALL TRUCKS ARE SCHEDULED AT THE LANDING
C*****CHECK WHETHER THE SCHEDULING IS AT THE BEGINNING OF THE DAY OR
C*****AFTER A BREAKDOWN REPAIR. FOR TRUCKS WHICH ARE SCHEDULED AT THE
C*****BEGINNING OF THE DAY SCHEDULE SUCCESSIVE TRUCKS AFTER ALTERNATING
C*****THE FIRST TRUCK SCHEDULED.
C
  4 IF(SCBD) 7,8,9
  7 CALL ERROR(59,NSET)
       RETURN
  8 IF(DAYS=1) 10,10,11
 10 FTSPD=2,
 11 ITK=TK+1,
     XTKN=TK+1,
     FTSV=FTSPD-1,
        IF(KSYS=1) 80,80,81
   80 XLDM=0.0
       G0 TO 82
C
C*****FOR A PRELOAD SYSTEM SCHEDULE THE INITIAL LOADING OF THE BUNK
C
  81 IF(BKFUL) 550,550,551
  550 XLDM=0.0
       G0 TO 82
  550 XLDM=XDTM(LCAT,NSET)
     ATRIB(1)=TNBW+XLDM
     ATRIB(2)=2.0
     ATRIB(3)=TNBW
     ATRIB(4)=1.0
     ATRIB(5)=0.0
     CALL FILEM(I,NSET)
     CALL TMST(BUS1,TN8W,2,NSET)

Figure 39: (continued)
82 ITSV = FTSV
83 DB 20 J = 2, ITK
84 FTSV = FTSV + 1
85 IF (FTSV = XTKN) 14, 14, 15
15 FTSV = 2
14 ITSV = FTSV
15 IF (BUSTK (ITSV)) 90, 20, 91
90 CALL ERRBR (60, NSET)
RETURN
C
C*****NOW SCHEDULE THE INITIAL ARRIVAL OF EACH TRUCK
C
91 ATRIB (1) = TN8W + XLDM
92 ATRIB (2) = 1 * 0
93 ATRIB (3) = 0 * 0
94 ATRIB (4) = 0 * 0
95 ATRIB (5) = FTSV
96 CALL FILEMK (1, NSET)
97 HBUR (ITSV) = HBUR (ITSV) + TRIP (3, ITSV, NSET)
98 IF (KSYS = 1) 83, 83, 84
83 XLDM = XLDM + SCINC * XDTM (LCAT, NSET)
84 XLDM = XLDM + SCINC * XDTM (LCAT, NSET) + XDTMB (KSYS)
90 TO 20
20 CONTINUE
16 FTSPD = FTSPD + 1
17 IF (FTSPD = XTKN) 12, 12, 13
13 FTSPD = 2
12 RETURN
C
C*****IF THE SCHEDULING OCCURS AFTER THE REPAIR OF A BREAKDOWN TRUCKS
C*****MAY ONLY BE SCHEDULED IF TIME REMAINS IN THE DAY; SCHEDULING
C*****TAKES PLACE IN THE SAME MANNER AS PREVIOUSLY;
C
9 CALL FIND (8, 5, 1, 2, KCB, NSET)
10 IF (KCB) 22, 22, 23

Figure 39: (continued)
22 CALL ERROR(61, NSET)
   RETURN
23 TSAVE = ATRIB(1)
   CALL FILEM(1, NSET)
   ITK = TK + 1
   XTKN = TK + 1
   FTSV = FTSPD + 1
   ITSV = FTSV
   IF (KSYS = 1) 85, 85, 86
   XLDM = 0
   G0 TO 87
85 XLDM = .0
   IF (BKFUL) 552, 552, 553
   XLDM = 0.0
   G0 TO 87
552 XLDM = XDTM(LCAT, NSET)
   ATRIB(1) = TNOW + XLDM
   ATRIB(2) = 2.0
   ATRIB(3) = TNOW
   ATRIB(4) = 1.0
   ATRIB(5) = 1.0
   CALL FILEM(1, NSET)
   CALL TMST(BUS1, TNOW, 2, NSET)
   BUS1 = 1.0
87 CONTINUE
   D0 21 J = 2, ITK
   TVLT = XLDM + TRIP(3, ITSV, NSET)
   IF (TSAVE = TNOW - TVLT) 16, 17, 17
   FTSV = FTSV + 1
   IF (FTSV = XTKN) 18, 18, 19
17 FTSV = 2
   ITSV = FTSV
   IF (BUSTK(ITSV)) 90, 21, 92
C
C*****NOW SCHEDULE AS MANY TRUCKS AS TIME PERMITS
C
92 ATRIB(1) = TNOW + TVLT

Figure 39: (continued)
ATRIB(2)=1.
ATRIB(3)=0.0
ATRIB(4)=0.0
ATRIB(5)=FSV
CALL FILEM(1,NSET)
H8UR(ITSV)=H8UR(ITSV)+TVLT-XLDM
IF(KSYS=1) 88,88,89
88 XLDM=XLDM+SCINC+XDTM(LCAT,NSET)  
GO TO 21
89 XLDM=XLDM+SCINC+XDTM( LCAT,NSET )+XDTMB( KSYS)  
GO TO 21
21 CONTINUE
GO TO 16

C
C*****F8R THE PREHAUL TRAILER SY8EM THE SCHEDULE TECHNIQUE VARIES SINCE
C*****SHUTTLE AND HIGHWAY TRUCKS MUST BE SCHEDULED DIFFERENTLY. FIRST,
C*****HOWEVER, THE TIME THE SCHEDULING IS TAKING PLACE MUST BE CHECKED.
C*****IF THE SCHEDULING IS TAKING PLACE AT THE BEGINNING OF THE DAY
C*****BEGIN BY S8CHULING THE SHUTTLE TRUCKS,

5 SUTKN=SUTK+1.
IF(SCHBD) 30,31,32
30 CALL ERROR(62,NSET)
RETURN
31 IF(DAYS=1) 33,33,34
33 FSHTK=2.
FHWTK=SUTKN+1.
34 ISHTK=SUTKN
IHWTK=TK+1.
XHTK=TK+1.
FSHSV=FSHTK+1.
FHSV=FHWTK+1.
SHAVL=SUTK
NTNTR=0.
XLDM=0.0.
XSHDW=0.0.
XHWDW=0.0.

Figure 39: (continued)
D8 35 J=2, ISHTK
FSHSV = FSHSV + 1
IF (FSHSV = SUTKN) 36, 36, 37
37 FSHSV = 2
36 ISHSV = FSHSV
IF (BUSTK(ISHSV)) 94, 250, 95
94 CALL ERR8R(63, NSET)
RETURN
95 IF (TRNT(ISHSV)) 300, 300, 301

C****SCHEDULE A SHUTTLE TRUCK EITHER TO THE DOCK OR LANDING DEPENDING
C UPON WHETHER THE TRUCK HAD A TRAILER ATTACHED
C
300 ATRIB(1) = TNGW
ATRIB(2) = 3.0
ATRIB(3) = 5.0
ATRIB(4) = 1.0
ATRIB(5) = ISHSV
CALL FILEM(1, NSET)
XSTIM = ATRIB(1)
NTNTR = NTNTR + 1
GO TO 35
301 ATRIB(1) = TNGW + XLDM
ATRIB(2) = 1
ATRIB(3) = 0
ATRIB(4) = 0
ATRIB(5) = FSHSV
CALL FILEM(1, NSET)
HSUR(ISHSV) = HSUR(ISHSV) + TRIPTR(5, ISHSV, NSET)
XLDM = XLDM + SCINC + XDTM(LCAT, NSET)
XSTIM = ATRIB(1)
GO TO 35
250 XSHDW = XSHDW + 1
35 CONTINUE

C**** IF ALL SHUTTLE TRUCKS ARE DOWN, A HIGHWAY TRUCK WILL BE ASSIGNED

Figure 39: (continued)
C*****AS A SHUTTLE TRUCK

C
IF(XSHDW=SUTK) 251,252,252
252 IF(TKSYS=1*) 254,253,255
254 CALL ERR8R(80,NSET)
RETURN
253 ATRIB(1)=XLDMTN8W
ATRIB(2)=1.0
ATRIB(3)=0.0
ATRIB(4)=0.0
III=SUTKN+1
DB 256 J=III,IHWTK
IF(BUSTK(J)) 94,256,257
256 CONTINUE
257 ATRIB(5)=J
IF(TRNT(J)) 500,500,501
500 ATRIB(2)=3.0
ATRIB(3)=5.0
ATRIB(4)=1.0
501 CONTINUE
CALL FILEM(1,NSET)
RETURN
255 III=SUTKN+1
DB 258 J=III,IHWTK
FHWSV=FHWSV+1
IF(FHWSV=XHTK) 310,310,311
310 FHWSV=SUTKN+1
311 FHWSV=FHWSV
IF(BUSTK(IHWSV)) 94,258,259
258 CONTINUE
259 IF(TRNT(IHWSV)) 312,312,313
312 HRSV=TRIPT(7,IHWSV,NSET)
HOUR(IHWSV)=HOUR(IHWSV)+HRSV
ATRIB(1)=TN8W+HRSV
ATRIB(2)=3.0
ATRIB(3)=5.0

Figure 39: (continued)
ATRIB(4) = 1*0
ATRIB(5) = IHWSV
CALL FILEM(1, NSET)
G8 TO 314
313 ATRIB(1) = TNOW + XLDW
ATRIB(2) = 1*0
ATRIB(3) = 0*0
ATRIB(4) = 0*0
ATRIB(5) = IHWSV
CALL FILEM(1, NSET)
HOUR(IHWSV) = HOUR(IHWSV) + TRIPT(5, IHWSV, NSET)
314 IIHW = SUTKN+2*
G8 TO 260
251 FSHTK = FSHTK*1*
IF(FSHTK = SUTKN) 38, 38, 39
39 FSHTK = 2*
38 IF(NTNTR = ISHTK = 1) 303, 302, 302
302 IIHW = SUTKN+1*
LSVDK = TK
G8 TO 304
C
C*****NEW SCHEDULE THE ARRIVALS OF THE HIGHWAY TRUCKS AT THE DOCK. THE
C*****ARRIVAL TIME OF THE FIRST TRUCK WILL DEPEND ON WHETHER THERE ARE
C*****ANY FULL LOADS WAITING AT THE DOCK.
C
303 IIHW = SUTKN+1*
260 LSVDK = FADBK
304 J = IIHW
SHAVL = SHAVL * XSHDW
IF(LSVDK) 40, 41, 42
40 CALL ERROR(64, NSET)
RETURN
42 CONTINUE
D8 43 J = IIHW, IHWTK
FHWSV = FHWSV+1*
IF(FHWSV = XHTK) 44, 44, 45

Figure 39: (continued)
45  FHWSS=SUTKN+1
44  IHWSV=FHWSS
   IF(BUSTK(IHWSV)) 94,261,97

C

C*****SCHEDULE HIGHWAY TRUCKS TO THE PREHAUL DOCK
C

97  ATRIB(1)=TNBW
  ATRIB(2)=3.0
  ATRIB(3)=0.0
  ATRIB(4)=2.0
  ATRIB(5)=FHWSS
  CALL FILEM(1,NSET)
  H8UR(IHWSV)=H8UR(IHWSV)+TRIPT(7,IHWSV,NSET)
  LSVDK=LSVDK+1.
  GO TO 96
261  XHWDW=XHWDW+1.
96  IF(LSVDK) 40,315,43
43  CONTINUE
315  J=J+1
41  XXX=0.0

C

C*****WHEN ALL LOADS AT THE DOCK HAVE BEEN USED UP A DELAY IN SCHEDULEING WILL RESULT TO ALLOW FOR THE EXTRA TRIP TIME
C

IF(J-IHWSK) 47,48,48
47  FHWSS=FHWSS+1.
   IF(FHWSS=XHSTK) 49,49,50
50  FHWSS=SUTKN+1.
49  IHWSV=FHWSS
   IF(BUSTK(IHWSV)) 94,262,99
99  ATRIB(1)=TNBW+XXX+TRIPT(4,IHWSV,NSET)+XDTM(LCAT,NSET)
  ATRIB(2)=3.0
  ATRIB(3)=0.0
  ATRIB(4)=2.0
  ATRIB(5)=FHWSS
  CALL FILEM(1,NSET)

Figure 39: (continued)
HOUR(IHWSV)=HOUR(IHWSV)+TRIPT(7,IHWSV,NSET)
G0 TO 98
262 XHWDW=XHWDW+1.
98 J=J+1
   IF(J=IHWTK) 51,51,48
51 SHAVL=SHAVL-1
   IF(SHAVL) 53,53,54
54 XXX=SCINC+XDTM(LCAT,NSET)
G0 TO 47
53 XXX=ATRIB(1)=TNOW+SCINC+TRIPT(4,IHWSV,NSET)
G0 TO 47

C
C*****IF ALL HIGHWAY TRUCKS ARE DOWN A SHUTTLE TRUCK WILL BE ASSIGNED
C
48 IF(TK-SUTK-XHWDW) 265,263,264
265 CALL ERROR(81,NSET)
RETURN
263 IF(TKSYS-1.) 254,68,266
266 CALL FIND(XSTIM,5,1,1,KCBL,NSET)
   CALL RM6VE(KCBL,1,NSET)
   JJK=ATRIB(5)
   IF(LSVDK) 40,267,268
267 ATRIB(1)=TNOW
   G0 TO 269
268 ATRIB(1)=TNOW+TRIPT(4,JJK,NSET)+XDTM(LCAT,NSET)
269 ATRIB(2)=3.0
   ATRIB(3)=0.0
   ATRIB(4)=2.0
   ATRIB(5)=JJK
   CALL FILEM(1,NSET)
   RETURN
264 FHWTK=FHWTK+1.
   IF(FHWTK=XHTK) 68,68,69
69 FHWTK=SUTKN+1.
68 RETURN

Figure 39: (continued)
C*****IF PREHAUL TRAILERS ARE BEING SCHEDULED AFTER THE REPAIR OF A
C*****BREAKDOWN THEY CAN ONLY BE SCHEDULED IF THERE IS TIME LEFT IN THE
C*****DAY. THE ACTUAL SCHEDULING TAKES PLACE IN A NORMAL MANNER.

C 32 CALL FIND(8,5,1,2,KCOL,NSET)
      IF(KCOL) 55,55,56
      CALL ERROR(65,NSET)
      RETURN
C 55 CALL REMOVE(KCOL,1,NSET)
      TSAVE=ATRIB(1)
      CALL FILEM(1,NSET)
      ISHTK=SUTKN
      IHWTK=TK+1,
      XHTK=TK+1,
      FSHSV=FSHTK+1,
      FHWSV=FHWTK+1,
      XLDM=0.0
      DO 57 J=2,ISHTK
      TVLT=XLDM+TRIPT(5,J,NSET)
      IF(TSAVE=TNST+TVLT) 58,59,59
C 59 FSHSV=FSHSV+1,
      IF(FHSV=SUTKN) 60,60,61
C 61 FHSV=2.0
C 60 ISHSV=FSHSV
      IF(BUSTK(ISHSV)) 94,270,100
C 100 IF(TRNT(ISHSV)) 503,503,554
C 503 ATRIB(1)=TNST+TVLT
      ATRIB(2)=3.0
      ATRIB(3)=5.0
      ATRIB(4)=1.0
      G0 TO 504
C 554 ATRIB(1)=TNST+TVLT
      ATRIB(2)=1.0
      ATRIB(3)=0.0
      ATRIB(4)=0.0
C 504 ATRIB(5)=FSHSV

Figure 39: (continued)
CALL FILEM(1,NSET)
HOUR(IHSV)+HOUR(IHSV)+TRIPT(5,ISHSV,NSET)
XLDM=XLM+XDTM(LCAT,NSET)+SCINC
GB TO 57
270 XSHDW=XSHDW+1;
57 CONTINUE
IF(XSHDW=SUTK) 271,105,105
271 NSHSC=ISHTK+1
J=J+1
GB TO 110
58 NSHSC=J+1
110 IF(J=2) 105,105,62
62 FSHTK=FSHTK+1;
IF(FSHTK=SUTKN) 65,65,63
63 FSHTK=2.
C
C*****NEW SCHEDULE AS MANY HIGHWAY TRUCKS AS TIME WILL ALLOW.
C
65 XXX=0.0
NBR=SUTKN
74 IF(NBR=IHWTK) 75,64,64
75 TVLT=XXX+TRIPT(4,1HWTK,NSET)+XDTM(LCAT,NSET)
IF(TSAVE=TNBW-TVLT) 64,67,67
67 FHWSV=FHWSV+1;
IF(FHWSV=XHTK) 70,70,71
71 FHWSV=SUTKN+1;
70 IHWSV=FHWSV
IF(BUSTK(IHWSV)) 94,74,104
104 ATRIB(1)=TNBW+TVLT
ATRIB(2)=3.0
ATRIB(3)=0.0
ATRIB(4)=2.0
ATRIB(5)=FHWSV
CALL FILEM(1,NSET)
HOUR(IHWSV)=HOUR(IHWSV)+TRIPT(7,IHWSV,NSET)
NSHSC=NSHSC+1

Figure 39: (continued)
NBR = NBR + 1
IF (NSHSC) 72, 72, 73
72 XXX = ATRIB(1) - TNOW + TRIPT(4, IHWSV, NSET) + SCINC
G0 TO 74
73 XXX = XDTM(LCAT, NSET) + SCINC
G0 TO 74
64 FHWTK = FHWTK + 1
IF (FHWTK = XHTK) 105, 105, 112
112 FHWTK = SUTKN + 1
105 RETURN
END

Figure 39: (continued)
Several function subprograms are used to determine the costs and times associated with breakdowns. CPRT, shown in Figure 40, is used to determine the cost of repair parts. The mean time between truck breakdowns is determined in BKDTK as seen in Figure 41. The mean time between loader breakdowns is determined in BKDLR, shown in Figure 42. The repair time of a particular breakdown is determined in RPT and the duration is found in DBK. These are shown in Figures 43 and 44 respectively.
FUNCTION CPRT(ITKN, IXXX, NSET)
DIMENSION NSET(7, 1)

C*****GASP COMMON STATEMENTS
C

COMMON ID, IM, INIT, JEVNT, JMINIT, MFA, MST8P, MX, MXC, NCLCT, NHIST,
1NBG, 1N8RT, N8T, NPRMS, NRN, NRUN, NSTAT, BMT, SCALE, ISEED, TN8W,
2TBEG, TF1N, MXM, NPRINT, NCRDR, NQV (6)

COMMON ATRIB(5), ENQ(6), INN(6), JCELS(1, 2), KRANK(6), MA9NX(6), M
1FE(6), MLC(6), MLE(6), NCELS(1), NG(6), PARAM(12, 4), GTIME(6), SSUMA
2(10, 5), SUMA(10, 5), NAME(6), NPRINT, MBN, NDAY, NYR, JCLL

COMMON KFB, KLEL, KLEL

C*****N8N-GASP COMMON VARIABLES
C

COMMON LCAT, TSV(12), USL(12), VDFL(12), VGL(12), P0LR, AVMBF, C
16T, WGL9, RTLB, WGT8, RTTS, ITCA, CSTK(6), VDFT(T), VGT(T), NGT, RTTD(2)
20, KSY8, XMIPA, XMIPA, XMIPA, XMIPA, XMIPA, XMIPA, XMIPA, XPHS, XPHS, XPHS, DE8CT, DAY(12), WTHP(12)

COMMON M8NTH, FLC8T, FLC8T, FLC8T, FLC8T, FLC8T, RR, XMTBK(3), XMTBK(3)

1, XMDBK(3), XMDBK(3), XMDBK(3), XMDBK(3), XMDBK(3), XMDBK(3), XMDBK(3), XMDBK(3)
2, XNTDT, XNTDL, EY8H, SCINC, SUTK, REPR, MNVR, C8ST, CDV, CPD, TK, TKSYS

COMMON XMIDK, LD8DS, N8KTR, N8KTR, N8KTR, N8KTR, N8KTR, N8KTR, N8KTR, N8KTR, N8KTR, N8KTR

1B8K, CT8L, C88T, C88T, C88T, C88T, C88T, C88T, C88T, C88T, C88T, C88T, C88T

28UR(20), MILES(20), XIS88, BUS1, BUS2, ET8DK, FAD8K, BUSTK(20), SCH8D

COMMON CS8WL, C88T8K(20), ISY, TENDY, TIS88, WT, C88T, T8K8D, T8K8D, T8K8D, T8K8D

1WETHR, S8L8E, XLAND, C88LND, NCASE, WGM8

COMMON U8L8L, U8L8K, UL8TR, U8LRD, C88T8W, T8DAY(12), CL8ND

COMMON CLMSC(12), ICL8S, CST8T, P8TK(3), 8PDV(12, 25, 4, 4), CS8MSC(3)

COMMON DD8TK, C88IT, C88IT, C88IT, C88IT, TRNT(20), PTML

COMMON BKFUL, C88LBR

C

C******DETERMINE THE COST OF PARTS TO REPAIR THE BREAKDOWN, THE COST
C******WILL DEPEND ON THE SEVERITY LEVEL AND THE PIECE OF EQUIPMENT.
C******FIRST TRANSFER CONTROL DEPENDING ON WHETHER A LOADER OR TRUCK HAS
C******BROKEN DOWN AND THEN TRANSFER CONTROL DEPENDING ON THE SEVERITY

Figure 40: Computer Listing of Function Subprogram CPRT
C*****LEVEL*
C      IF (ITKN=1) 1/1,2
1  GO TO (3,4,5),IXXX
C
C*****IN THIS CASE THE SEVERITY LEVELS USE A NORMAL DISTRIBUTION
C
3 CPRT=RNORM(1)
   RETURN
C
4 CPRT=RNORM(2)
   RETURN
C
5 CPRT=RNORM(3)
   RETURN
C
C*****NOW FOR TRUCK BREAKDOWNS TRANSFER CONTROL DEPENDING ON THE
C*****SEVERITY LEVEL.
C
2 GO TO (6,7,8),IXXX
C
C*****IN THIS CASE THE SEVERITY LEVELS USE NORMAN DISTRIBUTIONS.
C
6 CPRT=RNORM(4)
   RETURN
C
7 CPRT=RNORM(5)
   RETURN
C
8 CPRT=RNORM(6)
   RETURN
END

Figure 40: (continued)
FUNCTION BKDTK(IXXX,NSET)
DIMENSION NSET(Till)

C*****GASP COMMON STATEMENTS
C
COMMON ID, IM, INIT, JEVNT, JMNIT, MFA, MSTD, MX, MXC, NCLCT, NHIST,
1NG, NPRM, NPRN, NRUN, NRRS, NTAT, OUT, SCALE, ISEED, TNOW,
2TBEG, TFIN, MXS, NPRMT, NCRDR, NEP, VNG(6)
COMMON ATRIB(5), ENG(6), INN(6), JCELS(1, 2), KRAK(6), MAXNO(6), M
1FE(6), MLC(6), MLE(6), NCELS(1), NQ(6), PARAM(12, 4), GTIME(6), SSUMA
2(10, 5), SUMA(10, 5), NAME(6), NPRBJ, MN, NDAY, NYR, JCLR
COMMON KSF, KLE, KBL

C*****NON-GASP COMMON VARIABLES
C
COMMON LCAT, TSV(12), USL(12), VDFL(12), VGL(12), POLR, AMBF, C
169, WGBL, RTLB, WGT(1), RTTS, ITCA, CSTK(6), VDFT(6), VGT(6), VGT(6), RTTD(2)
20), KSYS, XMIPA, XMIPK, XMS, XPHPA, XPHPR, XPHS, DEFCT, DAY(12), WTHP(12)
COMMON MOUTH, FLC, FCTG, FLCD, TFN, RR, XMTEK(3), STMK(3)
1, XMDBK(3), XMCTK(3), XMRTK(3), XNC, XFE, WGP, XMCN(20)
2, XNTDT, XNTDL, EY, SCINC, SUTK, REPRT, MNYR, CBST1, CDVA, CPD, TK, TKSYS
COMMON XMIDK, LADDS, NKTK, NBKLR, DIL, DSB, DAT(6), TNYR, YEAR, CCRB, C
1BKTK, CTIT, CTTB, CSV1, CSV2, CSV3, CSV4, CSV5, CSV6, CL9AD, DAYS, H
2BUR(20), MILES(20), XISYS, BUS1, BUS2, ETADK, FADK, BUSTK(20), SCHBD
COMMON CM2L, CMWT(20), ISV, TENDY, TYS, W, DBTK, TIDK, TIDBK,
1WETH, SLOPE, XLAND, CSLN, NCA, WGMT
COMMON ULEL9, ULRK, ULTRK(3), ULET, CST9, TIDAY(12), CLND
COMMON CLMSC(12), ICLAS, CST9, P8T(3), 6PDV(12, 25, 4, 4), CMS2C(3)
COMMON DONTK, CIDT, CBIDT, CDNT, TRNT(20), PTML
COMMON BKFUL, CDBLR

C*****GENERATE THE TIME UNTIL THE NEXT BREAKDOWN OF THE TRUCK FOR THIS
C*****SEVERITY LEVEL.
C
C*****IN THIS CASE A POISSON DISTRIBUTION OF THE TIME BETWEEN BREAKDOWNS

Figure 41: Computer Listing of Function Subprogram BKDTK
C****IS USED:
C
CALL DRAND(ISEED,RNUM)
BKDTK=XMTTK(Ixxx)*ALBG(RNUM)
RETURN
END

Figure 41: (continued)
FUNCTION BKDLR(JXXX,NSET)
DIMENSION NSET(7,1)

C*****GASP COMMON STATEMENTS
C
COMMON ID, IM, INIT, JEVT, JMNIT, MFA, MST8P, MX, MXC, NCLCT, NHIST,
1NQ, NERRT, NST, NFRMS, NRUN, NRUNS, NSTAT, OUT, SCALE, ISEED, TNOW,
2TREG, TFIN, MXM, NPRNT, NCRDR, TNEP, VNO(6)
COMMON ATRIB(5), ENG(6), INN(6), JCELS(1,2), KRANK(6), MAXNQ(6), M
1FE(6), ML(6), MLE(6), NCELS(1), NQ(6), PARAM(12,4), QTIME(6), SSUMA
2(10,5), SUMA(10,5), NAME(6), NPR0J, M8N, NDAY, NYR, JCLR
COMMON K8F, KLE, KBL

C****NON-GASP COMMON VARIABLES
C
COMMON LCAT, TSV(12), USL(12), VDFL(12), VGL(12), P0LR, AVMBF, C
167, WGL0, RTL0, WGT1, RTT1, ITCA, CSTK(6), VDFT(6), VGT(6), WGTD, RTTD(2
20), KSYS, XMIF, XMIP, XMIS, XHFA, XPHR, XHPS, DEFC, DAY(12), WTP(12)
COMMON MONT, FLCGT, FLCQ, FLGN, TFLCN, RR, XMTBK(3), XMTTK(3)
1, XMDBK(3), XMKT(3), XMRTB(3), XMNCL, UFE, WGMP, XMNCNT(20)
2, XNTDD, XNDDL, EYBH, SCINC, SUTK, REPR, MNVR, C8ST1, CDV, CPD, TK, TKSYS
COMMON XMIDK, LOADS, NBK, NBKLP, NSDL, DSBD, DATOT, TENYR, YEAR, CCRBK, C
1BK1, CKTIT, CTKT, CTBK, CSV1, CSV2, CSV3, CSV4, CSV5, CSV6, CSY, CLBAD, DAYS, H
2SUR(20), MILES(20), XISYS, BUS1, BUS2, ETADK, FADK, BUSTK(20), SCHBD
COMMON CSW, C8WTK(20), ISV, TENDY, TISYS, WT, CDBTK, TIDKL, TIDBK,
1WETHR, SLAP, XLAND, CLND, NCA8, WGMT
COMMON ULEL, ULTRK, ULDTR(3), ULETD, CST8W, TIDAY(12), CLND
COMMON CLMSC(12), ICLAS, CST8T, P8TK(3), 8PDV(12,25,4,4), CSMS(3)
COMMON DONTK, CDIT, CDBIT, CDNIT, TRNT(20), PTRL
COMMON BKFUL, CDBLR

C
C*****GENERATE THE TIME UNTIL THE NEXT BREAKDOWN OF THE LOADER FOR THIS
C*****SEVERITY LEVEL.
C
C*****IN THIS CASE A POISSON DISTRIBUTION OF THE TIME BETWEEN

Figure 42: Computer Listing of Function Subprogram BKDLR
C*****BREAKDOWNS IS USED.

C

CALL DRAND(ISEED,RNUM)
BKDLR=XMTBK(Ixxx )*ALOG(RNUM)
RETURN
END

Figure 42: (continued)
FUNCTION RPT(ITKN,IXXX,NSET)
DIMENSION NSET(7,1)

C*****GASP COMMON STATEMENTS
C
COMMON ID,IM,INIT,JEVNT,JMNT,MFA,MST6P,MX,MXC,NCLCT,NHIST,
1NG,1NRPT,NS,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNGW,
2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNG(6)
COMMON ATRI(5),ENQ(6),INN(6),CELS(1,2),KRANK(6),MAXNQ(6),M
1FE(6),MLC(6),MLE(6),CELS(1),NG(6),PARAM(12,4),QTIME(6),SSUMA
2(10,5),SUMA(10,5),NAME(6),NPR6J,M6N,NDAY,NYR,JCLR
COMMON KGK,KLE,KBL

C*****GASP COMMON VARIABLES
C
COMMON LCAT,TSV(12),USL(12),VDFL(12),VGL(12),POLR,AMBF,C
10,T,WGL,T,RT6,WGTS,RTTS,ITCA,CSTK(6),VDFT(6),VGT(6),WGT,RTTD(2)
20,KSYS,XMIPA,XMPI,XMIS,XHPA,XPHPR,XPHS,DEFC,TAY(12),WTHP(12)
COMMON M6NTH,FCLTD,FCLGN,FECN,TFCN,RKMXTBK(3),XMTTK(3)
1,XM0BK(3),XM0TKEK(3),XM0BK(3),XMNL,T,F,UGMP,XMNT(20)
2,XNTDG,T,XNTDL,EY6H,SCINC,SUTK,REPRT,M6VY,C6ST1,CDV,CPD,T6K,T6KSY
COMMON XM6CK,L,LOADS,NBTK,NBKR,DSDL,DSBD,DAT6,T6NYR,YEAF,CC0K,C
18IT,CITIT,CITIT,CTBK,CV1,CV2,CV3,CV4,CV5,CV6,CLGAD,Day(20)
26UX(20),MILES(20),XISYS,BUS1,BUS6,ETADK,6AD6K,BUSTK(20),SCHB
COMMON C66W,CA66W,C66W(20),ISV,T3NY,T6SY,S,W,T6BTK,T6IKL,T6IK
18ETHER,SL6PAR,XLAND,CLN6D,NCASE,W6MT
COMMON U66L6,UL6TK,UL6TR(3),ULEDY,CST6W,T6DAY(12),CL6N
COMMON CLMSC(12),ICLASS,CST6,T,PDV(12,25,4,4),CSM6C(3)
COMMON DDNTK,CDIT,CBDIT,C6DIT,TRNT(20),PTML
COMMON BKFUL,CD6L6R
C
C*****THE ACTUAL REPAIR TIME OF THE BREAKDOWN WILL DEPEND ON BOTH THE
C*****SEVERITY LEVEL AND THE PIECE OF EQUIPMENT.  FIRST TRANSFER
C*****CONTROL DEPENDING ON WHETHER A LOADER OR A TRUCK SUFFERED A
C*****BREAKDOWN AND THEN FIND THE REPAIR TIME FOR EACH CASE.

Figure 43: Computer Listing of Function Subprogram RPT
C IN THIS CASE A POISSON DISTRIBUTION WITH A MEAN REPAIR TIME IS
C USED:
C
IF(ITKN=1) 1,1,2
1 CALL DRAND(ISEED,RNUM)
   RPT=-XMBK(Ixxx)*AL8G(RNUM)
   RETURN
2 CALL DRAND(ISEED,RNUM)
   RPT=-XMTK(Ixxx)*AL8G(RNUM)
   RETURN
END

Figure 43: (continued)
FUNCTION DBK(ITKN,IXXX,NSET)
DIMENSION NSET(7,1)

C*****GASP COMMON STATEMENTS
C
COMMON ID, IM, INIT, JEVNT, JMNIT, MFA, MSTA, MX, MXC, NCLCT, NHIST,
1NQ, NBRPT, NSTNP, NRUN, NRUNS, STAT, OUT, SCALE, ISEED, TNOW,
2TBEG, TFIN, MXO, NPRNT, NECRD, NEP, VNQ(6)
COMMON ATRIB(5), ENQ(6), INN(6), JCELS(1,2), KRANK(6), MAXNQ(6), M
1FET(6), MLC(6), LLE(6), NCELS(1), NQ(6), PARAM(12,4), QTIM(6), SSUMA
2(10,5), SUMA(10,5), NAME(6), NPRQ, M8ON, NDAY, NNYR, JCLR
COMMON K6F, KLE, KBL
C
COMMON LCAT, TSV(12), USL(12), VDFL(12), VGL(12), P0LR, AVMBF, C
GET, WGL6, RTL9, WGT5, RTTS, ITCA, CSTK(6), VDFT(6), VGT(6), WGTD, RTTD(2
20), KSYS, XMPA, XMIPR, XMS, XMPA, XMPR, XPHS, DEPC, DAY(12), WTHP(12)
COMMON M8OTH, FLCTD, FLCTG, FLCN, TFLCN, RR, XMTRK(3), XMTDK(3)
1, XMDBK(3), XMDTK(3), XMTRK(3), XMNET, UFE, WGM, XMNT(20)
2, XNTVT, XNTDL, EY6H, SCINC, SUTK, REPR, M8VR, CBST1, CDV, CPD, TK, TKSYS
COMMON XMI, XMBK, LBADS, NBKTR, NTLR, DIDL, CSSD, DAD8T, TNNR, YR, CCRBK, C
1BKIT, CCLIT, CWTI, CXTK, CSSV1, CSSV2, CSSV3, CSSV4, CSSV5, CSSVT, CLBAD, DAYS, H
28UR(20), MILES(20), XISYS, BUS1, BUS2, ETADK, FAD8K, BUSTK(20), SCHBD
COMMON CSWL, CBCTK(20), 68, TENDY, TIS, WT, CDTK, TIDK, TID6K,
1WETHR, SLOPE, XLAND, CSND, NCASE, WMG
COMMON U6L, ULTRK, ULETD, CST6W, TIDAY(12), CLND
COMMON CLHSC(12), ICNSL, CST6T, P6TK(3), 6PDV(12, 25, 4, 4), CSMSC(3)
COMMON DDTK, CIDIT, CDBT, CDIT, TMRN(20), PTL
COMMON BKFUL, CBLDR
C
C*****THE TOTAL DURATION OF THE BREAKDOWN WILL DEPEND ON BOTH THE
C*****SEVERITY LEVEL AND WHETHER THE BREAKDOWN IS A LOADER OR A TRUCK
C*****FIRST TRANSFER CONTROL DEPENDING ON WHETHER A LOADER OR TRUCK HAS
C*****BROKEN DOWN AND THEN DETERMINE DURATION FOR EACH CASE.

Figure 44: Computer Listing of Function Subprogram DBK
IN THIS CASE A POISSON DISTRIBUTION WITH A MEAN DURATION IS USED.

I F ( I T K N = 1 ) 1 , 1 , 2
1 CALL DRAND ( I S E E D , R N U M )
 DBK = XMDBK ( I X X X ) * AL0G ( R N U M )
 RETURN
2 CALL DRAND ( I S E E D , R N U M )
 DBK = XM DTK ( I X X X ) * AL0G ( R N U M )
 RETURN
END

Figure 44: (continued)
APPENDIX 14

PRODUCTIVITY SUBROUTINES

The productivity of various parts of the system is expressed in three function subprograms. Subprogram XDTM determines the loading time of a loader when loading a truck or preload bunk. It is shown in Figure 45. The transfer time when loading a truck from a preload bunk is found in subprogram XDTMB as shown in Figure 46. Finally, the time required to hook and unhook trailers at the prehaul dock is shown in Figure 47 as subroutine ULTDK.
FUNCTION XDTM(LCCC, NSET)
DIMENSION NSET(7, 1)
COMMON ID, IM, INIT, JEVNT, JMNT, MFA, MSTOP, MX, MXC, NCLCT, NHIST,
NDEF, NRPT, NRT, NPRMS, NRUN, NRUNS, NSTAT, BUT, SCALE, ISEED, TNEW,
TBEG, TFIN, MXX, NPRINT, NCIRD, NPE, NVNQ(6),
COMMON ATRIB(5), ENQ(6), INN(6), JCELS(1, 2), KRAKT(6), MAXNO(6), MMD,
MFE(6), MLC(6), MLE(6), NCELS(1), NOQ(6), NVOICE, NPROJ, NDAY, NNYR, JCLR,
COMMON KBF, KLE, KAL
COMMON LCAT, TSV(12), USL(12), VDLF(12), VGL(12), P3RL, AVMBF, C,
16T, WGLB, RL8, WGTs, RTTS, ITCA, CSTK(6), VDFT(6), VGT(6), WGTD, RTTD(2),
20J, KSYS, XMIPA, XMIPR, XMIS, XPHPA, XPHPR, XPHS, DEFC, DAY(12), WTHP(12),
COMMON M8NTH, FLCTD, FLCTG, FLCN, TFLCN, RR, XMTBK(3), XMTTK(3),
1, XMDBK(3), XMNTK(3), XMTRK(3), XMNC, UFEP, WGM, XMNCT(20),
2, XMTKD, XMTL, EY8H, SINC, SUTK, REPRT, MNVR, C6ST1, CDV, CPT, TK, TKSYS,
COMMON XMID, LAD, NBBTK, NBKLR, DSDL, DSDB, DATOT, TENYR, YEAR, CCRBK, C,
18KITA, C6LIT, C6WTIT, CCTB, CSV1, CSV2, CSV3, CSV4, CSV5, CSVTT, CLOAD, DAY(12),
26J, MILES(20), XISYS, BUS1, BUS2, ETAKD, FAD8K, BUSTK(20), SCHB, D
COMMON CSB, LW, CWT(20), ISV, TENDY, TISYS, WT, CDBTK, TID, TID8K,
1WETHR, SL8PE, XLAND, CSTLD, NCASE, WGM,
COMMON ULE, ULTRK, ULTRDR(3), ULETD, CSTTW, TIDAY(12), CLND,
COMMON CLMSC(12), CLAS, CSTT, PS6T(3), PPDV(12, 25, 4, 4), CSMC(3),
COMMON DDNTK, CIDIT, CDBIT, CDNIT, TRNT(20), PTML
COMMON BKFUL, CDBLR

C******DETERMINE DECK CLASS AND ITS EFFECT ON THE LOADING TIME
C
C
C******NOW DETERMINE TRUCK LOADING TIME
C
NYEAR=YEAR
XDTM=PDV(LCAT, NYEAR, ISV, ICLAS)/RL8
GB TO (1, 1, 2), KSYS
1 XDTM=XDTM+PTML
2 RETURN

Figure 45: Computer Listing of Function Subprogram XDTM
FUNCTION XDTMB(KSYS)

C****BUNK LOADING TIME IS EQUAL TO THE ACTUAL TRANSFER TIME PLUS THE
C****TIME NEEDED TO POSITION THE TRUCK AND TO LEAVE THE LANDING.
C
C****IN THIS CASE AVERAGES ARE USED FOR BOTH THE TRANSFER AND
C****POSITIONING TIMES.
C
XLBTM=7.0
PTML=2.5
XDTMB=XLBTM+PTML
RETURN
END

Figure 46: Computer Listing of Function Subprogram XDTMB
FUNCTION ULTDK(II)
C
C*****CALCULATE THE TIME TO EITHER HOOK OR UNHOOK A TRAILER AT THE DOCK.
C
C*****IN THIS CASE UNHOOKING TIME IS GIVEN AVERAGE VALUE OF 5 MINUTES
C*****AND HOOKING TIME IS GIVEN AN AVERAGE VALUE OF 2 MINUTES,
C
G8 TO(1,1,3,3),II
1 ULTDK=5.
RETURN
3 ULTDK=2.
RETURN
END

Figure 47: Computer Listing of Function Subprogram ULTDK
APPENDIX 15

SUBPROGRAM TRIPT

The time required to travel a certain type of trip is determined in subprogram TRIPT. The trips may be one of ten types. The codes for these trips are listed on page 95. The subprogram is listed in Figure 48.
FUNCTION TRIP T(I, ITKN, NSET)
DIMENSION NSET(7, 1)

C****GASP COMMON STATEMENTS

COMMON ID, IM, INIT, JVNT, JMNIT, JMA, MSTOP, MX, MXC, NCLCT, NHIST,
1NBG, NBRPT, NET, NPROST, NRUN, NRUNS, INSTAT, OUT, SCALE, ISEED, TNBK,
2TBEG, TFIN, MXX, NPRNT, NCRDR, NPE, VNG(6)
COMMON ATRIB(5), ENQ(6), INN(6), CELES(1, 2), KRANK(6), MAXNQ(6), M
1FE(6), MLC(6), MLE(6), NCELS(1), NQ(6), PARAM(12, 4), QTME(6), SSSUMA
2(10, 5), SUMA(10, 5), NAME(6), NPRBJ, MONT, DAY, NVR, JCLR
COMMON KBF, KLE, KBL
COMMON LCAT, TSV(12), USL(12), VDFL(12), VGL(12), P0LR, AVMBF, C
15T, WGL, RTL, WGT, PTTS, ITCA, CSTK(6), VDL(6), VGT(6), WGT, RTTD(2)
20T, KSYS, XMIPA, XMIPR, XMIS, XPHPA, XPHPR, XPHS, DEFCT, DAY(12), WTHP(12)
COMMON MNTH, FLCTD, FLCTG, FLCN, TFLCN, RR, XMTRK(3), XMTRK(3)
1, XMDBK(3), XMTRK(3), XMTRK(3), XMTRK(3)
2, XTNDT, XTNTD, EYH, SCINC, SUTK, REPRT, MNVR, CBST, CDV, CPD, TK, TKSYS
COMMON XMIDK, LOADS, NBLKT, NBLKR, NDKL, TSID, TSBD, DAT3T, TERYR, YER, CCRBK, C
1BK, CMTL, CWIT, CTCTB, CSV1, CSV2, CSV3, CSV4, CSV5, CSV6, CLBND, DAYS, H
2BUR(20), MILES(20), JSX, BUS1, BUS2, EADK, FADBK, BUSTK(20), SCHBD
COMMON CSWBL, CSWTK(20), ISV, TENDY, TISYS, W'T, CDBTK, TISY, TIDK, TID8K,
1WETHR, SLOPE, XLAND, CSLND, NCAE, WGMT
COMMON ULET, ULTRK, ULTRD(3), ULET, CSTW, TIDAY(12), CLND
COMMON CLMSC(12), ICLS, CSTW, PBYK(3), OPDV(12, 25, 4, 4), CSMSC(3)
COMMON DONTK, CID, CBIDT, CDN, TRNT(20), PTML
COMMON BKFUL, CDBLR

C*****TEN POSSIBLE MOVES EXIST AND THE TRAVEL TIME WILL BE DIFFERENT
C*****FOR EACH OF THESE CASES:

C GO TO (1, 2, 9, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4)

C*****THE FIRST CASE IS A ROUND TRIP FROM THE LANDING TO THE MILL AND
C*****BACK TO THE LANDING. FIRST DETERMINE THE UNLOADING TIME AT THE

Figure 48: Computer Listing of Function Subprogram TRIP T
C****MILL
C
C****FOR THIS CASE THE UNLOADING TIME IS AN AVERAGE EXPRESSED IN
C****MINUTES:
C
1 ULMIL=24.241
C
C****NOW DETERMINE THE AMOUNT OF TIME TAKEN AS A PERSONAL ALLOWANCE:
C
C****FOR THIS CASE THIS TIME IS DETERMINED FROM A STRAIGHT-LINE
C****DISTRIBUTION BETWEEN 10 AND 120 MINUTES USING 10 MINUTE INCREMENTS
C
A=10.0
B=120.0
TIM=UNFRM(A,B)
TRIPT=(TIM+ULMIL+(2.0*60.0*((XMIPA/XPHPA)+(XMIPR/XPHPR)+(XMIS/XPHS 1))))/RTTD(ITKN)
RETURN
C
C****THE SECOND CASE IS A ONE WAY TRIP FROM THE LANDING THROUGH THE
C****MILL INCLUDING UNLOADING TIME AT THE MILL. FIRST DETERMINE THE
C****UNLOADING TIME AT THE MILL:
C
C****FOR THIS CASE UNLOADING TIME IS AN AVERAGE VALUE EXPRESSED IN
C****MINUTES
C
2 ULMIL=24.241
GO TO 15
C
C****CASE NINE IS ALSO A TRIP FROM THE LANDING TO THE MILL. HOWEVER
C****IN THIS CASE THE TRAILER IS EMPTY SO THERE WILL BE NO UNLOADING
C****TIME AT THE MILL. FROM THIS POINT ON CASE TWO AND CASE NINE CAN
C****BE PROCESSED IN THE SAME MANNER. NOW DETERMINE THE ALLOWANCE TIME
C
C****SINCE THIS TYPE TRIP WILL OCCUR EITHER AT THE END OF THE DAY OR
C****WHEN THE LOADER BREAKS DOWN, THE ALLOWANCE FOR PERSONAL NEEDS WILL

Figure 48: (continued)
C*****BE LESS AND IN THIS CASE WILL BE SET AT AN AVERAGE VALUE OF 10
C*****MINUTES

9 ULMIL=0.0
15 TIM=10.0
TRPT=(ULMIL+TIM+((XMIPA/XPHPA)*60.0)+((XMIIPR/XPHPR)*60.0)+((XMIS/
XPHS)*60.0))/RTTD(ITKN)
RETURN

C*****CASE THREE IS A ONE WAY TRIP FROM THE MILL TO THE LANDING AND
C*****IS PROCESSED ABOVE IN THE SAME MANNER AS CASE NINE.

C*****CASE FOUR IS A ONE WAY TRIP FROM THE LANDING TO THE PREHAUL DECK
C*****USED WITH THE PREHAUL TRAILER SYSTEM. FIRST DETERMINE THE
C*****PERSONAL ALLOWANCE TIME FOR THE TRIP.
C*****FOR THIS CASE THE ALLOWANCE IS GIVEN AN AVERAGE VALUE OF 10 MINUTE

C

4 TIM=10.0
IF(XMIDK>=XMIPA=XMIPR) 31, 33, 33
33 XXMIS=XXMIS+XMIPA+XMIPR+XMIDK
XXMPR=0.
XXMPA=0.
GO TO 30
31 IF(XMIDK>=XMIPA) 34, 36, 36
36 XXMIS=XXMIS
XXMPR=XMIPA+XMIDA+XMIDK
XXMPA=0.
GO TO 30
34 XXMIS=XXMIS
XXMPR=XMIPA
XXMPA=XMIPA+XMIDK
30 TRPT=(TIM+((XXMIS/XPHS)*(XXMPR/XPHPR)+((XXMPA/XPHPA))*60.0))/RTTD
1(ITKN)
RETURN

Figure 48: (continued)
CASE FIVE IS A ONE WAY TRIP FROM THE DOCK TO THE LANDING AND IS
PROCESSED IN THE SAME MANNER AS CASE FOUR.

CASE SIX IS A ONE WAY TRIP FROM THE DOCK THROUGH THE MILL AND
INCLUDES THE UNLOADING TIME AT THE MILL. FIRST DETERMINE THIS
UNLOADING TIME.

FOR THIS CASE UNLOADING TIME IS AN AVERAGE EXPRESSED IN MINUTES.

IF (XMIDK = XMIPA = XMIPR) 37, 38
XXMIS = XMIDK, XMIPA, XMIPR
XXMPR = XMIPR
XXMPA = XMIPA
G0 TO 35
IF (XMIDK = XMIPA) 39, 40
XXMIS = 0.
XXMPR = XMIDK, XMIPA
XXMPA = XMIPA
G0 TO 35
XXMIS = 0.
XXMPR = C.
XXMPA = XMIDK
JJ = JJ - 5
G0 TO (6, 10, 8, 9, 10), JJ

CASE TEN IS SIMILAR TO CASE SIX EXCEPT THAT THE TRAILER IS EMPTY.
THERE IS NO UNLOADING TIME AT THE MILL. CASES SIX AND TEN MAY
BE PROCESSED IN THE SAME MANNER FROM THIS POINT. THE
NEXT STEP IS TO DETERMINE PERSONAL ALLOWANCE TIME.
IN THIS CASE IT IS GIVEN AN AVERAGE VALUE OF 10 MINUTES.

ULMIL = 24.241
TIM = 50

Figure 48: (continued)
**Figure 48:** (continued)
APPENDIX 16

SUBROUTINES FOR END-OF-TIME PERIOD

The end of a simulated year marks a time when calculations are brought up to date and printed out if desired. This is signaled by the calling of subroutine ENDYR. It is listed in Figure 49. The end of a simulation run implies that all statistics must be brought up to date and a final print-out of results made. This is done in subroutine ENDSM as shown in Figure 50.
SUBROUTINE ENDYR(NSET)
DIMENSION NSET(7,1)

C
C*****GASP COMMON STATEMENTS
C
COMMON ID, INIT, JEVNT, JMNIT, MFA, MSTBP, MX, MXC, NCLCT, NHIST,
1 NBQ, N8RPT, N9T, NPRMS, NRUNS, NSTAT, BUT, SCALE, ISEED, TNOW,
2 TBEG, TFIN, MXX, N8RPT, NCRDR, NEP, VNQ(6)
COMMON ATRIB(5), ENQ(6), INN(6), JCELS(1,2), KRANK(6), MAXNO(6), M
1 FE(6), MLC(6), MLE(6), NCELS(1), NOQ(6), PARAM(12,4), QTIME(6), SSUMA
2 (10,5), SUMA(10,5), NAME(6), N8RBJ, M8N, NDAY, Nyr, JCLR
COMMON KBF, KLE, KBL
COMMON LCAT, TSV(12), USL(12), VDFL(12), VGL(12), P8LR, AVMBF, C
1 BT, WGL9, RTLE, WGT, RTTS, ITCA, CSTK(6), VDFT(6), VTG(6), WGT, RTTD(2
20), KSYS, XMIPA, XMIPR, XMIS, XPHPA, XPHPR, XPHS, DEFC, DAY(12), WTHP(12)
COMMON M8NTH, FLCTD, FLCTG, FLTN, TLN, RR, XM8BK(3), XMTTK(3)
1 XMDBK(3), XM8TK(3), XMRTK(3), MNCL, UFE, WGM, XMNC(20)
2 XNTDT, XNTDL, YE8H, SCINC, SUTK, RE8PT, MNVR, COST1, CDV, CPO, TK, T8YS
COMMON XM8K, LBADS, N8TK, N8KLR, DSIDL, DS8D, DAT8T, TENYR, YEAR, CCR8K, C
18K, CLT8, CT8T, CTT8K, CS8V, CS8V, CS8V, CS8V, CS8V, CS8V, CS8V, CL8AD, D8Y8, H
28UR(20), MILES(20), XISYS, BUSI, BUS2, ETADK, FAD8K, BUS8K, BUS8K(20), S8HBD
COMMON CS8WL, C8T8K(20), ISV, TENDY, T8YS, W8, C8DBTK, T8DKL, T8DBK,
1 WETH, SL8PE, XLAND, CS8ND, NCASE, W8MT
COMMON U8LE8, ULTRK, UL8TDR(3), U8LED, CST8W, T8DAY(12), CL8D
COMMON CL8SC(12), I8CLS, CST8T, PT8K(3), P8DV(12,25,4,4), CS8SC(3)
COMMON D8NTK, C8DIT, C8DBIT, CD8T, TRNT(20), P8ML
COMMON BK8UL, C8BLR
CALL OTPUT(N8SET)
IF(RE8RT) 1,1,2
2 CALL SUMRY(N8SET)

C
C*****NOW REINITIALIZE CUMULATIVE VARIABLES FOR THE NEXT YEAR.
C
1 LBADS=0
2 CCR8BK=0.

Figure 49: Computer Listing of Function Subprogram ENDYR
CDBTK=0.0
CDCLR=0.0
CCTBK=0.0
CLND=0.0
CSLND=0.0
NBKLR=0
NBKTK=0
ITK=TK+1
DB 3 K=2, ITK
HOUR(K)=0
3 MILES(K)=0
RETURN
END

Figure 49: (continued)
**GASP COMMON STATEMENTS**

**COMMON ID, IM, INIT, JENV, JMINIT, MFA, MSTOP, MX, MXC, NCLCT, NHIST, IANG, NBRRT, NST, NFRMS, NRYN, NRUNS, NSTAT, OUT, SCALE, ISEED, TNBW, 2TBEG, TFIN, MXX, NPRNT, NCRDR, NEP, VNQ(6), COMMON ATRIB(6), ENG(6), INN(6), JCELS(1, 2), KRAK(6), MAXNQ(6), M1F(6), MLC(6), MLE(6), NCELS(1), NO(6), PARAM(12, 4), QT1ME(6), SSUMA 2(10, 5), SUMA(10, 5), NAME(6), NPRUS, MN, NDAY, NVR, JCLR COMMON K9F, KLE, KBL**

**GASP COMMON VARIABLES**

**COMMON LCAT, TSV(12), USL(12), VDFL(12), VGL(12), PBLR, AVMBF, C 16T, WGLB, RTLB, WGT, RTTS, ITC, CSTK(6), VDFT(6), VGT(6), WGT, RTTD(2 20), XSYS, XMPA, XMPI, XMIS, XPHPA, XPHPI, XHPS, DEFCT, DAY(12), WTHP(12) COMMON MONTL, FLCDT, FLCTG, TFLCN, TFLCN, RR, XMDBK(3), XMRTK(3) XMDBK(3), XMNTK(3), XMCN, XMSL, XMPR, XMRTK(3), XMCN, UFE, WGM, XMCN(20) 2, XNTDT, XNTDL, XSB, SCINC, SUTK, REPR, MVR, C9ST1, CDV, CPD, TK, TKSYS COMMON VMIDK, LOADS, NBK, NBKLR, DSI, DSD, DAT, TNYR, YEAR, CCRBK, C 1BM, CTIT, CTIT, CTIT, CST, CSV1, CSV2, CSV3, CSV4, CSV5, CSV6, CSV7, CLAD, DAYS, H 20UR(20), MILES(20), XISYS, BUS, BUS2, ETADK, FA6K, BUS, DSTK(20), SCHBD COMMON CSSWL, CWT(20), IMS, TENDT, TISYS, WT, CDBT, TIDK, TIDK, 1WETHR, SLAE, XLAND, CSLND, NCA, WGM COMMON ULEL, ULTRK, ULTR(3), ULET, CSSW, TIDAY(12), CLND COMMON CLMSC(12), ICLASS, CST(6), P8T(6), 8PDV(12, 25, 4, 4), CSMS(3) COMMON DONTK, CDIT, CDBIT, CDNIT, TRNT(20), PTML COMMON BFKUL, CDBLR**

**COLLECT STATISTICS ON ALL TMST VARIABLES SO THAT THEY ARE BROUGHT UP TO DATE**

**CALL TMST(XISYS, TNBW, 1, NSET)**

*Figure 50: Computer Listing of Function Subprogram ENDSM*
CALL TMST(BUS1, TNBW, 2, NSET)
CALL TMST(BUS2, TNBW, 3, NSET)
CALL TMST(TKSYS, TNBW, 4, NSET)
IF(KSYS=2) 10, 11, 10
10 CALL TMST(FAD8K, TNBW, 5, NSET)
   CALL TMST(ETADK, TNBW, 6, NSET)
   CONTINUE

C*****SET THE SUMMARY AND REPORT VARIABLES SO THAT THEY WILL CALL FOR
C*****FINAL PRINTED REPORTS.
C
DDNTK=1.0
NBRPT=0
MSTBP=-1
RETURN
END

Figure 50: (continued)
APPENDIX 17

SUBROUTINE OTPUT

The final subroutine of the computer program calculates and prints out all relevant costs. This is done in subroutine OTPUT. The costs are calculated once per year, but are printed out only if desired. Subroutine OTPUT is shown in Figure 51.
SUBROUTINE OTPUT (NSET)
DIMENSION NSET (7, 1), CBPTK (20)

C
C****GASP COMMON STATEMENTS
C
COMMON ID, IM, INIT, JEVNT, JMNIT, MFA, MSTBP, MX, MXC, NCLCT, NHIST,
INQ, NRPRT, NBT, NPRMS, NRUN, NSTAT, OUT, SCALE, ISEED, TNOW,
2TBEG, TFIN, MXX, NPTNT, NCDRS, NEP, VNG (6)
COMMON ATRIP (5), ENG (6), INN (6), JCELS (1, 2), KRANK (6), MAXQ (6), M
1FE (6), MLC (6), MLE (6), NOTS (1), NQ (6), PARAM (12, 4), OTIME (6), SSUMA
2 (10, 5), SUMA (10, 5), NAME (6), NPRBJ, MBN, NDAY, NYR, JCLR
COMMON KBF, KLE, KBL

C
C****GASP COMMON VARIABLES
C
COMMON LCAT, TSV (12), USL (12), VDFL (12), VGL (12), POLR, AVMBF, C
1BT, WGL, JRTB, WGTSS, RTTS, ITCA, CSTK (6), VDFM (6), VGT (6), WGTDS, RTTD (2)
201, KSYS, XMIPA, XMIPR, XMIS, XPHAP, XPHAP, XPHS, DEFC, DAY (12), WTHP (12)
COMMON MANT, FLC, FLC, VFLCN, TFLCN, RR, XMTBK (3), XMTTK (3)
1, XMDBK (3), XMUTK (3), XMRBK (3), XMRTK (3), XMNCL, UFE, WGMPI, XMNT (20)
2, XNIT, XNIT, EY8H, SCIENC, SUTK, REFR, MNVR, COST, CTV, CPD, TK, TKSYS
COMMON XMIDK, LOADS, NBKTK, NSKLB, DDSKL, DSBD, DATB, TENYR, YEAR, CESTB, C
1BKIT, CTTIT, CTTBK, CSV1, CSV2, CSV3, CSV4, CSV5, CSV6, CSV7, CLBAD, DAYS, H
280, MILES (20), XISYS, BUS1, BUS2, ETAK, FADB, BUSTK (20), SCHBD
COMMON CSBL, CWT2K (20), ISV, TENDY, TISYS, WT, CDBTK, TIDK, TIDBK,
1WETHR, SLOPE, XLAND, CSLND, NCASE, WGM
COMMON ULEL, ULTRK, ULTRD (3), ULET, CSTE, TDAY (12), CLND
COMMON CLMSC (12), ICLAS, CSTE, PTK (3), 0PDV (12, 25, 4, 4), CSMSC (3)
COMMON DDNTK, CIDIT, CDBIT, CIDNTK, TRNT (20), PTML
COMMON BKFUL, CDBLR
IRPT = REPRT
NYRS = YEAR
IF (DNTK) 200, 200, 17
200 CONTINUE

C

Figure 51: Computer Listing of Subroutine OTPUT
SUM ALL WAGES WHICH ARE INVOLVED IN THE LOADING AND HAULING SYSTEM EXCEPT FOR THAT OF THE LOADER OPERATOR.

SMWG = (WGTD * TK) + (WGTS * TSV(LCAT))

CALCULATE THE YEAR'S IDLE TIME DUE TO LOADER BREAKDOWNS AND DUE TO HAVING NO TRUCKS AT THE LANDING.

BKIT = ((1 - (SSUMA(3,2) / SSUMA(3,1))) * TNOW) * CBKIT
TLIT = ((1 - (SSUMA(2,2) / SSUMA(2,1))) * TNOW) * CTLIT

IF (SSUMA(7,1)) 210, 210, 211

DIDIT = 0.0
G0 TO 216

DIDIT = ((1 - (SSUMA(7,2) / SSUMA(7,1))) * TNOW) * CIDIT

IF (SSUMA(8,1)) 212, 212, 213

DBDIT = 0.0
G0 TO 217

DBDIT = ((1 - (SSUMA(8,2) / SSUMA(8,1))) * TNOW) * CBKIT

CONTINUE

WTIT = TLIT - BKIT - DBDIT

APHL = (TNOW * TLIT - TENYR) / 60.0
YRHR = ((TNOW - TENYR) * TK) - CDBTK = (CDBLR * TK) / 60.0
CBKIT = CBKIT + BKIT
CTLIT = CTLIT + TLIT
CIDIT = CIDIT + DIDIT
CBDIT = CBDIT + DBDIT

CALCULATE THE FUEL COST OF THE LOADER

FCSL = ((FLCTD * VDFL(LCAT)) + (FLCTG * VGL(LCAT))) * FLCN * A6PHL
CS8PL = FCSSL + XMNCL + (A6PHL * WGL6) + (A6PHL * WGTS * TSV(LCAT))
CWTIR = (DIDIT * CS8WL) / 60.0
XLAD = LOADS
PRSDL = AVMBF * XLAD * (1 - DEFC) + CSST1 = C6ST1

Figure 51: (continued)
****CALCULATE CST2, THE COST OF LOADING
C
CST2 = (CSBPL + CLND + CWTHR + (CSWL * A8PHEL)) / PR8DL
CST2 = CST2 * PR8DL
C
****CALCULATE CST3, THE COST OF A BREAKDOWN
C
CST3 = CCRBK / PR8DL
EESBK = (CSWL + (SMWGS * (1 - UFE))) * BKIT / 60.0
CST3 = CST3 * PR8DL
C
****CALCULATE CST4, THE COST OF IDLENESS DUE TO NO TRUCKS AT LANDING
C
CST4 = (CSWL * WGLB + (WGTS * TSV (LCAT))) * WTIT / (60.0 * PR8DL)
CST4 = CST4 * PR8DL
C
****CALCULATE CST5, THE COST OF OWNING AND OPERATING TRUCKS BY
CUMULATING THE COST FOR EACH TRUCK,
C
CST5 = 0.0
ITKN = TK + 1.
TISYS = SUMA(1,1) / SUMA(1,3)
DO 10 J = 2, ITKN
CWTHR = (DIDIT * CSWTK(J)) / 60.0
CSTK(J) = (MILES(J) * FLCN + (FLCTD * VDFT (ITCA)) * (FLCTG * VGT (ITCA))) * X
10 1MNCT(J) = (WGTD * HUR (J)) / 60.0 + CWTHR
CST5 = CST5 + CSTK(J)
CST5 = CST5 + CCRBK + CSLND + (CSWTK(2) * YRHRS)
CST5 = CST5 + (WGTD * TISYS * XL0AD) / 60.0
CST5 = CST5
CST5 = CST5 / PR8DL
IC1A = CST1 * 1000
IC1A = IC1A + 10
IC1 = CST1 * 10000
IC1 = IC1 + 5
IF (IC11 = IC1A) 850, 852, 852

Figure 51: (continued)
Figure 51: (continued)
C
C*****NOW CHECK WHETHER A PRINTOUT IS DESIRED. IF SO BRANCH TO THE
C*****PRINT STATEMENTS. IF NOT CUMULATE THE TOTAL COSTS TO DATE.
C
18 IF (REPORT=1.) 11,12,13
11 IF (REPORT=2.) 16,15,15
16 XL9AD=CL9AD+XL9AD
PR8DL=AVMBF*XL9AD*(1.+DEFCX)
CSVTT=CSVTT+(CST8T/((1.+RR)**NYRS))
UEAC=CSVTT
C8ST2=CV82+CSST2
C8ST3=CV83+CSST3
C8ST4=CSV4+CSST4
C8ST5=CSV5+CSST5
CV82=C8ST2
CV83=C8ST3
CV84=C8ST4
CV85=C8ST5
C8ST2=C8ST2/PR8DL
C8ST3=C8ST3/PR8DL
C8ST4=C8ST4/PR8DL
C8ST5=C8ST5/PR8DL
IC1A=C8ST1*1000.
IC1A=IC1A*10
IC1=IC81*10000
IC11=IC1=5
IF (IC11=IC1A) 866,867,867
866 C8ST1=IC1A/10000
G8 TO 868
867 C8ST1=(IC1A+10)/10000.
868 IC2A=C8ST2*1000.
IC2A=IC2A*10
IC2=C8ST2*10000.
IC22=IC2=5
IF (IC22=IC2A) 869,870,870
869 C8ST2=IC2A/10000.

Figure 51: (continued)
G9 T0 871
870 CBSST2=(IC2A+10)/10000
871 IC3A=CBSST3*1000
IC3A=IC3A*10
IC3=CBSST3*10000
IC33=IC3*5
IF(IC33=IC3A) 872,873,873
872 CBSST3=IC3A/10000
G9 T0 874
873 CBSST3=(IC3A+10)/10000
874 IC4A=CBSST4*1000
IC4A=IC4A*10
IC4=CBSST4*10000
IC44=IC4*5
IF(IC44=IC4A) 875,876,876
875 CBSST4=IC4A/10000
G9 T0 877
876 CBSST4=(IC4A+10)/10000
877 IC5A=CBSST5*1000
IC5A=IC5A*10
IC5=CBSST5*10000
IC55=IC5*5
IF(IC55=IC5A) 878,879,879
878 CBSST5=IC5A/10000
G9 T0 880
879 CBSST5=(IC5A+10)/10000
880 CONTINUE
CBSST=CBSST1+CBSST2+CBSST3+CBSST4+CBSST5
IF(REPRT) 15,15,17
17 REPRT=2
G9 T0 18
C
C*****NOW SAVE THE CUMULATIVE COSTS FOR THE NEXT YEAR.
C
15 CBSST1=CSST1
CLoad=XLoad

Figure 51: (continued)
TENYR=TNBY
REPRT=IRPT
IF(IDNTK) 355,355,356
355 CONTINUE
IF(YEAR-USL(LCAT)) 350,351,351
351 UAC=CSVTT
CSVTT=CSVTT*((RR*(1+RR)**NYRS))/(((1+RR)**NYRS)*1.)
356 CONTINUE
WRITE(NPRNT,352)
352 FORMAT(1/)
WRITE(NPRNT,100)
WRITE(NPRNT,101)
WRITE(NPRNT,101)
WRITE(NPRNT,353)
353 FORMAT(20X,'*****','EQUIVALENT ANNUAL COST','8X','*****!)
WRITE(NPRNT,101)
WRITE(NPRNT,354) CSVTT
354 FORMAT(20X,'*****','EQA= ',8X,'*****!)
WRITE(NPRNT,101)
WRITE(NPRNT,101)
WRITE(NPRNT,100)
350 RETURN
C
C*****IF A PRINTOUT IS DESIRED, PRINT THE DESIRED RESULTS BOTH FOR THE
C*****YEAR AND CUMULATED TO DATE,
C
C*****CALCULATE QUANTITIES TO BE PRINTED OUT IN THE YEAR END REPORT.
C
12 AAA=(1.*(SSUMA(3,2)/SSUMA(3,1)))*100.
BBB=(1.*(SSUMA(2,2)/SSUMA(2,1)))*100.
XAA=SSUMA(1,2)/SSUMA(1,1)
XBB=SSUMA(4,2)/SSUMA(4,1)
XCC=SSUMA(5,2)/SSUMA(5,1)
XDD=SSUMA(6,2)/SSUMA(6,1)
XEE=SSUMA(1,1)/SSUMA(1,3)

Figure 51: (continued)
XFF = SUMA(2,1) / SUMA(2,3)
XGG = SUMA(3,1) / SUMA(3,3)
XHH = SUMA(4,1) / SUMA(4,3)
ATRIB(1) = TBNW
ATRIB(2) = 101.0
CALL FILEM(1, NSET)
WRITE(NPRNT, 99)

99 FORMAT(1H1)
WRITE(NPRNT, 100)

100 FORMAT(20X, '*******************************************************)
WRITE(NPRNT, 101)

101 FORMAT(20X, '*****', 37X, '*****', 20X, '*****', 37X, '*****')
WRITE(NPRNT, 102) NYRS, NCASE

102 FORMAT(20X, '******', 3X, 'NBN-CUMULATIVE COST SUMMARY THROUGH', 3X, '******'
WRITE(NPRNT, 103)
WRITE(NPRNT, 100)
WRITE(NPRNT, 101)
WRITE(NPRNT, 103)

103 FORMAT(///)
G9 TO 14

13 WRITE(NPRNT, 99)
WRITE(NPRNT, 100)
WRITE(NPRNT, 101)
WRITE(NPRNT, 104) NYRS, NCASE

104 FORMAT(20X, '*****', 3X, 'CUMULATIVE COST SUMMARY THROUGH', 3X, '******'
WRITE(NPRNT, 101)
WRITE(NPRNT, 100)
WRITE(NPRNT, 101)
WRITE(NPRNT, 103)
WRITE(NPRNT, 140) PRODL
WRITE(NPRNT, 105)
WRITE(NPRNT, 106) CBST1
WRITE(NPRNT, 107)
WRITE(NPRNT, 111) CBST2
WRITE(NPRNT, 112)
WRITE(NPRNT, 115) AAA

Figure 51: (continued)
WRITE(NPRINT,116) C6ST3
WRITE(NPRINT,117)
WRITE(NPRINT,119) BBB
WRITE(NPRINT,120) C6ST4
WRITE(NPRINT,121)
WRITE(NPRINT,134) C6ST5
WRITE(NPRINT,135)
WRITE(NPRINT,136) C6ST6
WRITE(NPRINT,99)
WRITE(NPRINT,100)
WRITE(NPRINT,101)
WRITE(NPRINT,150)
150 FORMAT(20X,'*****,5X,'PRESENT VALUE OF THE SUM 6F',5X,'*****'/20X
         1,'*****',12X,'YEARLY TOTALS',12X,'*****')
WRITE(NPRINT,101)
WRITE(NPRINT,101)
WRITE(NPRINT,151) NYRS, NCASE
151 FORMAT(20X,'*****,6X,'YEAR',2X,'3X,'CASE',2X,'10X,'******')
WRITE(NPRINT,101)
WRITE(NPRINT,152) UEAC
152 FORMAT(20X,'*****,6X,'PRESENT VALUE OF TOTAL',16X,'*****'/20X
         1,'*****',7X,'CSVT',6F12,4,8X,'*****')
WRITE(NPRINT,101)
WRITE(NPRINT,100)
G8 TO 11
14 WRITE(NPRINT,140) PRGDL
140 FORMAT(20X,'PRODUCTIVITY = ',F14,3,1 MBF')
WRITE(NPRINT,105)
105 FORMAT(15X,'COST TO DECK LOGS AT LANDING')
WRITE(NPRINT,106) C6ST1
106 FORMAT(20X,'COST1',10X,'= ',F10,3,1 PER MBF')
WRITE(NPRINT,107)
107 FORMAT(15X,'COST2 --- ACTUAL LOADING COST')
WRITE(NPRINT,108) CSQPL
108 FORMAT(20X,'COST TO OPERATE = CSQPL = ',F10,3,1 PER YEAR')
WRITE(NPRINT,109) CSQWL
288
Figure 51: (continued)
109 FORMAT(20X,'COST TO OWN = COST1 = $1,F10.3,' PER HOUR'/)
WRITE(NPRNT,110) A5PHL
110 FORMAT(20X,'ACTUAL OPERATING HOURS = ',F10.3,' HOURS'/)
WRITE(NPRNT,111) COST2
111 FORMAT(20X,'LOADING COST = COST2 = $1,F10.3,' PER MBF'/)
WRITE(NPRNT,112)
112 FORMAT(15X,'COST3 --- COST OF LOADER BREAKDOWN'/)
WRITE(NPRNT,113) CCRBK
113 FORMAT(20X,'YEARLY COST TO REPAIR BREAKDOWNS = $1,F10.3'/)
WRITE(NPRNT,114) EESBK
114 FORMAT(20X,'COST OF IDLE TIME!,17X,' = $1,F10.3'/)
WRITE(NPRNT,115) AEE
115 FORMAT(20X,'BREAKDOWN TIME AS PERCENT OF TOTAL = ',F8.4,' %'/)
WRITE(NPRNT,116) COST3
116 FORMAT(20X,'TOTAL BREAKDOWN COST = COST3 = $1,F10.3,' PER MBF'/)
WRITE(NPRNT,117)
117 FORMAT(15X,'COST4 --- COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING'/)
WRITE(NPRNT,118) XAA
118 FORMAT(20X,'AVERAGE NUMBER OF TRUCKS AT THE LANDING = ',F7.4'/)
WRITE(NPRNT,119) BBS
119 FORMAT(20X,'TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = ',F8.4,' %'/)
WRITE(NPRNT,120) COST4
120 FORMAT(20X,'COST OF UNPRODUCTIVE TIME = COST4 = $1,F10.3,' PER MBF'/)
WRITE(NPRNT,121)
121 FORMAT(15X,'COST5 --- COST TO OWN AND OPERATE TRUCKS'/)
WRITE(NPRNT,122) TK
122 FORMAT(20X,'TOTAL NUMBER OF TRUCKS = ',F6.1'/)
WRITE(NPRNT,123) XEE
123 FORMAT(20X,'AVERAGE TRUCK TIME AT LANDING = ',F10.3,' MINUTES'/)
WRITE(NPRNT,124) XFF
124 FORMAT(20X,'AVERAGE TIME WAITING TO BEGIN LOADING = ',F10.3,' MINUTES'/)

Figure 51: (continued)
IF(KSYS = 2) 125,126,127
126 WRITE(NPRNT,128) XGG
128 FORMAT(20X,'AVERAGE TIME IN DOCK BY HIGHWAY TRUCKS = ',F10.3,' MIN')
WRITE(NPRNT,129) XHH
129 FORMAT(20X,'AVERAGE TIME IN DOCK BY SHUTTLE TRUCKS = ',F10.3,' MIN')
WRITE(NPRNT,130) XCC
130 FORMAT(20X,'AVERAGE NUMBER OF FULL TRAILERS AT THE DOCK = ',F10.3)
WRITE(NPRNT,131) XDD
131 FORMAT(20X,'AVERAGE NUMBER OF EMPTY TRAILERS AT THE DOCK = ',F10.3)
GO TO 127
127 WRITE(NPRNT,132) CSLND
132 FORMAT(20X,'EXTRA COST TO BUILD LANDINGS IF BUNK IS USED = $',F10.3)
WRITE(NPRNT,133) XBB
133 FORMAT(20X,'AVERAGE NUMBER OF TRUCKS NOT BROKEN DOWN = ',F10.3)
WRITE(NPRNT,134) COST5
134 FORMAT(20X,'COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $',F10.3, ' PER MBF')
WRITE(NPRNT,135)
135 FORMAT(20X,'TOTAL COST OF THE SYSTEM')
WRITE(NPRNT,136) CST6T
136 FORMAT(20X,'TOTAL COST = CST6T = $',F10.3, ' PER MBF')
GO TO 11
END

Figure 51: (continued)
APPENDIX 18

SIMULATION RESULTS

The results of one case studied in the simulation program are shown in Figure 52. The cost for the first year was shown earlier in the thesis. Figure 53 shows a part of the print-out presenting the results obtained from the statistical storage gathering subroutine of GASP II. The codes have the following significance:

Under generated data;

1, implies the time at the landing
2, implies the time spent waiting for loading

Under time generated data;

1, implies the average number of trucks at the landing
2, implies the percent of the time the loader was busy
3, implies the percent of the time the loader was operational
4, implies the average number of trucks not broken down
7, implies the percent of the time the weather prevented work
8, implies the percent of the time the weather was bad
**NON-CUMULATIVE COST SUMMARY FOR YEAR 2 CASE 1**

PRODUCTIVITY = 6317.996 MBF

COST1 --- COST TO DECK LOGS AT LANDING

COST1 = $0.011 PER MBF

COST2 --- ACTUAL LOADING COST

COST TO OPERATE = COSTPL = $12080.906 PER YEAR
COST TO OWN = COSTL = $4.139 PER HOUR
ACTUAL OPERATING HOURS = 1406.358 HOURS
LOADING COST = COST2 = $3.125 PER MBF

COST3 --- COST OF LOADER BREAKDOWN

Figure 52
YEARLY COST TO REPAIR BREAKDOWNS = $ 24,230.582
COST OF IDLE TIME = $ 5,173.168
BREAKDOWN TIME AS PERCENT OF TOTAL = 10.0016%
TOTAL BREAKDOWN COST = COST3 = $ 3,835 PER MBF

COST4 --- COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING
AVERAGE NUMBER OF TRUCKS AT THE LANDING = 4.8581
TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = 35.4965%
COST OF UNPRODUCTIVE TIME = COST4 = $ 0.006 PER MBF

COST5 --- COST TO OWN AND OPERATE TRUCKS
TOTAL NUMBER OF TRUCKS = 7.0
AVERAGE TRUCK TIME AT LANDING = 79.031 MINUTES
AVERAGE TIME WAITING TO BEGIN LOADING = 19.296 MINUTES
AVERAGE NUMBER OF TRUCKS NOT BROKEN DOWN = 6.517
COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $ 14,595 PER MBF

TOTAL COST OF THE SYSTEM
TOTAL COST = COST8T = $ 21,560 PER MBF

Figure 52: (continued)
IDENTIFICATION OF SYSTEM VARIABLES --- CASE 1

SKIDDING SYSTEM 1 --- ROLLING STOCK

LOADER CATEGORY 4 --- TONGS WITH TONGSETTER

LOADER COST \( \text{CDV} = 30000.00 \)  

LOADER CAPACITY \( \text{CPD} = 3000.000 \) POUNDS

TRUCK CATEGORY 5 \( \text{COST} = 25000.000 \)

NUMBER OF TRUCKS = 7

TYPE TRAILER SYSTEM 1 --- REGULAR OR NORMAL TRAILERS

Figure 52: (continued)
PRODUCTIVITY = 12892.496 MBF

Cost1 --- Cost to Deck Logs at Landing
Cost1 = $0.011 PER MBF

Cost2 --- Actual Loading Cost
Loading Cost = Cost2 = $3.095 PER MBF

Cost3 --- Cost of Loader Breakdown
Breakdown Time as Percent of Total = 10.0016%
Total Breakdown Cost = Cost3 = $4.084 PER MBF

Figure 52: (continued)
COST4 --- COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING

TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = 35.4965%

COST OF UNPRODUCTIVE TIME = COST4 = $0.036 PER MBF

COST5 --- COST TO OWN AND OPERATE TRUCKS

COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $14.711 PER MBF

TOTAL COST OF THE SYSTEM

TOTAL COST = COST5T = $21.937 PER MBF

Figure 52: (continued)
PRESENT VALUE OF THE SUM OF
YEARLY TOTALS

YEAR 2 CASE 1

PRESENT VALUE OF TOTAL = CSVTT = 37.0964

Figure 52: (continued)
NON-CUMULATIVE COST SUMMARY FOR YEAR 3 CASE 1

PRODUCTIVITY = 7217.996 MBF

COST1 --- COST TO DECK LOGS AT LANDING

COST1 = $0.011 PER MBF

COST2 --- ACTUAL LOADING COST

COST TO OPERATE = COSTPL = $13669.215 PER YEAR
COST TO OWN = COSTWL = $4.139 PER HOUR
ACTUAL OPERATING HOURS = 1594.365 HOURS
LOADING COST = COST2 = $3.065 PER MBF

COST3 --- COST OF LOADER BREAKDOWN

Figure 52: (continued)
YEARLY COST TO REPAIR BREAKDOWNS = $12276.980
COST OF IDLE TIME = $1570.944
BREAKDOWN TIME AS PERCENT OF TOTAL = 7.6117%
TOTAL BREAKDOWN COST = COST3 = $1.701 PER MBF

COST4 = COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING
AVERAGE NUMBER OF TRUCKS AT THE LANDING = .8898
TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = 33.4813%
COST OF UNPRODUCTIVE TIME = COST4 = $ .226 PER MBF

COST5 = COST TO OWN AND OPERATE TRUCKS
TOTAL NUMBER OF TRUCKS = 7.0
AVERAGE TRUCK TIME AT LANDING = 79.524 MINUTES
AVERAGE TIME WAITING TO BEGIN LOADING = 19.812 MINUTES
AVERAGE NUMBER OF TRUCKS NOT BROKEN DOWN = 6.547
COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $14.073 PER MBF

TOTAL COST OF THE SYSTEM
TOTAL COST = COST5 = $19.076 PER MBF

Figure 52: (continued)
**PRESENT VALUE OF THE SUM OF YEARLY TOTALS**

**YEAR 3 CASE 1**

**PRESENT VALUE OF TOTAL = CSVTT = 50.6743**

---

Figure 52: (continued)
### Non-Cumulative Cost Summary for Year 4 Case 1

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>6529.496 M3F</td>
</tr>
<tr>
<td>Cost 1: Cost to Deck Logs at Landing</td>
<td>$0.011 per MBF</td>
</tr>
<tr>
<td>Cost 2: Actual Loading Cost</td>
<td></td>
</tr>
<tr>
<td>Cost to Operate: CostopL</td>
<td>$12499.812 per year</td>
</tr>
<tr>
<td>Cost to Own: CostowL</td>
<td>$4.139 per hour</td>
</tr>
<tr>
<td>Actual Operating Hours:</td>
<td>1455.945 hours</td>
</tr>
<tr>
<td>Loading Cost: Cost2</td>
<td>$3.109 per MBF</td>
</tr>
</tbody>
</table>

**Cost 3: Cost of Loader Breakdown**

Figure 52: (continued)
YEARLY COST TO REPAIR BREAKDOWNS = $37,804.672
COST OF IDLE TIME = $50,941.64
BREAKDOWN TIME AS PERCENT OF TOTAL = 8.1044%
TOTAL BREAKDOWN COST = COST3 = $5,790 PER MBF

COST4 --- COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING
AVERAGE NUMBER OF TRUCKS AT THE LANDING = .8325
TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = 33.8667%
COST OF UNPRODUCTIVE TIME = COST4 = $ .163 PER MBF

COST5 --- COST TO OWN AND OPERATE TRUCKS
TOTAL NUMBER OF TRUCKS = 7.0
AVERAGE TRUCK TIME AT LANDING = 79.297 MINUTES
AVERAGE TIME WAITING TO BEGIN LOADING = 19.611 MINUTES
AVERAGE NUMBER OF TRUCKS NOT BROKEN DOWN = 6.534
COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $ 14,854 PER MBF

TOTAL COST OF THE SYSTEM
TOTAL COST = COST9T = $ 23,927 PER MBF

Figure 52: (continued)
CUMULATIVE COST SUMMARY THROUGH YEAR 4 CASE 1

PRODUCTIVITY = 26639.980 MBF

COST1 --- COST TO DECK LOGS AT LANDING
COST1 = $0.011 PER MBF

COST2 --- ACTUAL LOADING COST
LOADING COST = COST2 = $3.090 PER MBF

COST3 --- COST OF LOADER BREAKDOWN
BREAKDOWN TIME AS PERCENT OF TOTAL = 8.1044%
TOTAL BREAKDOWN COST = COST3 = $3.856 PER MBF

Figure 52: (continued)
COST4 --- COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING
TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = 33.8667 %
COST OF UNPRODUCTIVE TIME = COST4 = $ .118 PER MBF

COST5 --- COST TO OWN AND OPERATE TRUCKS
COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $ 14.573 PER MBF

TOTAL COST OF THE SYSTEM
TOTAL COST = COSTT = $ 21.643 PER MBF

Figure 52: (continued)
PRESENT VALUE OF THE SUM OF YEARLY TOTALS

YEAR 4 CASE 1

PRESENT VALUE OF TOTAL = CSVTT = 65,8304

Figure 52: (continued)
**NON-CUMULATIVE COST SUMMARY FOR YEAR 5 CASE 1**

PRODUCTIVITY = 6412.496 MBF

**COST1 --- COST TO DECK LOGS AT LANDING**

COST1 = $0.011 PER MBF

**COST2 --- ACTUAL LOADING COST**

COST TO OPERATE = COSTPL = $12252.797 PER YEAR
COST TO OWN = COSTWL = $4.139 PER HOUR
ACTUAL OPERATING HOURS = 1426.705 HOURS
LOADING COST = COST2 = $3.149 PER MBF

**COST3 --- COST OF LOADER BREAKDOWN**

Figure 52: (continued)
YEARN COST TO REPAIR BREAKDOWNS = $15470.027
COST OF IDLE TIME = $3518.410
BREAKDOWN TIME AS PERCENT OF TOTAL = 7.8238%
TOTAL BREAKDOWN COST = COST3 = $2.412 PER MBF

COST4 --- COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING
AVERAGE NUMBER OF TRUCKS AT THE LANDING = .8750
TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = 34.2084%
COST OF UNPRODUCTIVE TIME = COST4 = $ .208 PER MBF

COST5 --- COST TO OWN AND OPERATE TRUCKS
TOTAL NUMBER OF TRUCKS = 7.0
AVERAGE TRUCK TIME AT LANDING = 79.051 MINUTES
AVERAGE TIME WAITING TO BEGIN LOADING = 19.376 MINUTES
AVERAGE NUMBER OF TRUCKS NOT BROKEN DOWN = 6.508
COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $16.111 PER MBF

TOTAL COST OF THE SYSTEM
TOTAL COST = CSTOT = $21.891 PER MBF

Figure 52: (continued)
PRODUCTIVITY = 33052.480 MBF

COST1 --- COST TO DECK LOGS AT LANDING
COST1 = $0.011 PER MBF

COST2 --- ACTUAL LOADING COST
LOADING COST = COST2 = $3.102 PER MBF

COST3 --- COST OF LOADER BREAKDOWN
BREAKDOWN TIME AS PERCENT OF TOTAL = 7.8238%
TOTAL BREAKDOWN COST = COST3 = $3.576 PER MBF

Figure 52: (continued)
COST4 --- COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING
TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = 34.2084%
COST OF UNPRODUCTIVE TIME = COST4 = $ 0.136 PER MBF

COST5 --- COST TO OWN AND OPERATE TRUCKS
COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $ 14.872 PER MBF

TOTAL COST OF THE SYSTEM
TOTAL COST = COSTT = $ 21.697 PER MBF

Figure 52: (continued)
PRESENT VALUE OF THE SUM OF YEARLY TOTALS

YEAR 5 CASE 1

PRESENT VALUE OF TOTAL = CSVTT = 78.3019

Figure 52: (continued)
PRODUCTIVITY = 6533.996 MBF

COST1 --- COST TO DECK LOGS AT LANDING
COST1 = $0.011 PER MBF

COST2 --- ACTUAL LOADING COST
COST TO OPERATE = COSTL = $12450.094 PER YEAR
COST TO OWN = COSTWL = $4139 PER HOUR
ACTUAL OPERATING HOURS = 1450.059 HOURS
LOADING COST = COST2 = $3080 PER MBF

COST3 --- COST OF LOADER BREAKDOWN

Figure 52: (continued)
YEARLY COST TO REPAIR BREAKDOWNS = $41947.664

COST OF IDLE TIME = $4256.383

BREAKDOWN TIME AS PERCENT OF TOTAL = 7.8557%

TOTAL BREAKDOWN COST = COST3 = $6,420 PER MBF

COST4 --- COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING

AVERAGE NUMBER OF TRUCKS AT THE LANDING = .8738

TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = 34.3710%

COST OF UNPRODUCTIVE TIME = COST4 = $341 PER MBF

COST5 --- COST TO OWN AND OPERATE TRUCKS

TOTAL NUMBER OF TRUCKS = 7.0

AVERAGE TRUCK TIME AT LANDING = 79.147 MINUTES

AVERAGE TIME WAITING TO BEGIN LOADING = 19.452 MINUTES

AVERAGE NUMBER OF TRUCKS NOT BROKEN DOWN = 6.517

COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $14,118 PER MBF

TOTAL COST OF THE SYSTEM

TOTAL COST = COSTOT = $23,970 PER MBF

Figure 52: (continued)
PRODUCTIVITY = 39586.484 MBF

COST1 --- COST TO DECK LOGS AT LANDING
COST1 = $0.011 PER MBF

COST2 --- ACTUAL LOADING COST
LOADING COST = COST2 = $3.098 PER MBF

COST3 --- COST OF LOADER BREAKDOWN
BREAKDOWN TIME AS PERCENT OF TOTAL = 7.8557%
TOTAL BREAKDOWN COST = COST3 = $4.046 PER MBF

Figure 52: (continued)
COST4 --- COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING

TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = 34.3710 %

COST OF UNPRODUCTIVE TIME = COST4 = $0.170 PER MBF

COST5 --- COST TO OWN AND OPERATE TRUCKS

COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $14.747 PER MBF

TOTAL COST OF THE SYSTEM

TOTAL COST = COSTT = $22.072 PER MBF

Figure 52: (continued)
PRESENT VALUE OF THE SUM OF YEARLY TOTALS

YEAR 6 CASE 1

PRESENT VALUE OF TOTAL = CSVTT = 90.4459

Figure 52: (continued)
PRODUCTIVITY = 6560.996 MBF

COST1  ---  COST TO DECK LOGS AT LANDING

COST1 = $0.011 PER MBF

COST2  ---  ACTUAL LOADING COST

COST TO OPERATE = CS0PL = $12412.074 PER YEAR
COST TO OWN = CS0WL = $4.139 PER HOUR
ACTUAL OPERATING HOURS = 1445.558 HOURS
LOADING COST = COST2 = $3.141 PER MBF

COST3  ---  COST OF LOADER BREAKDOWN

Figure 52: (continued)
YEARELY COST TO REPAIR BREAKDOWNS = $27,930.48
COST OF IDLE TIME = $5,722.32
BREAKDOWN TIME AS PERCENT OF TOTAL = 8.2811%
TOTAL BREAKDOWN COST = COST3 = $4.257 PER MBF

COST4 --- COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING
AVERAGE NUMBER OF TRUCKS AT THE LANDING = .8746
TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = 34.4563%
COST OF UNPRODUCTIVE TIME = COST4 = $.078 PER MBF

COST5 --- COST TO OWN AND OPERATE TRUCKS
TOTAL NUMBER OF TRUCKS = 7.0
AVERAGE TRUCK TIME AT LANDING = 79.256 MINUTES
AVERAGE TIME WAITING TO BEGIN LOADING = 19.562 MINUTES
AVERAGE NUMBER OF TRUCKS NOT BROKEN DOWN = .6515
COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $14.849 PER MBF

TOTAL COST OF THE SYSTEM
TOTAL COST = CSTOT = $22.180 PER MBF

Figure 52: (continued)
CUMULATIVE COST SUMMARY THROUGH YEAR 7 CASE 1

PRODUCTIVITY = 46147.480 MBF

COST1 --- COST TO DECK LOGS AT LANDING
COST1 = $0.011 PER MBF

COST2 --- ACTUAL LOADING COST
LOADING COST = COST2 = $3.104 PER MBF

COST3 --- COST OF LOADER BREAKDOWN
BREAKDOWN TIME AS PERCENT OF TOTAL = 8.2811%
TOTAL BREAKDOWN COST = COST3 = $4.076 PER MBF

Figure 52: (continued)
COST4 --- COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING
TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = 34.4563%
COST OF UNPRODUCTIVE TIME = COST4 = $0.134 PER MBF

COST5 --- COST TO OWN AND OPERATE TRUCKS
COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $14.762 PER MBF

TOTAL COST OF THE SYSTEM
TOTAL COST = COST5T = $22.087 PER MBF

Figure 52: (continued)
PRESENT VALUE OF THE SUM OF YEARLY TOTALS

YEAR 7: CASE 1

PRESENT VALUE OF TOTAL = CSVTT = 100*4790

Figure 52: (continued)
PRODUCTIVITY = 6524.996 MBF

COST1 --- COST TO DECK LOGS AT LANDING
COST1 = $0.11 PER MBF

COST2 --- ACTUAL LOADING COST
COST TO OPERATE = CS0PL = $12426.168 PER YEAR
COST TO OWN = CS0WL = $4.139 PER HOUR
ACTUAL OPERATING HOURS = 1447.227 HOURS
LOADING COST = COST2 = $3.127 PER MBF

COST3 --- COST OF LOADER BREAKDOWN

Figure 52: (continued)
YEARLY COST TO REPAIR BREAKDOWNS = $25,810.285
COST OF IDLE TIME = $5,152.320
BREAKDOWN TIME AS PERCENT OF TOTAL = 8.4565%
TOTAL BREAKDOWN COST = COST3 = $3,956 PER MBF

COST4 -- COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING
AVERAGE NUMBER OF TRUCKS AT THE LANDING = .8763
TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = 34.5837%
COST OF UNPRODUCTIVE TIME = COST4 = $ .135 PER MBF

COST5 -- COST TO OWN AND OPERATE TRUCKS
TOTAL NUMBER OF TRUCKS = 7.0
AVERAGE TRUCK TIME AT LANDING = 79.547 MINUTES
AVERAGE TIME WAITING TO BEGIN LOADING = 19.873 MINUTES
AVERAGE NUMBER OF TRUCKS NOT BROKEN DOWN = 6.538
COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $13,902 PER MBF

TOTAL COST OF THE SYSTEM
TOTAL COST = COSTBT = $21,131 PER MBF

Figure 52: (continued)
PRODUCTIVITY = 52672.480 MBF

COST1 --- CST TO DECK LOGS AT LANDING
COST1 = $ 0.011 PER MBF

COST2 --- ACTUAL LOADING COST
LOADING COST = COST2 = $ 3.107 PER MBF

COST3 --- COST OF LOADER BREAKDOWN
BREAKDOWN TIME AS PERCENT OF TOTAL = 8.4565 %
TOTAL BREAKDOWN COST = COST3 = $ 4.061 PER MBF

Figure 52: (continued)
COST4 --- COST OF UNPRODUCTIVE TIME DUE TO NO TRUCKS AT THE LANDING
TOTAL UNPRODUCTIVE TIME AS PERCENT OF TOTAL = 34.5837%
COST OF UNPRODUCTIVE TIME = COST4 = $ .134 PER MBF

COST5 --- COST TO OWN AND OPERATE TRUCKS
COST TO OWN AND OPERATE ALL TRUCKS = COST5 = $ 14.655 PER MBF

TOTAL COST OF THE SYSTEM
TOTAL COST = COST5 = $ 21.968 PER MBF

Figure 52: (continued)
PRESENT VALUE OF THE SUM OF YEARLY TOTALS

YEAR 8 CASE 1

PRESENT VALUE OF TOTAL = CSVTT = 109.0135

EQUIVALENT ANNUAL COST

EQAC = 21.9448

Figure 52: (continued)
**GAS* SUMMARY REPORT**

SIMULATION PROJECT NO. 1 BY JOHNSON L

DATE 3/ 1/ 1970

RUN NUMBER 1

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Figure 53
APPENDIX 19

DATA CONCERNING LOADING TIMES

The data concerned with the loading times of the six loader categories was not included in Figure 17. It is listed here in the six figures that follow: Figure 53 depicts the times for a fully articulated, hydraulic loader; Figure 54, for a loader with air or hydraulic pinchers; Figure 55, for a heelboom loader with a gravity grapple; Figure 56, for a heelboom loader with tongs, Figure 57, for a front-end loader, and Figure 58, for a long-boom loader.
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Figure 54: Data concerned with loader category one, a fully articulated hydraulic loader.
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Figure 57: Data concerned with loader category four, a heelboom loader with tongs
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Figure 58: Data concerned with loader category five, a front-end loader
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**Figure 58:** (continued)

XLDN
VDFL, VGL, CLMSc

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**Figure 59:** Data concerned with loader category six, a long-boom loader.
APPENDIX 20

GLOSSARY OF COMPUTER VARIABLES AND SUBROUTINES

The following pages contain a list of all relevant variables used in the simulation model. They also contain a brief description of all subprograms used in the model. Variable names are listed just as they appear in the computer printout. As such, all names are in capital letters and subscripts are given in parenthesis immediately following and on the same line as the variable name. An asterick (*) indicates an input value.

ADMC - portion of owning cost attributable to administrative expense.

*ADMPR - administrative expense expressed as a percent of equipment value.

AOPHL - yearly hours of actual loader operation.

ARDOK - computer subroutine processing arrivals at the prehaul dock.

ARRVL - computer subroutine processing arrivals at the landing.

*AVDBH - average diameter of the timber being processed.

*A VMBF - average truck load in thousand board feet.

*BHP(LCAT,ISV) - brake-horsepower of a loader in category LCAT and size class ISV.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tr>
<td>BKDLR(IXXX,NSET)</td>
<td>function subprogram determining time between loader breakdowns for severity level IXXX.</td>
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<tr>
<td>BKDTK(IXXX,NSET)</td>
<td>function subprogram determining time between truck breakdowns for severity level IXXX.</td>
</tr>
<tr>
<td>BKDWN</td>
<td>computer subroutine processing equipment breakdowns.</td>
</tr>
<tr>
<td>BKFUL</td>
<td>variable which is one if the bunk is full and zero if it is not.</td>
</tr>
<tr>
<td>BKIT</td>
<td>number of minutes the loader was down in a year.</td>
</tr>
<tr>
<td>BUSTK(ITKN)</td>
<td>variable which is one if truck number ITKN is operational and zero if it is broken down.</td>
</tr>
<tr>
<td>BUS1</td>
<td>variable which is one if the loader is operating and zero if it is idle.</td>
</tr>
<tr>
<td>BUS2</td>
<td>variable which is one if the loader is operational and zero if it is down.</td>
</tr>
<tr>
<td>*CAPL(LCAT,ISV)</td>
<td>lifting capacity of a loader in category LCAT and size class ISV.</td>
</tr>
<tr>
<td>CBKLR</td>
<td>cost of a loader breakdown.</td>
</tr>
<tr>
<td>CBKTK</td>
<td>cost of a truck breakdown.</td>
</tr>
<tr>
<td>CCRBK</td>
<td>yearly cost of loader breakdowns.</td>
</tr>
<tr>
<td>CCTBK</td>
<td>yearly cost of truck breakdowns.</td>
</tr>
<tr>
<td>CDBLR</td>
<td>total duration of all loader breakdowns.</td>
</tr>
<tr>
<td>CDBTK</td>
<td>total duration of all truck breakdowns.</td>
</tr>
</tbody>
</table>
CDV - original cost of loader.

CEXTP - cost of an extra round trip following a loader breakdown.

CINS - portion of equipment owning cost attributable to insurance, interest, and taxes.

*CLMSC(LCAT) - cost per excavated landing for loader category LCAT.

CLND - cost of extra landings built for the front-end loader.

CLOAD - cumulative number of truck loads produced from the beginning of the simulation.

CNTKI - yearly cost of loader idle time because all trucks were down.

*COOS - cost to own and operate a skidder.

COPTK(J) - cost to operate truck J for a year.

COST1 - decking cost in dollars per MBF.

COST2 - loading cost in dollars per MBF.

COST3 - cost of loader breakdowns in dollars per MBF.

COST4 - cost of loader unproductive time caused by no trucks at the landing.

COST5 - cost to own and operate a certain number of trucks.
*COT - maximum time trucks will remain at the landing following a loader breakdown.

COWTK(J) - owning cost of truck J in dollars per hour.

CPD - lifting capacity of the loader.

CPRT(ITKN,IXXX,NSET) - cost of repair parts for a breakdown of equipment number ITKN and severity level IXXX.

*CSBK(KSYS) - cost of a preload bunk for trailer-bunk combination KSYS.

*CSLD(LCAT,ISV) - original cost of a loader in category LCAT and size class ISV.

CSLND - total cost of excavated landings needed by a preload bunk.

*CSMSC(KSYS) - cost per landing for trailer-bunk combination KSYS.

CSOPL - cost to operate the loader for a year.

CSOWL - owning cost of the loader in dollars per hour.

*CSTK(ITCA) - original cost of a truck in class ITCA.

CSTMN - uniform equivalent annual cost of the minimum cost combination.

CSTOT - total cost of loading and hauling subsystems in dollars per MBF.

*CSTOW - cost in dollars per mile to tow a truck.

*CSTR(KSYS) - original cost of a trailer in trailer-bunk combination KSYS.
- present "value" of all yearly costs.
- cost for trucks to wait at the landing during loader breakdown repair.
- cost resulting from bad weather.
- computer subroutine which inputs values necessary for GASP II simulation.
- total number of days since beginning of simulation.
- number of scheduled working days in month number MONTH.
- current working day of the month.
- function subprogram which determines the duration of a breakdown of equipment number ITKN and severity level IXXX.
- duration of a particular loader breakdown.
- duration of a particular truck breakdown.
- average percent defect present in the timber being processed.
- yearly depreciation charged to the preload bunk.
- yearly depreciation charged to the loader.
- yearly depreciation charged to a truck.
- yearly depreciation charged to a trailer.
- total number of days weather was bad.
DSIDL  - number of bad-weather days when no work could take place.
ENDAY  - computer subroutine processing events at the end of each simulated day.
ENDSM  - computer subroutine that makes final statistical calculations at the end of a simulation run.
ENDSV  - computer subroutine processing the end-of-loading event at the landing.
ENDYR  - computer subroutine signaling the calculations and printout made at the end of each year.
ESVBK  - computer subroutine processing in end-of-break down events.
ESVDK  - computer subroutine processing an end-of-service at the prehaul dock.
ETADK  - number of empty trailers at the prehaul dock.
EVNTS  - computer subroutine that directs control to an appropriate subroutine.
EXTRC  - cost of owning extra prehaul trailers.
EXTRK  - total number of extra prehaul trailers.
*EXTR1  - control variable specifying the initial number of empty trailers at the dock.
*EXTR2  - control variable specifying the initial number of full trailers at the prehaul dock.
*EYOH - expected yearly operating hours.
FADOK - number of full trailers at the prehaul dock.
FHWTK - number of the first highway truck to be scheduled in subroutine SCHTK.
FLCN - loader fuel consumption in gallons per hour.
*FLCNL - loader fuel consumption in gallons per hour per brake horsepower.
FLCSL - yearly fuel consumption of the loader.
*FLCTD - cost of diesel fuel in dollars per gallon.
*FLCTG - cost of gasoline in dollars per gallon.
FSHTK - number of the first shuttle truck to be scheduled in subroutine SCHTK.
GASP - computer subroutine serving as the executive subroutine of the simulation.
HOUR(ITKN) - cumulative number of operating hours of truck number ITKN in a year.
*ICASE - control variable specifying the initial case number.
*ICLAS - timber class being processed.
ISEVL - severity level of a particular breakdown.
ISV - size class of a loader.
*ISVL - control variable specifying the first loader size class.
*ISV2  
- control variable specifying the final loader size class.

ITCA  
- truck category being simulated.

*ITCA1  
- control variable specifying the first truck category.

*ITCA2  
- control variable specifying the final truck category.

*ITK1  
- control variable specifying minimum number of trucks.

*ITK2  
- control variable specifying maximum number of trucks.

KSYS  
- trailer-bunk combination being simulated.

*KSYS1  
- control variable specifying the first trailer-bunk combination.

*KSYS2  
- control variable specifying the final trailer-bunk combination.

LCAT  
- loader category being simulated.

*LCAT1  
- control variable specifying the first loader category.

*LCAT2  
- control variable specifying the final loader category.

LOADS  
- the total number of truck loads processed to date.
MILES(ITKN) - the number of miles traveled by truck ITKN to date.

MILTW - miles a truck is towed after a breakdown.

MNVR - skidding system in use.

*MNVR1 - control variable specifying the first skidding system tested.

*MNVR2 - control variable specifying the final skidding system tested.

MONTH - current month of the year.

NBKLR - number of loader breakdowns.

NBKTK - number of truck breakdowns.

NCASE - current case number.

*OPDV(LCAT,NYEAR,ISV,ICLAS) - productivity of a loader in category LCAT, of age NYEAR, in size class ISV, loading timber in class ICLAS.

OUTPUT - computer subroutine that calculates and prints out the cost incurred in a year's time.

OUTSD - variable which is one if outside help is needed to repair a breakdown and zero if not.

*PARAM(I,J) - input array used to input values used in normal distributions having code I with J varying from one to four.

PDS11 - productivity of the skidder when skidding to a class one deck.
PDS12 - productivity of the skidder when skidding to a class two deck.

*POLR - probability that outside help will be needed to repair a second severity level loader breakdown.

*POTK(ISEVL) - probability that outside help will be needed to repair a truck breakdown of severity level ISEVL.

PRODL - yearly productivity in MBF per year.

*PTML - positioning time of trucks at the landing.

*REPRRT - variable specifying the type of output desired.

RPT(ITKN,ISEVL,NSET) - repair time of a breakdown of equipment number ITKN and severity level ISEVL.

REPBK - repair time of a loader breakdown.

REPTK - repair time of a truck breakdown.

*RR - rate of return.

*RTLO - skill rating of the loader operator.

*RTSO - skill rating of the skidder operator.

*RTTD(ITKN) - skill rating of the driver of truck number ITKN.

*RTTS - skill rating of the tongsetter.

SCHBD - variable which is zero if truck scheduling takes place after a breakdown and one if scheduling is at the beginning of the day.
SCHTK - computer subroutine which schedules initial truck arrivals at the landing.

SCINC - increment of time allowed between trucks in scheduling.

*SCIN1 - initial value of the scheduling increment.

*SCPH - skidding cycles per hour.

SLOPE - daily slope of the terrain at the logging site.

SMWGS - sum of the wages of truck drivers and the tong-setter.

SUTK - number of shuttle trucks in the prehaul system.

*SUTK1 - control variable specifying the initial number of shuttle trucks.

*SUTK2 - control variable specifying the maximum number of shuttle trucks.

*SVL(LCAT) - salvage value of a loader in category LCAT expressed as a percent of the original cost.

*SVLBK(KSYS) - salvage value of the preload bunk of trailer-bunk combination KSYS expressed as a percent of the original cost.

*SVLTK(ITCA) - salvage value of a truck in category ITCA expressed as a percent of the original cost.

*SVLTR(KSYS) - salvage value of a trailer in trailer-bunk combination KSYS expressed as a percent of the original cost.
*SVPC  - timber volume skidded per skidding cycle.
*TBEG  - simulated time at beginning of the simulation.
TENDY  - simulated time at the end of a day.
TENYR  - simulated time at the beginning of each year or end of the previous year.
*TFLCN - truck fuel consumption in gallons per mile.
*TIDAY(MONTH) - scheduled working hours in a day in month number MONTH.
TIDKL  - time spent in the prehaul dock by shuttle trucks.
TIDOK  - time spent in the prehaul dock by highway trucks.
*TIIPR - cost of insurance, interest, and taxes expressed as a percent of equipment value.
TISYS  - time spent at the landing by trucks.
TK     - number of trucks in the system.
TKRTN  - number of trucks returning to the mill after a loader breakdown.
TKSYS  - number of trucks which are operational in the system.
TKWTN  - number of trucks waiting at the landing during repair of a loader breakdown.
*TQ1   - time in minutes required to deck logs to a class one deck.
*TQ2
- time in minutes required to deck logs to a class two deck.

TRIPT(I,J,NSET)
- function subprogram that determines the time in minutes required for a trip of code I in truck J.

TRNT (ITKN)
- variable which is one if truck number ITKN has a prehaul trailer attached and zero if not.

*TSV(LCAT)
- variable which is one if a loader in category LCAT needs a tongsetter and zero if not.

*UFE
- percent utilization of truck drivers and the tongsetter while the loader is down.

*ULELO
- percent utilization of the loader operator while waiting for parts.

*ULETD
- percent utilization of the truck driver while waiting for repair parts.

ULTDK (II)
- function subprogram that determines unhooking time of code II at the prehaul dock.

*ULTRK
- percent utilization of the truck unit during a loader breakdown.

*USBK(KSYS)
- economic life of a bunk in trailer-bunk combination KSYS.

*USL(LCAT)
- economic life of a loader in category LCAT.

*USTK(ITCA)
- economic life of a truck in category ITCA.
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<td>economic life of a trailer in trailer-bunk combination KSYS.</td>
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<td>*VDFL(LCAT)</td>
<td>variable that is one if a loader in category LCAT uses diesel fuel and zero if not.</td>
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<td>*VDFT(ITCA)</td>
<td>variable that is one if a truck in category ITCA uses diesel fuel and zero if not.</td>
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<td>*VGL(LCAT)</td>
<td>variable that is one if a loader in category LCAT uses gasoline and zero if not.</td>
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<tr>
<td>*VGT(ITCA)</td>
<td>variable that is one if a truck in category ITCA uses gasoline and zero if not.</td>
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<td>cost of workmen's compensation insurance expressed as a percent of total wages.</td>
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<td>variable that is one if weather is good and zero if not.</td>
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<td>*WGLO</td>
<td>wage of the loader operator.</td>
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<tr>
<td>*WGMP</td>
<td>wage of loader repair personnel.</td>
</tr>
<tr>
<td>*WGTM</td>
<td>wage of truck repair personnel.</td>
</tr>
<tr>
<td>*WGSO</td>
<td>wage of the skidder operator.</td>
</tr>
<tr>
<td>*WGTD</td>
<td>wage of the truck driver.</td>
</tr>
<tr>
<td>*WGTS</td>
<td>wage of the tongsetter.</td>
</tr>
<tr>
<td>WT</td>
<td>waiting time of trucks at the landing.</td>
</tr>
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</table>
*WTHP (MONTH) - probability weather will be good in month number MONTH.

XCSBK - cost to own a bunk in dollars per hour.

XCSTR - cost to own a trailer in dollars per hour.

XDTM(LCAT,NSET) - function subprogram that determines loading time for a loader in category LCAT.

XDTMB(KSYS) - function subprogram that determines the transfer from a bunk to a truck in trailer-bunk combination KSYS.

XISYS - current number of trucks at the landing.

*XLAND - slope limit above which excavated landings must be built for excess cost.

*XLDMN(LCAT,ICLAS) - the minimum loader size of a loader in category LCAT that can pick up timber in class ICLAS.

*XMDBK(ISEVL) - mean duration of a loader breakdown of severity level ISEVL.

*XMDKI - control variable specifying the distance from the prehaul dock to the mill.

*XMDTK(ISEVL) - mean duration of a truck breakdown of severity level ISEVL.

XMIDK - distance from the prehaul dock to the mill.

*XMIPA - miles of pavement.

*XMIPR - miles of primary road.
**XMIS** - miles of spur road.

**XMNCL** - yearly preventive maintenance expenditure for the loader.

**XMNCT(ITKN)** - yearly preventive maintenance expenditure for truck number ITKN.

**XMRBK(ISEVL)** - mean repair time of a loader breakdown of severity level ISEVL.

**XMRTK(ISEVL)** - mean repair time of a truck breakdown of severity level ISEVL.

**XMTBK(ISEVL)** - mean time between loader breakdowns of severity level ISEVL.

**XMTTK(ISEVL)** - mean time between truck breakdowns of severity level ISEVL.

**XNTDL** - necessary remaining time in a day after repair of a loader breakdown before trucks can be scheduled.

**XNTDT** - necessary remaining time in a day after repair of a truck breakdown before an arrival of that truck can be scheduled.

**XPHPA** - average truck speed on pavement.

**XPHPR** - average truck speed on primary road.

**XPHS** - average truck speed on spur road.

**YEAR** - current year of the simulation.
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