STOCHASTIC SIMULATION FOR PLANNING OPTIMAL LOG HAULING OPERATIONS

by

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ORIGINALITY OF THESIS

Except where otherwise acknowledged, this thesis is the author's original work.

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ABSTRACT

Log transport operations are becoming more complex and there are increasing opportunities to apply Operations Research techniques to their planning and evaluation. A stochastic simulation model representing log hauling operations was developed and statistically validated in a case study of haulage to a centralized mill from several forest blocks.

Theoretical distributions are presented for the elements of the log hauling cycle and the loadweights of the trucks in the case study. The results of a separate study of the frequency and duration of log truck breakdowns are also presented.

The simulation model was used in conjunction with a mixed-integer programme to plan optimal log hauling operations for delivery of 8 000 tonnes of wood per week to a central mill from nine forest blocks. The simulation studies showed substantial yearly savings with increases in gross vehicle weight limits, adoption of double shifts for trucks and loaders and reduction in the loading times. The results of an evaluation of leasing or purchasing for equipment procurement is also presented. The simulation studies indicated that leasing was more cost effective.

It is concluded that stochastic simulation is a useful tool for analyzing log hauling systems and that the model developed could be adapted to assess other log hauling operations.

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CHAPTER 1

THE TRANSPORTATION OF LOGS

1.1 INTRODUCTION

Nowadays, transport of logs throughout Australia is almost universally by road. It was not of course always so and without doubt, changes and developments that can now be appreciated in an historical perspective will continue to be part of future log haulage systems.

In the early part of the century, sawmills were located as close as possible to the forests to minimize the haulage distance. Bullock teams were commonly used to haul logs from the forest to the mill, sometimes for distances up to 11 kilometres (Simmons 1977). Draught horses with their greater strength, intelligence and more amicable disposition were also used, particularly in hauling the more valuable wood. Bullocks and horses were still used until recently in some parts of New South Wales, because of low volumes of timber per hectare and the small size of the harvesting and transport operations. Horses were used in many parts of the Cypress pine areas of Barradine district while the crack of the bullock whip was heard until 1974 at Bulahdelah (Golding 1974).

In many places, the second phase of log transport was by water. Bullocks and draught horses hauled the logs to a wharf on the river, to be loaded onto wide beamed, flat bottomed punts, which were manhandled down the rivers and lakes to the coastal ports of Tea Gardens and Port Stephens. The punts were too slow however, and the paddle wheel driven droghers replaced them. Larger loads were carried by the droghers which, since they were equipped with cranes, were not dependent on port facilities as were the punts (Simmons 1977). While the boats provided a ready second phase of transport there were many forests which relied on horses and bullocks to haul directly to the mill.

After the closer forests had been logged and haul distances were beyond the animals' endurance, other hauling systems such as tramways were developed. Initially, the trolleys that carried the logs were pulled by horses along steel capped wooden rails, but as the distance from the mill to the accessible timber increased, a light locomotive running on steel rails was found to be economic. These railway lines extended several kilometres into the forest and were fed directly by bullock teams or winches driven by a steam donkey engine (Johnson 1980).

During the 1920's, there were many attempts to replace the bullock and draught horse haulage teams by machines, but these were not successful until the 1930's when motor trucks gradually began to replace the tramways as the distances from the mill to the desirable timber stands grew still greater. The replacement of tramways and railways by trucks was accomplished because road transport was much more flexible and economic than rail or tramways. By the 1930's, there was already a widespread network of roads covering the country. With many companies and the public using the roads, the costs of construction were borne by many users resulting in lower transport costs. For the tramways and railways however, the capital costs of construction of longer and longer lengths of rail could not be supported by logging alone.

Since the first motorised trucks were introduced during the 1930's, there has been a steady improvement in their power and performance (Golding 1974 and Johnson 1980) and the modern truck, capable of hauling large loads at high speeds, is now the most efficient for hauling from most landings to mills. There has also been a trend for amalgamation of small individual haulage operations with increasing truck fleet sizes.

The increasing fleet sizes have brought the need for new management techniques. This study is concerned with this need and seeks to make a contribution to the development of techniques to improve the management and operation of truck fleets.

1.2 COST PARAMETERS FOR LOG HAULAGE

In Australia, the transportation of logs has always been a major component of the cost of delivering wood to processing plants. The haulage costs are often second only to the stumpage or royalty (the cost of the standing wood to the user) and usually ranges from 8 to 29 per cent of the total logging costs (FORWOOD Report 1974). Excluding stumpage, these percentages translate to 26 to 42 per cent of the logging costs. Ada (1979) gave for pine plantations in the A.C.T. a range of 18 to 46 per cent for costs excluding stumpage. In the United States and New Zealand, transport costs of 50 to 60 per cent of the total logging costs seem to be the norm (Conway 1976 and Logging Industry Research Institute 1978).

If total logging costs are to be reduced, then haulage costs offer one of the most advantageous opportunities for effecting reductions. As would be expected, given the diversity of log hauling operations, there is conflict in the literature on the most important parameters affecting log hauling costs. However, it is possible to find broad agreement on the major components of hauling costs. The following main components will be briefly discussed:

1. Vehicle costs
2. Loads carried by trucks
3. Speed of trucks
4. Haul distance
5. Delays and breakdowns to equipment
6. Managerial efficiency.

1.2.1 Vehicle Costs

Martin (1971) suggested that the most important components of log hauling costs were the hourly wage of truck drivers, the purchase price of the truck and the maintenance and repair costs. However, in 1985, with increasing fuel costs and interest charges, the variable costs of the truck and the opportunity cost in considering the purchase of a truck are also important. If a truck is purchased, then the service life of that machine also becomes an important component of the fixed costs of owning the truck.

1.2.2 Loads Carried by Trucks

Solomon and Conroy (1974) suggest that, for commercial vehicles, a marked reduction occurs in the haulage costs per tonne/kilometre with increasing load size. Beath (1976) showed for log trucks that there were significant savings available where higher loads than normal were allowed. He compared the cost of log haulage by a typical 5-axle semi-trailer under the 48 tonne gross vehicle weight (gvw) limit imposed by the Forests Branch in the Australian Capital Territory (ACT), with the statutory limit (36.4 tonnes gvw for a 5-axle semi-trailer) imposed at the time in New South Wales (NSW) (Table 1.1). The higher limits for the ACT compared with NSW showed a significant saving in the cost per tonne of hauling woods from these forests; 33 cents per tonne, 73 cents per tonne and 91 cents per tonne for trips from Kowen, Pierce's Creek and Uriarra forests respectively. However a study of loads in Australia and New Zealand showed that some log haulers were not maximizing the load in order to minimize the cost (Ridley 1978). He found wide variations in payloads, "influenced by the attitudes of drivers to fines for overloading and the nature (piece size) of the load carried."

Table 1.1 Costs of log haulage from ACT forests under two load limits

Log Source	Distance per year (km)	Annual payload (tonnes)	Total haulage cost ($)	Cost per tonne ($/tonne)
		ACT Load Limits		
Kowen	90 000	80 000	63 700	0.80
Pierce's Creek	100 000	40 000	70 800	1.77
Uriarra	100 000	32 000	70 800	2.22
		NSW Load Limits		
Kowen	90 000	55 000	60 800	1.13
Pierce's Creek	100 000	27 300	68 200	2.50
Uriarra	100 000	21 800	68 200	3.13

Source: Beath (1976)

1.2.3 Speed of Trucks

Matthews (1942) and Shaw (1974) state that the single most important factor affecting the haulage costs for a particular truck is the speed at which the truck operated. However, they noted that a low standard of road only influenced the speed of the truck for that stretch of road, but the payload affected the entire cost of the trip. A study by the New Zealand Logging Industry Research Association (LIRA 1978) concluded that the most significant method to reduce log transport costs was to maximize the distance run per unit time of operation.

1.2.4 Haul Distance

Conway (1976) suggests distance is the most important factor: the longer the haul, the higher the cost and less production achieved. But this may not always be so, for allied to the costs of log transport is of course the truck productivity. As Conway (op.cit.) observed, a short haul distance may have high haulage costs, as trucks returned too quickly to the landing and had to wait for wood. Thus a contractor should ensure that the haulage capacity does not exceed the harvesting capacity that it is supporting since "first and foremost, log hauling is tied inextricably to all other harvest system components" (Conway op.cit.). However, Timson (1974) points out that for a given hauling distance, the actual cost of delivering a load remains relatively constant over a wide variation of load sizes and it is therefore important to maximise the load to minimise the unit delivery cost.

1.2.5 Delays and Breakdowns to Equipment

Delays and breakdowns also increase transportation costs. Conway (1976) suggests that delays account for up to 20 per cent of the total cycle time and that the actual percentage varies with the haul distance. Smith and Tse (1977) agreed and state that the most serious delays occurred on the landings, either waiting in a queue or waiting for wood to arrive. They suggested a need for improved despatching or better selection of the number of vehicles required.

1.2.6 Managerial Efficiency

The management of log trucks or truck fleets is also a significant parameter in hauling costs. Efficient management of trucks can improve truck utilization and reduce the total hauling costs. LIRA (1979) reported a physical device (Truck Control Board) which accurately and continuously simulates the locations of trucks and simplifies and assists in truck scheduling to reduce delays. McCormack (1983) developed a heuristic allocation algorithm for use in a centralized despatch office and demonstrated that in the operation studied, considerable improvements could be made towards equity in the distribution of work amongst drivers. Determining number of trucks is also important in reducing total hauling costs. Too many trucks may produce long queues at landings and the mill, while too few trucks under-utilize the loaders and increase total costs.

Over the past two decades, most studies of the parameters of road haulage costs have been of one parameter or of simple relations between several of the parameters. Smith and Tse (1977) suggested that the whole operational system must be examined "as increased productivity alone does not necessarily mean reduced total haul costs." Methods to examine the whole operational system are not however straight-forward. Clearly for example, there is the immediate problem of the definition of the whole operational system. Just as clearly, there will be changes and developments in log haulage systems, with innovations and inventions to equipment and system organisation. These may be seen as part of an operational system. Nonetheless, a rigorous examination of an operational system seems the best basis for insights toward improvements to the system and its management and in turn, lead to cost savings in haulage operations.

1.3 FORMULATION OF THE STUDY

1.3.1 Aims

Haulage costs are becoming increasingly important in Australia as large wood product mills with the necessary economies of scale are constructed in bigger towns but with longer haul distances from wood supply areas and as more small mills close to forests are amalgamated into large efficient mills situated further from individual forests. There is already a great diversity in the log haulage operations to mills and as the scale of individual operations rises, the problems of planning and evaluating the operations in terms of efficiency are becoming more complex.

In Australia, and in other places it seems, the rigorous systematic methods of Operations Research are not used to plan and evaluate log transport systems and the major purpose of this study was determined as the formulation and evaluation of a procedure to assess the efficiency of log haulage systems. In general, the procedure defined and adopted was to:

1. develop a stochastic simulation model, of general application, to assess and improve the operational efficiency of log hauling to a centralized mill
2. undertake a case study and obtain data to develop and statistically validate the model
3. apply the model to the case study to plan optimal log hauling operations and compare the cost of haulage when trucks are leased or purchased.

It was necessary to conceptualise a model of log haulage and this was named the "abstract model".

1.3.2 The Abstract Model

The cycle time of a truck, that is, the interval between two successive departures of a truck from the mill, is as follows:

(1) Cycle time = (travel to landing + load time + travel to mill + unload time + associated delays)

The associated delays represent trucks queueing for resources such as the loaders and unloaders, any breakdown or accidents that delay trucks and deliberate idleness by drivers.

There is not a deterministic relationship for (1) which includes the interaction of events, for within a haulage system, the interactions between trucks, loaders and unloaders cannot be predicted deterministically. If the events in (1) are treated separately, the cycle time can be modelled as in (2):

(2) Cycle time = f(travel to landing) + f(load time) + f(travel to mill) + f(unload time)

where f(-) represents a time selected from the function representing the distribution of the times associated with that component of the cycle.

Associated delays would be incorporated into each of the functions for the events.

Using (2), it is possible to model the trucks travelling between the mill and the landing provided that each function is defined.

Operations Research techniques were examined to select appropriate techniques, to synthesize a working model for a truck fleet with trucks interacting with each other but cycling in accordance with (2).

1.4 OPERATIONS RESEARCH

1.4.1 Introduction

Operations Research as a categorized activity had origins in World War II when groups of scientists with diverse backgrounds were brought together to develop quantitative techniques to solve problems that previously could only be solved by intuition and experience. An important factor in the increased use of Operations Research, has been the development of sophisticated electronic computers. Thus

> "had it not been for the digital computer, operations research with its large scale computational problems would not have acquired the present promising status."
>
> (Taha 1982)

A common purpose of an Operations Research program is to improve the effectiveness of the total system defined for study (Daellenbach and George 1978) and methods for evaluation of the response of a system to decisions made by management are an essential requirement. The basis of the evaluation of response in Operations Research is the construction and use of models (Phillips et al 1976).

The application of Operations Research to harvesting systems thus requires the development of a model or models of the system to be studied.

1.4.2 Classification of Models

A model is a simplified representation of an observed process which is used to explain or predict the behaviour of the real world process (Mihram 1971). Models may be classified into 3 groups (Fishman 1973 and Taha 1982):

1. Physical
2. Analogue
3. Symbolic

Physical models are scaled-down physical replica of a defined real world system. A common physical model is the representation of an aircraft in a wind tunnel. While they may reveal the consequences of applying physical actions to the model, they are unsuitable for revealing or understanding the flow of information within a system.

Analogue models represent a real system with an analogue which behaves in the same way as the real system, for example, an electrical circuit representing a mechanical or hydraulic system. Analogue models are often used to represent dynamic and continuous processes (Emshoff and Sisson 1970).

Symbolic models, also known as abstract or mathematical models, use mathematical relations to describe the status of variables and the operations and interactions between elements of a real system (Filmer 1978). They use a specific and logical language to represent the system.

Radford (1967) suggests that

> "the very act of constructing a mathematical model enforces precision since it requires a specific statement of what is meant."

This is often seen as an advantage of mathematical models for not only must the interrelationships between the variables describing the system be specifically defined, but also the assumptions and constraints.

Symbolic models can be further classified as:

1. Static or dynamic
2. Continuous or discrete
3. Deterministic or stochastic.

Static models either omit time from the model or take a 'snapshot' of the system at one point in time, for a given set of conditions (Chappelle 1966 and Fishman 1973). Static models are usually concerned with the allocation or design of buildings, where the passage of time has no effect on the system. Dynamic models are concerned with systems which have a variable response with the passage of time.

A continuous model has dependent variables which change in a continuous fashion and the objective in modelling is to observe the continuous variation of dependent and independent variables. A chemical reaction is often represented by a continuous model. Discrete models also involve the passage of time but the variables within the system take discrete values. Furthermore, variables change value at discrete points in time which coincide with events that alter the status of variables within the system.

A deterministic system has variables and interrelationships defined by fixed mathematical or logical relationships and no uncertainty is inherent in the outcome of the system. Thus, for a given input, a deterministic model always produces the same output. A stochastic model has uncertainty implied where part of the variation is random (Fishman 1973). Such models respond with an output associated with a certain probability, and thus a range of outputs can be generated for a given input.

Models do not necessarily conform solely to one or the other of the above classifications and it is becoming more common to find mixtures of models representing systems. Crookes (1981) and Adam and Dogramaci (1979) note that the distinction between continuous and discrete models is decreasing, since many systems have both continuous and discrete variables, requiring a composite model.

A range of symbolic or mathematical modelling techniques and procedures has developed under the umbrella of Operations Research and include linear programming, integer programming, dynamic programming, decision theory and heuristics and the numerical techniques of simulation.

Previous studies (Ada 1979) had indicated that a simulation model may be appropriate to analyse log hauling systems and further investigations of simulation modelling techniques were therefore undertaken in relation to the general aims defined for the study.

1.4.3 Simulation

Naylor et al (1966) define simulation as

> "a numerical technique for conducting experiments on a digital computer, involving certain types of mathematical and logical relationships necessary to describe the behaviour and structure of a complex real-world system over extended periods of time."

Lehman (1977) sees the theoretical considerations as a main reason for study by simulation, since simulation models are often the "outgrowth of theory" as it becomes impossible to describe a problem with mathematical equations and derive analytical solutions. Hypotheses may be evaluated by the use of simulation models and theories may be re-written with more complexity and understanding after simulation analysis.

Naylor et al (1966) suggest that a further rationale for simulation is that experimentation with the real world may be either too costly or impossible to perform and the development of a simulation model is the only feasible approach to enable experimentation. Morgenthaler (1961) lists eighteen reasons for and benefits from the use of simulation.

One major benefit is that the modeller must view the problem in terms of the total system and this may avoid such problems as suboptimization (Bare 1971, Newnham 1973 and Kleijnan 1974). Another is the compressing or expanding of time, for example a model may simulate in only seconds what are years in the real world system. Thus, there may be replication and development of experiments with the model in only a fraction of the real world time. Simulation models also enable examination of a real world process over very short intervals of simulated time, much shorter than would be possible in the real world (Fishman 1973).

Naylor et al (1966) suggest that the observation of the real world and the design of the corresponding simulation model may in themselves lead to a better understanding of the system, perhaps proving more valuable than the results of the simulation experiments. Once the model is constructed, it can be used in experiments to analyse different systems as many times as desired and in turn, the output can be used in further analysis. This output can be collected from the model much more cheaply than from the real world (Schmidt and Taylor 1970).

On the other hand, simulation does have disadvantages as an Operations Research technique. The collection of data and development of a model can be time consuming. A high level of detail in a model may be costly in building and running a model. Stochastic simulation involves all the statistical complications involved in design and analysis of experiments. Optimization is not inherent within simulation and other Operations Research techniques may be necessary for this purpose.

A major difficulty of simulation is the validation of the model. Validation compares the output from the model with the performance of the real system and is a measure of the reality of the model. However, there are no universally accepted statistical procedures that can be used to validate all system models and validation may rest finally on acceptance by the modeller of the model as a realistic simulator (Van Horn 1971). A simulation model may parallel reality very closely, so that the model becomes as complex as the system being studied. This may be seen as an advantage but it can be a disadvantage if

> "the assumptions incorporated in the model are complex and their mutual independence are obscure, (then) the simulation program is no easier to understand than the real process."
>
> (Dutton and Starbuck 1971)

Thus, simulation is not a panacea. It is inherently an abstraction and simulation output only provides estimates of the response variables and the models usually only compare alternative systems rather than generating the optimal alternative.

1.4.4 Methodology of Model Development

The purpose of many simulation models is to examine the responses of a system to alternative operational policies and decisions. There are a number of steps to achieve this and an understanding of the interactions between the variables that comprise the system (Naylor *et al* 1966, Mize and Cox 1968, Emshoff and Sisson 1970 and Phillips *et al* 1976):

1. Definition of a problem or problems in an operational system and a statement of the objectives of the study
2. Formulation of a conceptual model
3. Data collection and processing
4. Construction of the computer program to run the model
5. Verification and validation of the model
6. Experimentation and analysis of the results
7. Implementation of the results.

The number of steps and their order is dependent on each particular problem. However, the general sequence of steps is common to all problems (Emshoff and Sisson 1970).

The first step, that is, definition of a problem and a statement of objectives, is of course fundamental. The objectives usually arise from managers seeking improved efficiency. However, the objectives of the study may be stated in only qualitative terms by the managers and the modeller must then translate these into a quantitative basis, known as the objective function.

The objective of a study is unlikely to remain unchanged throughout the study and a modeller may redefine the objective function several or even many times through the study period, for:

> "problem formulation is a sequential process that usually calls for continuous and progressive reformulation and refinement of the experimental objectives throughout the duration of the experiment".
>
> (Naylor *et al* 1966)

1.5 HARVESTING AND TRANSPORT SIMULATION MODELS

1.5.1 Harvesting Simulation Models

Simulation techniques have been successfully applied to harvesting models concerned with the extraction of wood to the roadside, but most of the models have concentrated on the simulation of the harvesting technique. The transport of wood from landing to the mill has not received detailed attention. The following harvesting models included transport from landings and were assessed in relation to their application to this study:

1. Timber Harvesting and Transport Simulator (THATS) (Martin 1975)
2. Auburn Pulpwood Harvesting System Simulator (APHSS) (Goulet *et al* 1979)
3. Forest Harvesting Simulation Model (FHSM) (Webster 1975)
4. Full-tree Chipping and Transport Simulator (FCTS) (Bradley *et al* 1976)
5. Harvesting System Simulator (HSS) (O'Hearn *et al* 1976).

The above models were not considered applicable in this study for none had a well-developed transport phase. In addition, it would have taken as much work to adapt one of the above models as to build a new model. The models were also developed some time ago and as a consequence, mostly use the FORTRAN language rather than one of the more efficient simulation-oriented languages now available. Finally, many of the models were too restrictive. Some, such as the APHSS model were deterministic in nature and only gave averages as results while THATS advanced time in fixed intervals of one minute, which for the transport phase, was inefficient.

1.5.2 Transport Models

The literature search revealed only two major transport models directly related to the aims of this study. The first was a model simulating the hauling of cane to mills in the sugar cane industry (Sorenson and Gilheany 1970). This model embodies many of the principles of a log hauling simulation model and is reviewed below.

The simulation model, written in GPSS (Sorenson and Gilheany op.cit.), was developed to examine the response of a cane harvesting, transport and process system to different harvesting strategies and decision rules. It simulates the assignment of harvest units of men and equipment to various cane fields, harvesting of the cane and the hauling operation to the mills. Each operation in the real system was categorised as either critical or noncritical. Noncritical steps were those that could not or did not hinder the flow of cane. The actual harvesting of the cane and the processing at the mill were determined as noncritical operations. Critical operations were described as averages or empirical distributions. Thus the model, although partly deterministic, was stochastic in nature. The trucks used to transport the cane from the fields to the mill were dispatched by an allocation sub-model which acted like a 'dispatcher' who tried to meet mill requirement with available resources. Breakdowns to the trucks and the mill were included within the model.

The other model was developed by the Pulp and Paper Research Institute of Canada (PAPRICAN) (Routhier 1974). The model is based on the GASP (Routhier op.cit.) language and was developed for the analysis of pulpwood and sawlog hauling systems with trucks travelling from one or several loading areas to one mill site. The model simulates breakdowns and repairs for trucks, loaders and unloaders and supplies spare machines to replace those broken down. Input data for loading, unloading and haul times are empirical normal distributions. There is no description of the road classification. Input data on the duration of breakdowns for machines follows an exponential distribution. The program was tested against a company trucking fleet and found to be a reasonable representation of the system (Routhier op.cit.).

The review of simulation models associated with wood transport showed that most are associated with harvesting systems and that with one exception, the transport phase from the roadside to the mill was not well developed. The exception was the PAPRICAN model. While this model is a dedicated wood transport simulator, it has limitations as a basis for a generalised wood transport model for application to Australian log hauling systems. Only three loading zones are permitted in the model with a maximum of fifteen trucks. It was concluded that it was necessary to develop a new generalised model.

1.6 THE CONCEPTUAL MODEL

1.6.1 Introduction

The definition of the objective function of a model determines the kinds of measurements to be made, the level of detail to be studied and the recognition of system variables (Karplus 1977, Osbourne and Watts 1977 and Hillier and Lieberman 1980). These matters are therefore a part of the formulation of the conceptual model of the system which is

> "a concise, systematically organised statement of the process, including the specification of the input and the output, the processes and the subprocesses involved, the variables and constants and the data organisation".
>
> (Lehman 1977)

The model can be specified as dynamic or static, continuous or discrete and deterministic or stochastic. The constraints imposed by costs, nature of the system and technology help determine both the system variables and interactions that may be modelled. These, in relation to the objectives of the model, will indicate the appropriate level of detail adopted to simulate reality.

In formulating the conceptual model, it is essential for the modeller to be familiar with the system to be studied. The modeller then knows how it works and is better able to define the variables, parameters and the underlying theory of their behaviour. Emshoff and Sisson (1970) suggest approaches to identify the critical variables in an unfamiliar system:

1. the flow approach
2. the functional approach
3. the state-change approach.

The flow approach traces the flow of products through the system and identifies two elements: the "processes" where changes occur to the product and "movement" where the product moves from process to process. The functional approach identifies the system functions and orders them into the sequence in which they occur. The state-change approach identifies processes which change the state of the system and the times at which they occur.

"Variables" are quantifiable properties of the system that take on different values during the simulation while "parameters" are "quantifiable properties that control the behaviour of the system variables according to the functional relationships which specify the behaviour of the model" (Osbourne and Watts 1977). Parameters have only one value during a simulation run, but can be changed between runs.

The variables and parameters of a system can be classified as exogenous or endogenous. "Exogenous" parameters and variables are the specified inputs of the model and are independent of the model. They can be classed as controllable or noncontrollable. The former can be modified by management and the latter are generated by the environment of the model system. "Endogenous" parameters and variables are the output of the simulation model with their values determined by the interactions within the model.

However, an element of a system may be classified as a parameter or variable, exogenous or endogenous, controllable or noncontrollable, depending on what part of the system is studied, the level of detail required and the objective of the simulation model.

1.6.2 The Dynamics of Log Haulage Systems

The operational characteristics of a hauling system change with time and deterministic relationships are not known for the production of responses of the system to decisions on the operation of the system. Therefore, a simulation model for the study of such a system must be both dynamic and stochastic.

The state-change approach suggested by Emshoff and Sisson (1970) can be used to identify the relationships, variables and parameters of consequence in a log hauling system. These are shown in Figure 1.1. The status of the system changes only at discrete points. For each truck, these are when a truck arrives at the landing, when it starts loading, when it leaves the landing, when it arrives at the mill, and so on. The predicted wood flow from the landing to the mill is thus a result of the sequential processes among the trucks, loaders and unloaders.

Thus, the state-change approach enables identification of processes at the landing and the mill which change the state of the system. Since these changes occur at discrete times, an appropriate method of simulation would be to use a dynamic, stochastic, discrete event-oriented model.

The quantifiable properties common to all log hauling operations are identified in Table 1.2 for the trucking operations of the system. The noncontrollable exogenous parameters are usually noncontrollable only for any given system. For example, loadweights of trucks are noncontrollable once the loader and truck type are determined. Although it is possible to increase or decrease the loadweights by utilizing larger or smaller trucks, once the truck is determined for the model, the loadweight is generated within that physical system. Start times of trucks in the morning are controllable, since drivers can be instructed

Figure 1.1 Schematic diagram of a generalised hauling system

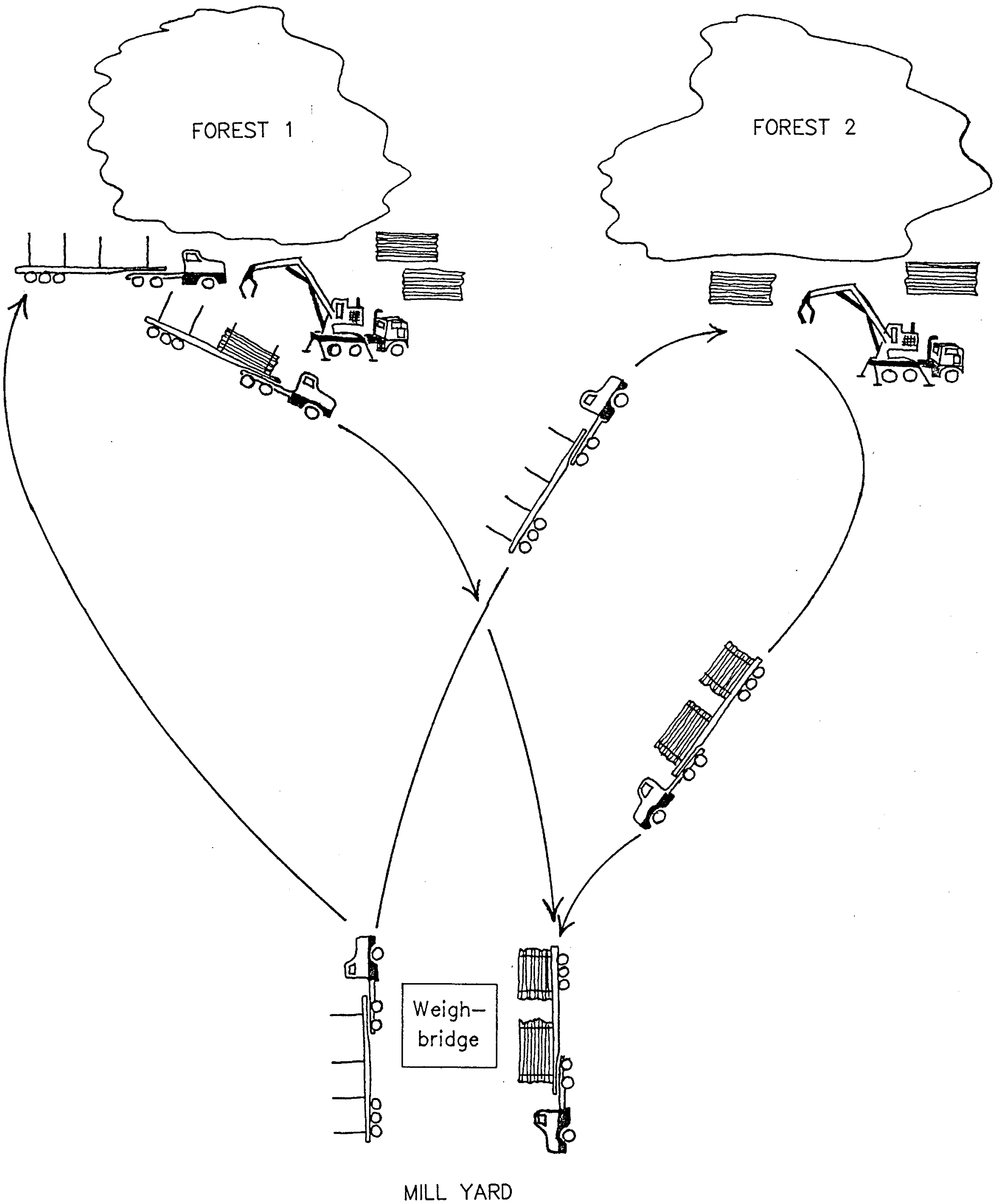


Table 1.2 Quantifiable properties of the truck fleet in a generalised hauling system

ITEM	Exogenous non controllable parameter	Exogenous controllable parameter	Endogenous variable
Number of trucks	X		
Type of truck/trailer combination	X		
Maximum hours allowed to work per day per shift	X		
Haul times to and from forests	X		
Loadweights carried	X		
Load time of trucks	X		
Start times of trucks in morning		X	
Hours worked by trucks			X
Cost of trucking operation			X

to start earlier or later. The model produces two endogenous variables, the hours worked by the trucks and the resulting cost of the trucking operation. The quantifiable properties for the loaders and mill are detailed in Table 1.3

The above variables, parameters and processes constituted the conceptual model of a log hauling operation to a centralised mill. The following exogenous noncontrollable parameters would vary in an actual hauling operation and in relation to a conceptual model, were envisaged as random events selected from a frequency distribution of times for that parameter:

1. Haul times to and from forests
2. Load times of trucks
3. Unload or time spent in the mill by trucks
4. Loadweights carried by trucks.

The sequential processes and the frequency distributions for the exogenous noncontrollable parameters are illustrated in Figure 1.2 and are the basis of the conceptual model.

1.7 THE CASE STUDY

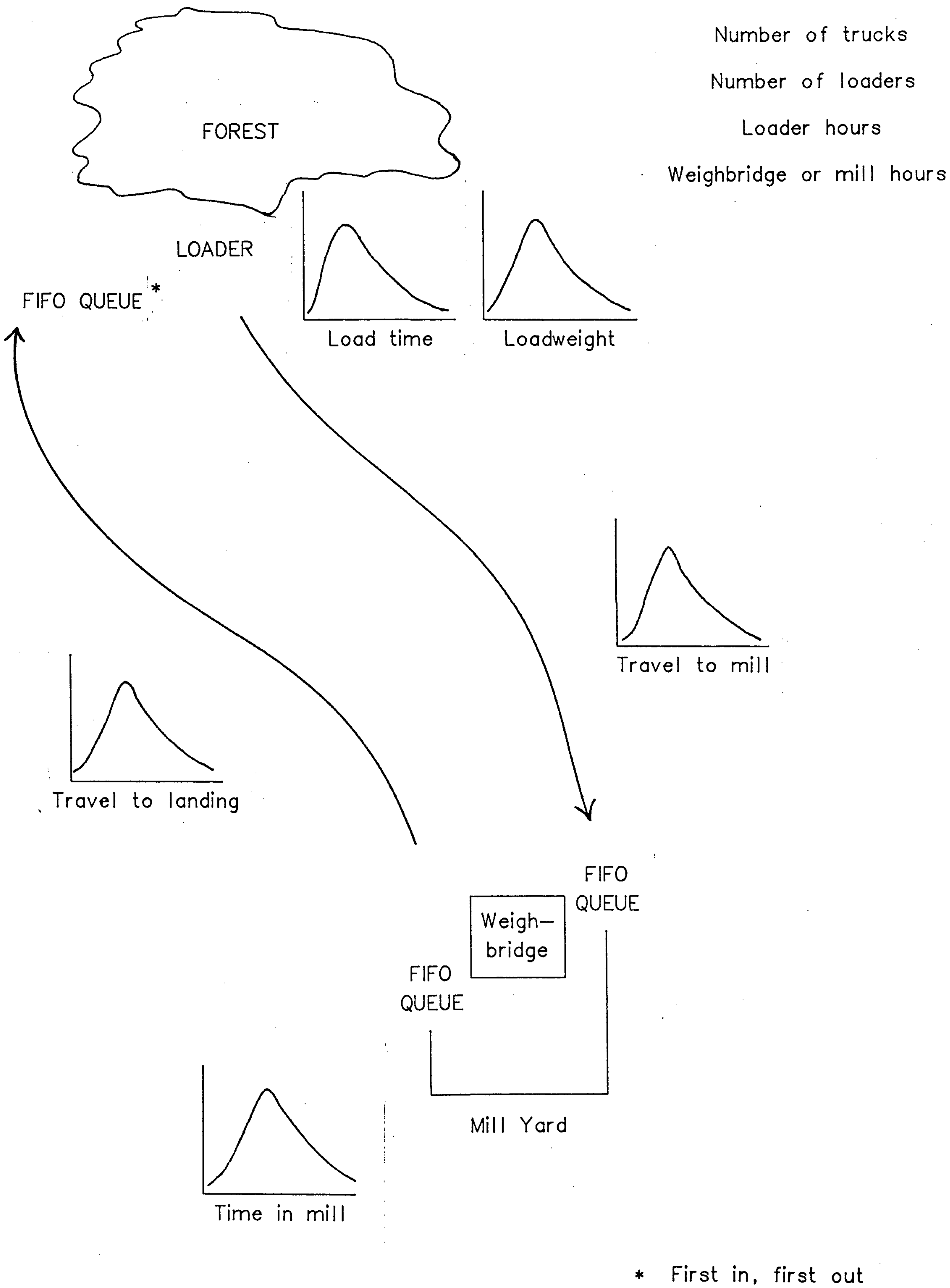
1.7.1 Introduction

There were several reasons for undertaking a case study of an actual hauling operation in connection with the development of the conceptual model described to achieve the aims of the study. Importantly, authentic validation of the model would be feasible. Furthermore, application of the model would be demonstrated, suggested

Table 1.3 Quantifiable properties for loaders and unloaders in a generalised hauling system

ITEM	Exogenous non controllable parameters	Exogenous controllable parameters	Endogenous variables
Number of loaders	X		
Time of unloading	X		
Scheduled hours of work for loader		X	
Start times in morning		X	
Opening and closing time of weighbridge		X X	
Hours worked by loader			X
Cost of loading operation			X
Number of loads and tons delivered to mill			X

Figure 1.2 Sequential processes and exogenous noncontrollable parameters of the conceptual model



improvements to an existing system could be evaluated, real rather than synthetic data could be used and the magnitude of the effort in obtaining the real data could be assessed.

Australian Newsprint Mills Ltd. (ANM) were in the process of completing a large centralised pulp and paper mill at Albury, (New South Wales (NSW) at the time this study was initiated. There were several advantages in using this operation as a case study:

1. It was relatively close to the Australian National University
2. Long haul distances were involved, with up to 200 kilometres one way
3. Several loaders and a relatively large (for Australia) truck fleet were required.

ANM agreed to provide access to their records.

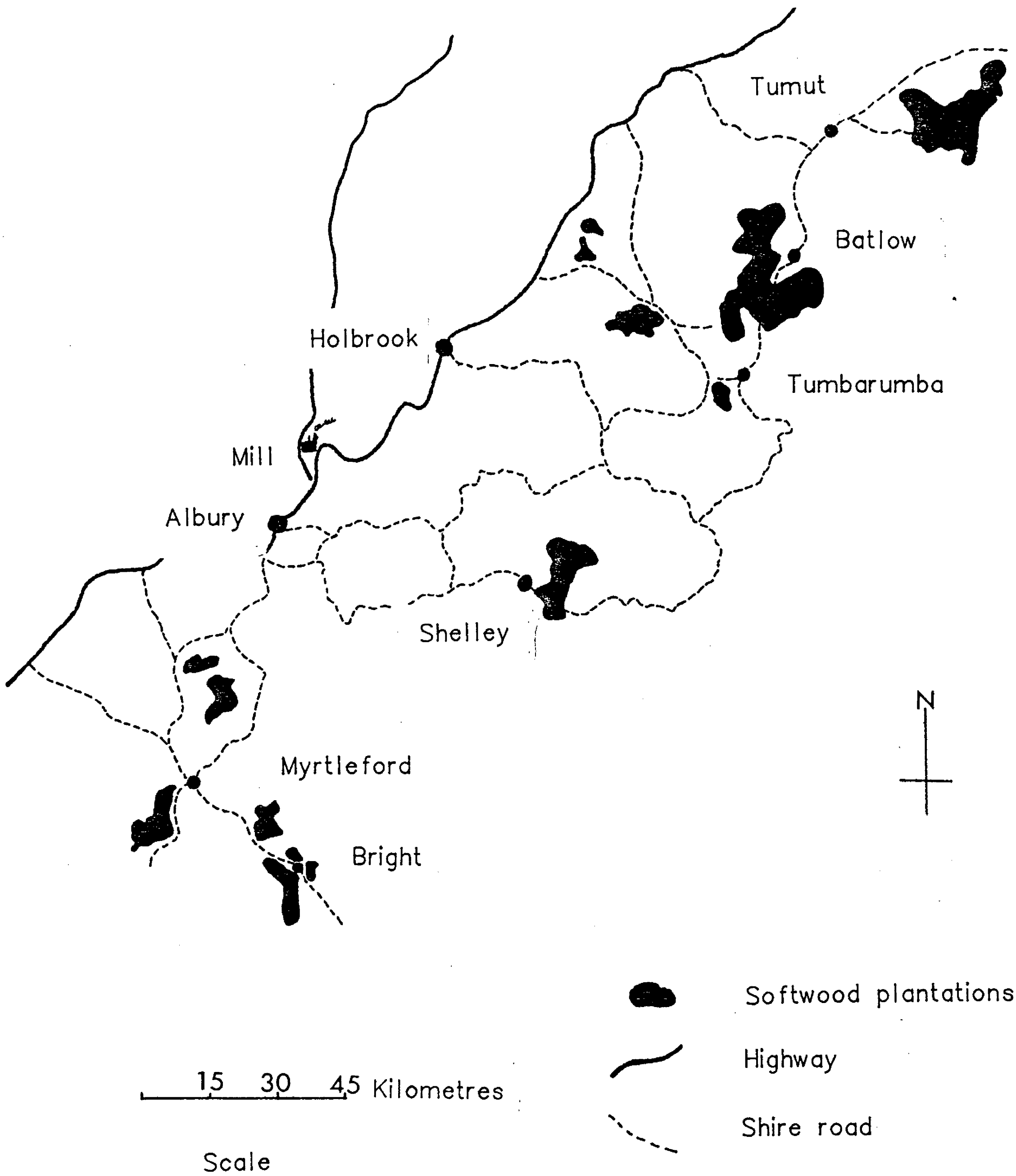
1.7.2 The ANM Operations at Albury, New South Wales

1.7.2.1 The overall system

At maximum annual production, the mill requires 477 000 tonnes of plantation grown softwood to produce 180 000 tonnes of newsprint. The geography of the operations is shown on Map 1.1.

The mill is supplied from both New South Wales and Victorian State Government softwood forests (Pinus radiata). Over two-thirds of the timber is supplied from forests in the Tumut region of NSW, while most of the other third is supplied from forests in Northern Victoria. The

Map 1.1 The area of supply for the ANM mill



mill also imports a small amount of long-fibred semi-bleached Kraft pulp.

The NSW area of supply encompasses five main forests: Bondo, Batlow-Bago, Green Hills, Mannus and Carabost. The average one way haul distance is 206 kilometres. The Victorian area of supply encompasses the forests of Koetong-Shelley, Beechworth, Myrtleford and Bright for which the average one way haul distance is 111 kilometres.

The majority of timber comes from either first or delayed first thinnings. In some operations, both pulp and sawlogs are produced and the logs are sorted within the forest for different destinations. ANM harvests the wood with a mechanical harvesting system. The Kockums Logma system produces timber between 3.6 and 5.4 metres in length. The control of the wood procurement operation is separated into harvesting, loading and transport operations.

The following brief description of the operations provides a background to the formulation of the study.

1.7.2.2 The harvesting system

ANM employs ten harvesting contractors, each using the Kockums Logma System. The system comprises an 880 feller buncher, an 85-41 Logma processor and an 85-33 forest tractor.

The harvesting method is based on a 5th row-outrow, with a selection of the remaining trees. The feller buncher holds the desired tree with grapples and shears it at ground level. The tree is moved in an upright position and laid down in bunches.

The Logma processor backs into the outrow to the first bunch. The stems are delimbed butt first and crosscut to the desired length with the processed log rolling on to the ground at the side of the machine. As the Logma moves to the next bunch, it leaves behind a stack of processed logs.

The forest tractor has a capacity of 12 tonnes and moves up and down the outrows picking up the processed logs for transport to the roadside. The harvesting contractors' task is completed with the stacking at roadside.

Of the ten harvesting contractors, seven are located in NSW, the other three in Victoria. Each contractor is given a yearly works programme by ANM and the State Forest Service, which specifies the compartments to be logged. These compartments are normally visited by the contractor sequentially, but this pattern may be interrupted by weather and the machines sometimes return to a compartment several times.

1.7.2.3 The loading system

One loading contractor to ANM loads all the trucks delivering wood to the mill. The loading contractor uses four loaders, three Prentice 210 knucklebooms and one Prentice 410. The loaders are scheduled to harvesters on a daily basis. The amount and the time in storage of the stockpiled logs and the terrain conditions at the landing are the main criteria for planning the loader operation, although it is desirable for the loader to visit the harvesters regularly.

One loader services the three harvesting contractors in Victoria, while the other loaders service those in NSW. Of the latter, one is usually employed full time in the Carabost and Mannus forests, while the other two service the Bondo, Green Hills and Batlow-Bago forests. All four loaders do not necessarily work every day, and when only three loaders work it is usual for one of the NSW loaders to be idle.

The loaders are mounted on either Mercedes or Nissan UD prime movers, are highly mobile and can rapidly shift from site to site (Plate 1.1). Within any one day, the loaders may shift from one site to another site, usually less than three kilometres away. This occurs when a stockpile runs low. On the other hand, loaders may not shift from two or three compartments which are adjacent, for several days.

Each loader is in radio contact with the weighbridge at the ANM mill and the operator can inform the weighbridge personnel of his intention to shift. Trucks can then be redirected to the new site from the mill. Trucks are not in radio contact with the weighbridge.

1.7.2.4 The hauling system

ANM employs two haulage contractors to haul wood from the supply areas to the mill. Up to 30 trucks are used, delivering between fifty and seventy loads per day. The number of trucks used on any one day is not fixed and depends on the number of trucks available, the number of working loaders, the location of the loaders and the mill stockpile. Both haulage contractors have contracts with other companies and can readily vary the number of trucks used for the ANM operation on any day.

Plate 1.1 A 410 Prentice loader

Trucks are assigned to loaders each day by the haulage contractors. A truck arrives in the morning at the assigned landing approximately every twenty minutes. Each truck operates usually between the mill and the assigned loader in a 'shuttle service' for each day, but may service two or three loaders in one day on occasions. The drivers work to meet the mill requirements up to a maximum of approximately fourteen hours per day.

The mill uses two weighbridges to weigh trucks into and out of the mill and the weighbridge attendant records information about the load when the truck enters the mill. The weighbridge and millyard are open to receive loads for sixteen hours per day, five days per week. Only one unloader is used in the mill.

Two types of truck/trailer combinations are in use. The more common combination is a prime mover with tri-axle skeletal semi-trailer (Plate 1.2). The second is a relatively new combination to the Australian harvesting scene: a prime mover with one bay, towing a short full tri-axle trailer, holding the second bay of wood (Plate 1.3). On the return trip to the landing, the prime mover piggy backs the trailer. The advantages of the pig trailer combination are:

1. Lower tare weight resulting in higher payloads compared to the skeletal trailers
2. Increased manoeuvrability both empty and loaded
3. Less tyre wear for trailer
4. Loading can be carried out over the back of the truck, rather than from the side as is usual.

The disadvantage is the instability when travelling fully loaded at speed.

Plate 1.2 A prime mover with a tri-axle skeletal trailer

Plate 1.3 A prime mover with a pig trailer

One haulage contractor uses all Volvo trucks, N12 prime movers with the skeletal trailers and F10 prime movers with the pig haulers. The other contractor uses International trucks, mainly the S2600 series, pulling skeletal trailers. Both truck/trailer configurations carry between twenty-three and twenty-four tonne payloads. Scales are fitted to some trucks.

1.7.3 The Study Approach

The collection and analysis of data from the case study operation is detailed in Chapters 2 and 3.

The development of the computer simulation model together with modifications for the case study are described in Chapter 4. The verification and statistical validation of the model using data from the case study is presented in Chapter 5. The results of experiments for the planning of optimal log hauling operations for the case study are presented in Chapter 6. A comparison of haulage costs using different costing systems for trucks is made in Chapter 7.

The study is reviewed in Chapter 8.

CHAPTER 2

DATA COLLECTION AND ANALYSIS

2.1 INTRODUCTION

The stochastic simulation model to represent the log hauling operation to the Albury plant of Australian Newsprint Mills Pty. Ltd. (ANM) required the collection of both operational and managerial data as follows:

A. Managerial data

1. Types and numbers of trucks
2. Types and location of loaders

B. Operational data

1. Time spent by trucks in the mill yard
2. Truck travel times between landing and mill
3. Loading times of trucks
4. Truck travel times between mill and landing
5. Frequency and duration of breakdowns to trucks
6. Nett loadweights carried by the truck.

The incorporation of the specific data for components of the cycle time for trucks hauling to the mill into the simulation model, enables prediction of inputs to the mill from a particular loader. Validation of the simulation model with several loaders, each at different locations and varying hours worked, requires the location and number of loaders and the number of trucks servicing that loader for each day of the validation period. The collection of this data is described in Chapter 5.

2.2 DATA COLLECTION

2.2.1 Sources of Data

The following sources of data were available at the commencement of the study:

1. The truck drivers
2. Tachographs fitted to some of the trucks
3. Loader operators
4. ANM weighbridge records.

2.2.1.1 The truck drivers

Truck drivers could provide some information on all of the operational elements of the model. However, it was clear that reliable and comprehensive data was not available and data from this source would therefore require the collaboration of truck drivers in recording the information on appropriate forms. While this would provide data with only a small investment of time by a data collector, it was assumed that if too much detail was included in the forms, the truck drivers might not bother to record all or any of the information. In addition, if all truck drivers would not co-operate by accurately filling in the forms, then a biased sample would result.

2.2.1.2 Truck tachographs

Truck tachographs automatically record the travel of the truck with respect to time and are a common method for recording operational data for trucks. Tachographs are versatile, for in recording speed with respect to time, they can be adapted to measure the time to accomplish a certain task and the distance travelled (Massey-Reed 1979). However, detailed data recorded on tachograph charts is usually difficult to extract without first hand knowledge of the truck's operations. In the ANM operation, not all the trucks were fitted with a tachograph. It was concluded that tachograph charts would not provide the data necessary to construct a truly validated model.

2.2.1.3 The loader operators

It was not the practice for loader operators to record times for loading each truck and as the operators were working close to capacity, it was concluded that collection of data through the loader operators would not be successful.

2.2.1.4 ANM weighbridge records

The following information was supplied to the weighbridge attendant from each truck driver for each truck load of wood delivered to the mill:

1. Haulage contractor
2. Truck registration number
3. Time and date of departure from the landing
4. Loader number
5. Forest district from which the load was obtained

6. Compartment number from which the wood was harvested
7. Harvesting contractor.

The weighbridge attendant added the following to the above information:

1. Date
2. Arrival time at mill
3. Gross weight
4. Departure time from mill
5. Tare weight
6. Nett weight of the load.

The ANM records thus provided information on travel times from the landings to the mill, loadweights, and time spent by the truck in the mill.

The existing sources of data did not provide all the information needed for the simulation model and data collection was therefore necessary. A combination of issuing forms to truck drivers and loader operators and assessment of the weighbridge records was adopted.

2.2.2 Data Collection and Compilation

ANM weighbridge records provided data on some of the elements of log hauling and data were extracted from the company records for the period 30th November 1981 to 31st January 1983.

Forms, detailed in Appendix 2.1, were distributed to the loader operators and truck drivers during the two periods: 5th April 1982 to 15th April 1982; and 26th May 1982 to 10th June 1982.

The extracted data were stored on a Univac 1100/82 computer which was used for all subsequent analysis and modelling. Programs were developed to check the data for obvious errors. It was not feasible to manually check every record for errors.

The three truck/trailer combinations used by ANM during the periods were:

1. Volvo F10 prime mover with pig trailer - P combination
2. International prime mover with skeletal trailer - S1 combination
3. Volvo N12 prime mover with skeletal trailer - S2 combination.

These combinations were used to classify the data using the truck registration number to identify the truck/trailer combination.

2.3 DATA ANALYSIS

The aim of the analysis of the collected data was to determine estimates (with their statistical significance) of the exogenous variables and parameters to be used in the model.

The discrete, stochastic simulation model requires for its application, probability density functions describing each element of the system. These functions may be empirical or theoretical. Empirical distributions represent the collected data precisely, but that is no more than a sample from the population of data (Kleijnan 1974). Theoretical distributions can, if chosen correctly, adequately represent the population and are consequently, more appropriate when the model is used to predict future system responses. It was determined therefore that theoretical distributions should be fitted to the collected data for use in the model.

However, there are difficulties associated with determining the most appropriate theoretical distribution from the relatively large number available. If only a small set of the theoretical distributions are chosen from which to determine the most appropriate one, then there is a greater possibility that the distribution that best characterizes the data is not in the chosen set and less accurate conclusions may be drawn. However, by examining a large set of possible distributions, inordinate time may be spent in examining the many possibilities with of course no guarantee that the best distribution is included. The modeller must compromise between the two extremes.

Fishman (1973) and Ross (1980) state that maximum likelihood estimation is the most common and efficient method of fitting distributions to data. The computer packages examined to fit theoretical distributions to the data were therefore the Maximum Likelihood Estimation for Selected Distributions (MLESD) program and the Maximum Likelihood Program (MLP), the former from the School of Forest Resources of North Carolina State University (USA), the latter distributed by the Rothamsted Experimental Station in England.

The MLESD program was developed primarily for dealing with data arising from forestry research and fits six common continuous distributions with a history of use in forestry, namely normal, log normal, Weibull, gamma, s_b and beta (Schreuder et al, undated). The program can handle either raw data or data that have been grouped into classes. The user must write his own subroutine to read the data into the program and data in a specific format is therefore unnecessary. Any or all of the six distributions may be fitted.

The Maximum Likelihood Program is part of a statistical package for fitting models to data and fits a range of both discrete and continuous distributions to either raw data or data grouped into classes. Eleven continuous distributions may be fitted, namely normal, three types of double normal, two types of log normal, exponential, Weibull, gamma and two types of beta.

Once a distribution has been fitted to the sample data, it is then necessary to decide whether the model adequately resembles the data. This is the question of goodness of fit, or the compatibility of the sets of observed and theoretical values from the chosen distribution. Unfortunately, goodness of fit statistics may give different rankings for any fitted distributions, since each statistic emphasises a different aspect of the observed and theoretical values. The Chi-square is the most common goodness of fit statistic, but requires each class interval or group to have five or more observations for a good approximation (Kendall and Stuart 1961, Brieman 1973, Fishman 1973 and Ross 1980). Massey (1951) and Sokal and Rohlf (1969) suggest the use of the Kolmogorov-Smirnov test for continuous distributions. This test is based on the absolute differences between the observed and expected cumulative frequency distributions.

MLESD provides a table of goodness of fit statistics to help choose between fitted distributions on the basis of the calculated values of Chi-square, Kolmogorov-Smirnov, Cramer-von Mises-Smirnov and Log Likelihood. MLP uses the Chi-square statistic to assist in selecting the 'best-fit' distribution.

The Maximum Likelihood Program was adopted for this study because a greater number of distributions can be fitted to the collected data. The chance that the 'best-fit' distribution was not among the selected distributions for fitting could therefore be reduced. The distributions fitted to the data in this study are detailed in Appendix 2.2. Both the Chi-square and Kolmogorov-Smirnov statistics were used to test the null hypothesis that the fitted distribution was not significantly different from the observed data at the 0.05 probability level.

2.3.1 Time in the Mill Yard by Trucks

The arrival and departure times of trucks are recorded at the weighbridge of the mill and thus data is readily available for the total time of trucks in the mill. While this information does not enable analysis of the unloading operations carried out in the mill, it is adequate for the purposes of the simulation model for it represents on average, between only three and six per cent out of the total cycle time of the truck.

All times greater than fifty minutes, representing one per cent of the data, were discarded from the analysis. The advice was that these times represented industrial disputes within the mill and not therefore, relevant to the model. Because of the large amount of data collected from the weighbridge records over the fourteen month period, it was possible to classify the time spent in the mill by the three truck/trailer combinations.

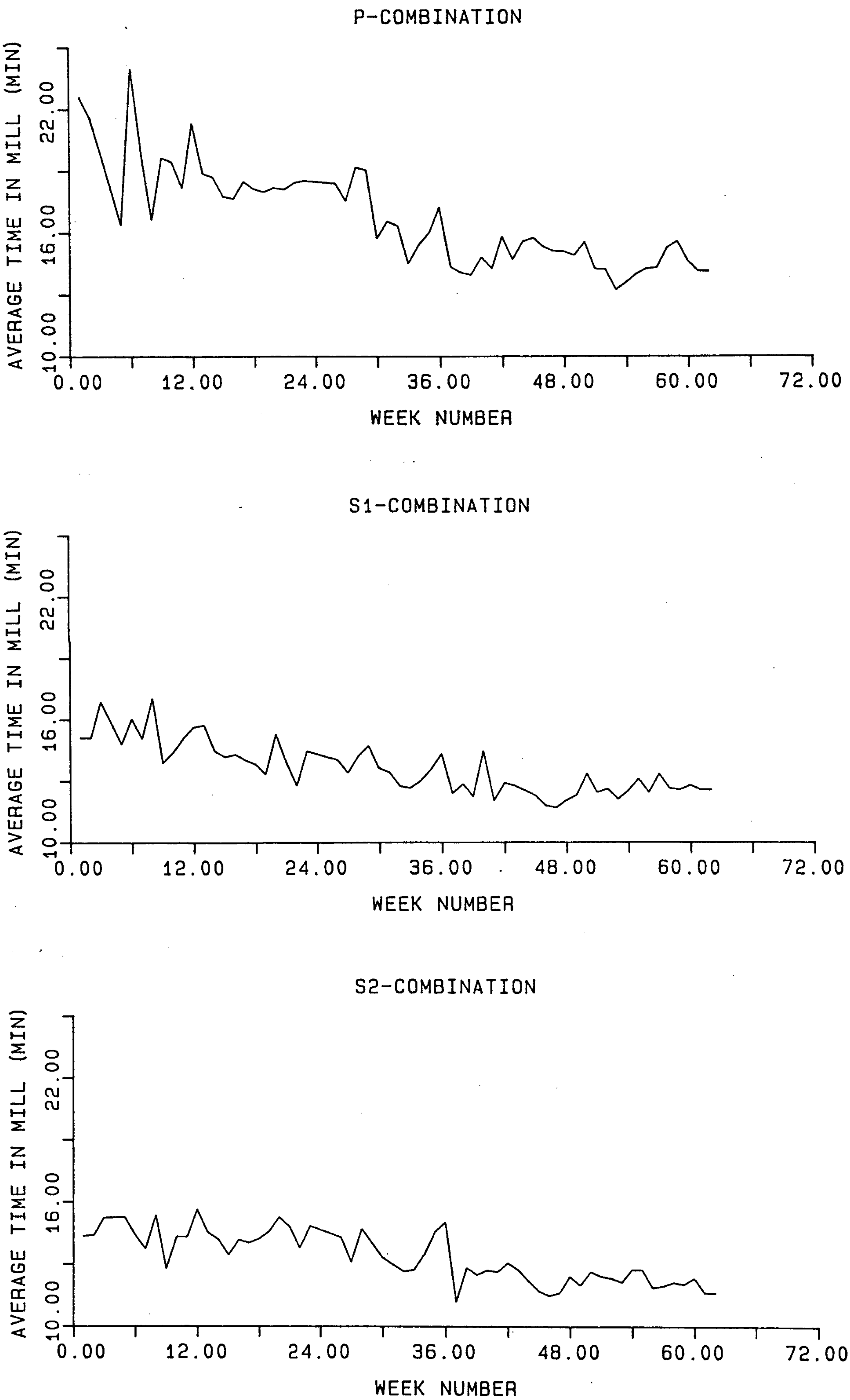
The average time spent in the mill for each load by the three truck/trailer combinations is shown for each week in Figure 2.1. The unload time for all trailers showed a steady decrease over the data collection period.

The unload time for the P-combination showed the greatest improvement over time, decreasing on the basis of the trend line from over 24 minutes initially to nearly 14 minutes towards the end of the period. The mean time in the mill for the S1- and S2- combinations decreased steadily, but from only 16 to 13 minutes over the time period. The higher times for the P-combination are due to the extra time for the loader to place the pig trailer on the back of the prime mover.

The graphs can be interpreted as learning curves for the unloading operation in the mill yard. The decrease in the time spent in the mill by trucks over the data collection period epitomizes the learning curve of unloader operators. The greater decrease for the P-combination truck/trailer, is most likely due to the increasing ability of the loader operator to position the pig trailer correctly on the prime mover.

Figure 2.1 indicates that the S1- and S2- combinations reached a stable average time in the mill at about Week 48 (October/November 1982). The P-combination time stabilized at about Week 50 (November/December 1982). These coincided with a more stable number of deliveries per month from November 1982. The period mid-November 1982 to the end of January 1983 was therefore selected as providing appropriate data for determining theoretical distributions for use in the model.

Figure 2.1 Average time spent by trucks in the mill for one load for the three truck/trailer combinations for each week of the data collection period



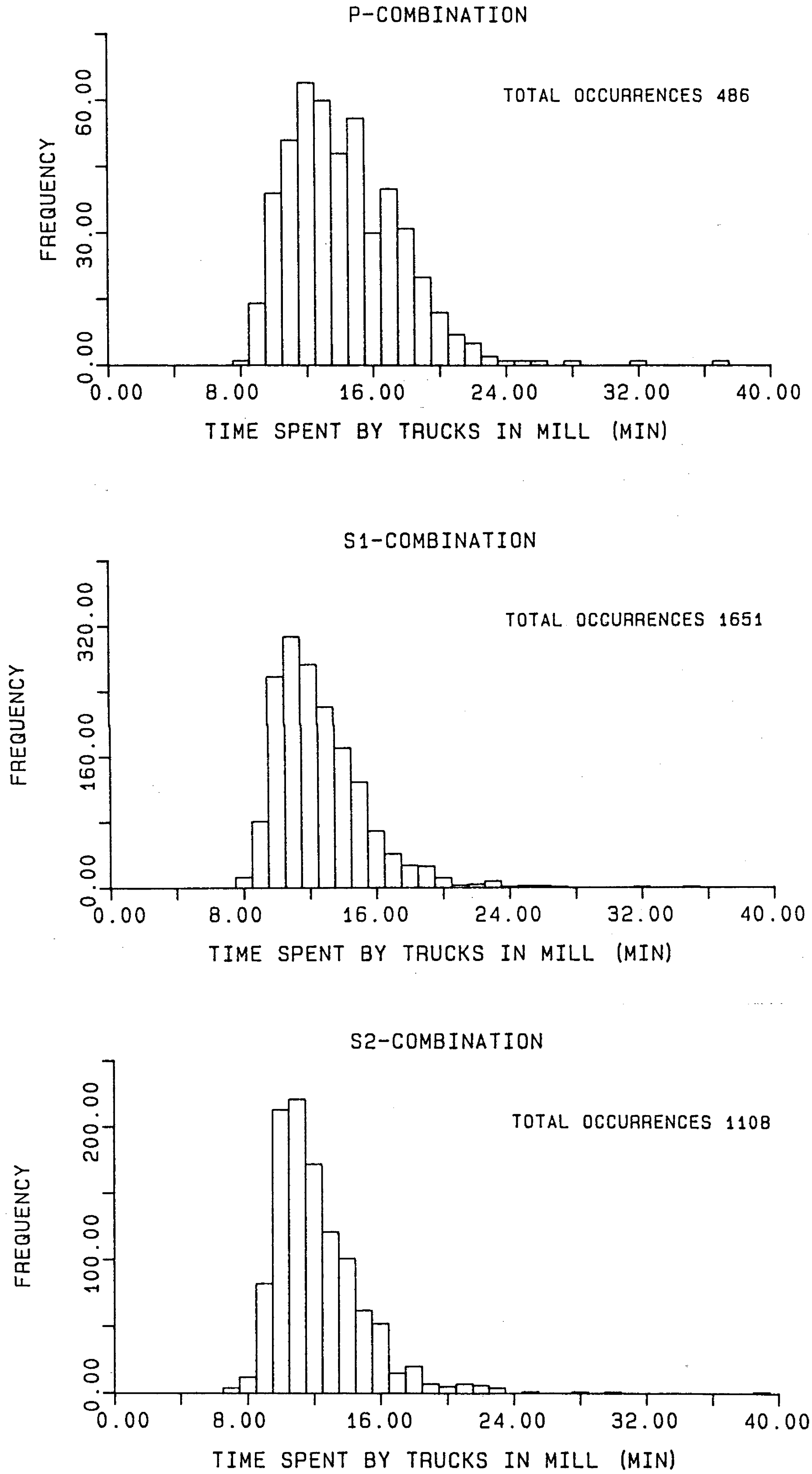
Histograms for the three truck/trailer combinations are shown in Figure 2.2. The histograms suggest positively skewed distributions and the following skewed distributions were fitted: 3-parameter log normal, Weibull, gamma and beta. Since the histograms were displaced from the origin, the 2-parameter log normal distribution was not fitted. The results of the goodness of fit tests are shown in Table 2.1.

Table 2.1 Goodness of fit statistics for the best distributions for time spent by trucks in the mill

Truck/ trailer	Distribution	$C\text{-}X^2$	df	$T\text{-}X^2$	C-KS	T-KS
	log normal[A]	9.07	6	12.59	0.020	
P-	Weibull	66.34*	7	14.07	0.068*	0.062
	gamma	16.00*	7	14.07	0.032	
	log normal[A]	12.88	11	19.68	0.008	
S1-	Weibull	645.8*	12	21.03	0.116*	0.034
	gamma	196.2*	12	21.03	0.055*	
	log normal[A]	9.28	5	11.07	0.009	
S2-	Weibull	453.4*	6	12.59	0.12*	0.041
	gamma	147.5*	6	12.59	0.06*	

* Significantly different at the 0.05 probability level
A 3 parameter log normal distribution
$C\text{-}X^2$ Calculated Chi-square value
df degrees of freedom
$T\text{-}X^2$ Tabulated Chi-square value
C-KS Calculated Kolmogorov-Smirnov value
T-KS Tabulated Kolmogorov-Smirnov value

Figure 2.2 Histograms of the time spent by trucks in the mill for the three truck/trailer combinations



The beta distribution did not satisfactorily fit the data. Both the Chi-squared and Kolmogorov-Smirnov statistic indicated that only the 3-parameter log normal distribution adequately characterized the observed data. However, the Kolmogorov-Smirnov statistic also found the gamma distribution for the P-combination adequately represented the observed data. Because the gamma distribution was not an acceptable fit for the other combinations and due to the conflicting evidence from the Chi-square and Kolmogorov-Smirnov statistics, this distribution was rejected and the 3-parameter log normal distribution accepted as the theoretical distribution for modelling purposes.

The parameter estimates and their standard errors for the 3-parameter log normal distribution are shown in Table 2.2. The mu(μ) parameter is the central measure of the distribution, sigma (σ) measures the dispersion and epsilon (ε) is an origin shift which measures the displacement of the distribution along the x-axis. Thus, epsilon represents the minimum time spent in the mill as calculated from the theoretical distribution.

The parameter estimates are all significantly different from zero. In addition, for the S1- and S2- combinations, the theoretical minimum time in the mill (ε) approximates that of the observed data. However, this was not the case for the P-combination. As no other distribution fitted the data as satisfactorily as the 3-parameter log normal distribution, it was accepted as the best fit for times spent in the mill for all three truck-trailer combinations. The parameters were used to calculate the mean and standard deviation of the distribution function (Appendix 2.3) and these were subsequently used in the model (Table 2.3).

Table 2.2 Parameter estimates (standard errors in brackets) for the 3-parameter log normal distribution representing times spent by trucks in the mill

Truck/ trailer	Parameter estimates μ	σ	ε	observed minimum
P-	2.357 (0.182)	0.288 (0.052)	3.656 (0.851)	8.0
S1-	1.706 (0.052)	0.423 (0.023)	7.094 (0.259)	8.0
S2-	1.597 (0.065)	0.457 (0.030)	7.207 (0.282)	7.0

All parameter estimates are significantly different from zero at the 0.05 probability level

Table 2.3 Mean and standard deviations of the 3-parameter log normal distributions for times spent by trucks in the mill

Truck/ trailer	observed mean(mins)	calculated mean(mins)	observed S.D.	calculated S.D.
P-	14.32	14.66	3.50	3.24
S1-	12.63	13.12	2.75	2.67
S2-	12.25	12.69	2.83	2.64

2.3.2 Travel Times by Trucks Between the Landing and the Mill

Travel times of trucks between the landing and the mill and from the mill to the landing are basic to the simulation model. The records held by ANM provided data on the loaded travel time. Data for those travel times were extracted for the period November 1981 to January 1983. This data was classified by origin in terms of state forest and compartment number. 347 compartments throughout the ANM supply area were represented: 53 from Batlow-Bago, 136 from Green Hills, 112 from Carabost, 26 from Shelley, 8 from Beechworth, 10 from Myrtleford and 2 from Bright (Figure 2.3).

However, the data obtained represents travel time from operational landings and is of course, historical data. The simulation model must be applied to hauling operations encompassing landings for which there is no historical basis of actual truck travel times to the mill. Two methods were examined for predicting these travel times:

1. Deterministic vehicle simulation models
2. Classification and extrapolation of the historical ANM data described above.

Vehicle simulation models use data of road type, standards, traffic conditions, together with information on the mechanical performance of the truck to generate a deterministic time for a truck to travel a particular section of road. Two vehicle simulation models were assessed for application to predicting travel times for this study: the New South Wales Forestry Commission Model (Massey-Reed 1979) and the ICES system (Suhrbier <u>et al</u> 1968).

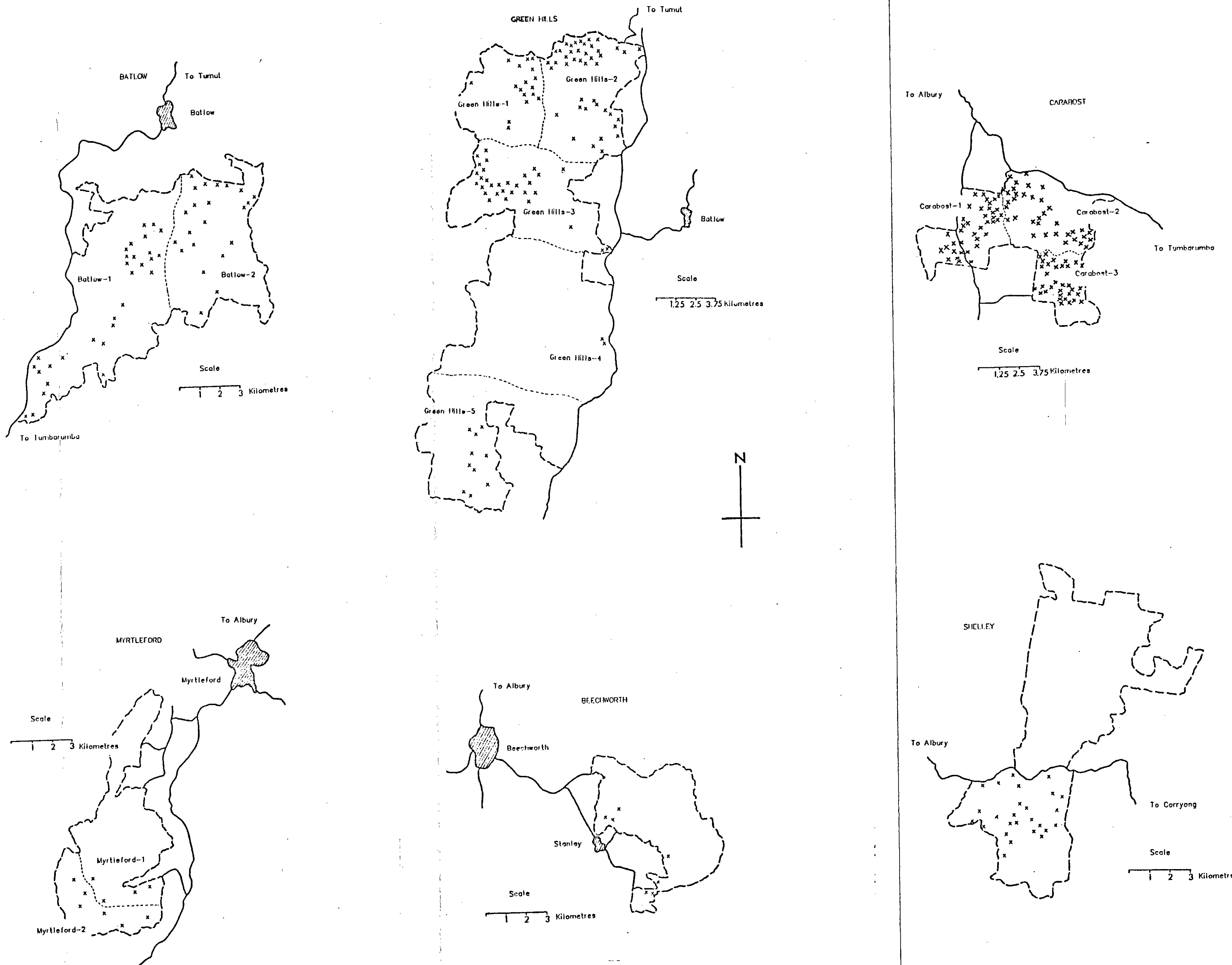


Figure 2.3 Location of the compartments for which data existed and delineation of forest blocks

The Commission model predicts travel times over sections of roads for different types of trucks of known weight (gross and tare), power, torque, gear ratios, final drive ratios, wheel circumference and radius. Road data needed for the model are surface type, grade, alignment and width. The ICES model was developed to predict horsepower requirements and optimum gear ratios to assist in the selection of trucks for particular haul routes. Speeds are also predicted and these can be used for the prediction of travel times. The model needs information on the road geometry and conditions, vehicle characteristics, traffic conditions and driver characteristics.

The models predict the time of travel deterministically and in the case of the vehicle simulation model, prediction requires very detailed information on the road geometry with prediction of speed over short sections. In this study, statistical prediction of travel times are required, and it was therefore determined to develop the prediction of travel times on the basis of the historical data available from the records made by ANM.

Compartments within a forest for which data on travel times to the mill were available, were grouped into 'blocks' and the mean travel time from all the compartments within one block was taken as the mean travel time from that 'block'. There was enough information in the data to calculate mean travel times for all fifteen forest blocks. The blocks were delineated in relation to major haul routes and natural boundaries.

There was insufficient data to estimate and fit separate distributions of travel time from all fifteen blocks for the three truck/trailer combinations defined previously. Examination of the data revealed that the differences between combinations in mean travel times to compartments were in many cases less than the corresponding standard deviations. Data for travel times to the mill were pooled for all truck/trailer combinations for fitting theoretical distributions.

The travel times to the mill to which distributions were fitted were for the calendar year 1st February 1982 to 31st January 1983. A range of weather conditions prevailed over this period and the effects of weather on the travel times are not incorporated into the model in a specific way. There was a detour on the main route to the Shelley block for part of the calendar year and this increased travel times by approximately one hour. Travel times associated with the detour (1st February to 2nd April) were excluded from the fitting of distributions.

Histograms for the travel times from each forest block are shown in Figure 2.4 and some evidence of positive skewness is apparent. The results of the goodness of fit tests associated with fitting distributions to the data are shown in Table 2.4. It was not possible to satisfactorily fit the beta distribution. On the basis of the Chi-square and Kolmogorov-Smirnov statistics, only the 3-parameter log normal distribution consistently adequately characterized the observed data. In the case of the Green Hills-5 forest block, all three distributions (normal, log normal and gamma) adequately fitted the data. For the Green Hills-1, -4, Carabost-1, -2 and Shelley forest blocks, there was disagreement between the Chi-square and Kolmogorov-Smirnov statistics for the normal and gamma distributions. The 3-parameter log normal distribution seemed the most appropriate theoretical distribution of all travel time data and the parameter estimates for the distribution were examined for each block.

Figure 2.4 Histograms of travel times to the mill

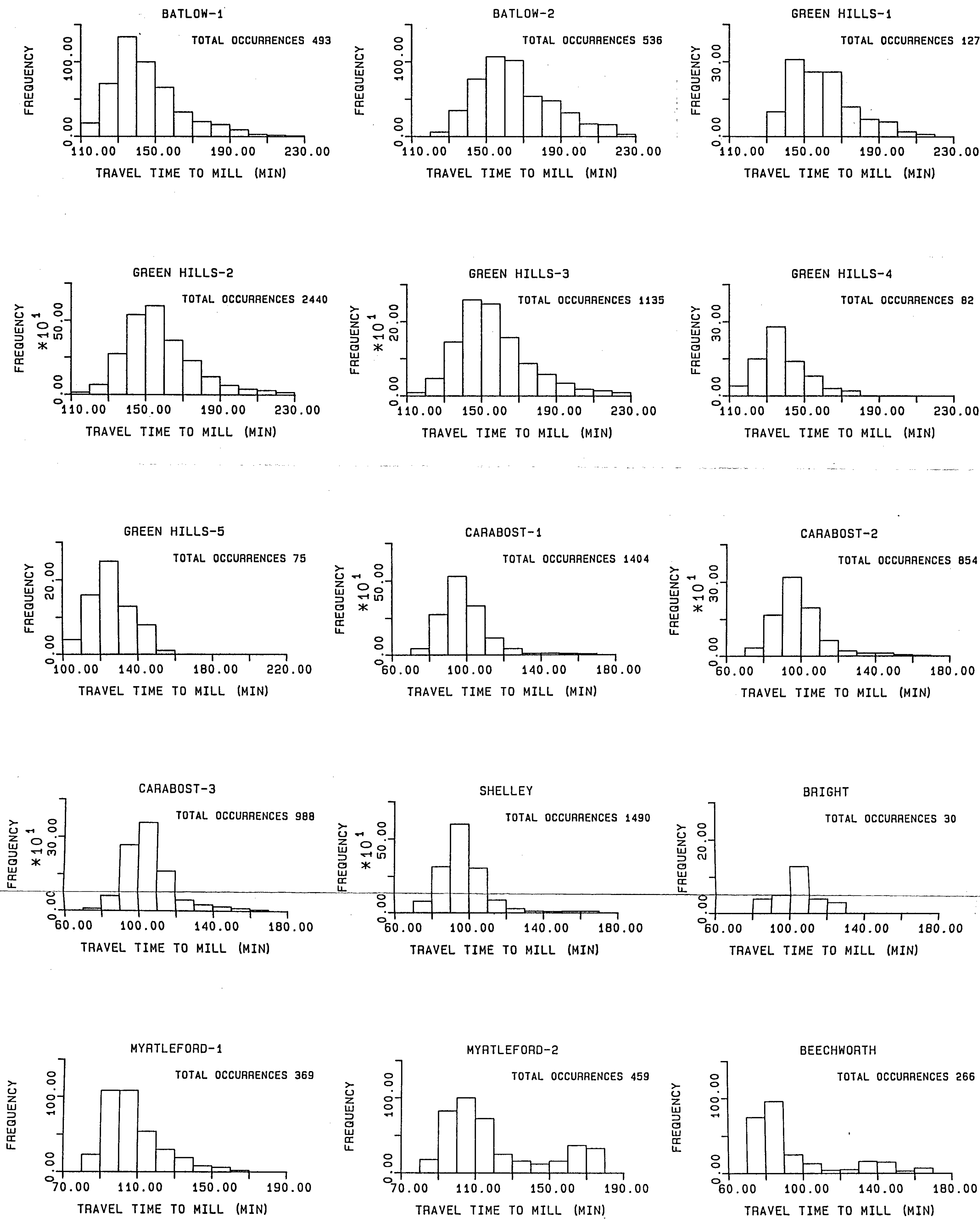


Table 2.4 Goodness of fit statistics for the best distributions for travel times from forest blocks to the mill

Forest block	Distribution	C-X^2	df	T-X^2	C-KS	T-KS
Batlow-1	log normal[A]	2.09	5	11.07	0.013	0.061
	gamma	88.8*	6	12.59	0.082*	
	Weibull	178*	6	12.59	0.115*	
Batlow-2	log normal[A]	8.78	5	11.07	0.028	0.059
	gamma	84.2*	6	12.59	0.092*	
	Weibull	202*	6	12.59	0.125*	
Green Hills-1	normal	25.6*	5	11.07	0.082	0.121
	log normal[A]	2.06	4	9.49	0.020	
	gamma	19.3*	5	11.07	0.069	
Green Hills-2	normal	215*	5	11.07	0.064*	0.027
	log normal[A]	6.01	4	9.49	0.009	
	gamma	158*	5	11.07	0.055*	
Green Hills-3	normal	128*	4	9.49	0.073*	0.040
	log normal[A]	5.61	3	7.82	0.012	
	gamma	93.5*	4	9.49	0.063*	
Green Hills-4	normal	24.6*	5	11.07	0.132	0.148
	log normal[A]	5.62	4	9.49	0.057	
	gamma	20.6*	5	11.07	0.121	
Green Hills-5	normal	7.46	5	11.07	0.082	0.154
	log normal[A]	1.54	4	9.49	0.029	
	gamma	5.70	5	11.07	0.073	
Carabost-1	normal	59.9*	4	9.49	0.04*	0.036
	log normal[A]	5.03	3	7.82	0.011	
	gamma	40.3*	4	9.49	0.031	
Carabost-2	normal	52.0*	5	11.07	0.046	0.046
	log normal[A]	5.14	4	9.49	0.014	
	gamma	33.2*	5	11.07	0.036	
Carabost-3	normal	79.8*	2	5.99	0.070*	0.043
	log normal[A]	1.41	1	3.84	0.007	
	gamma	57.9*	2	5.99	0.060*	

(Table continued next page)

Table 2.4 (Cont.) Goodness of fit statistics for the best distributions for travel times from forest blocks to the mill

Shelley	normal	41.5*	3	7.82	0.035	
	log normal[A]	3.94	2	5.99	0.008	0.035
	gamma	27.5*	3	7.82	0.029	
Myrtleford-1	log normal[A]	2.71	5	11.07	0.016	
	gamma	85.1*	6	12.59	0.102*	0.071
	Weibull	189*	6	12.59	0.149*	
Myrtleford-2	log normal[A]	6.57	3	7.82	0.018	
	gamma	166*	4	9.49	0.132*	0.063
	Weibull	281*	4	9.49	0.159*	
Beechworth	log normal[A]	1.78	2	5.99	0.017	0.083
	gamma	163*	3	7.82	0.136*	

* Significantly different at 0.05%

A 3 parameter log normal distribution

C-X^2 Calculated Chi-square value

df degrees of freedom

T-X^2 Tabulated Chi-square value

C-KS Calculated Kolmogorov-Smirnov value

T-KS Tabulated Kolmogorov-Smirnov value

All parameter estimates for the 3-parameter log normal distribution were significantly different from zero (Table 2.5) and the estimates for epsilon (ε) are all similar to the observed minimum travel time. Thus the results suggest that the 3-parameter log normal distribution is the most appropriate for all travel time distributions. The mean and standard deviation of the theoretical distribution function for travel times from each forest block are shown in Table 2.6.

There was insufficient data to fit a distribution to the Bright forest block. The data available showed a mean travel time and standard deviation similar to the Carabost-3 forest block and the theoretical distribution for this block was assumed to be applicable to the Bright block.

Table 2.6 also shows the average speed of trucks for each forest block, as calculated by average distances from the mill. Average speed ranges between 47 and 69 kilometres per hour. The results show a decrease in the average speed the further the block is from major haul routes. For example, Batlow-2 is on average, six kilometres further from a major haul route than Batlow-1 and the average speed differential is approximately 6 kilometres per hour. Similar decreases in speed were observed for Green Hills-1 and -3, which are further from major haul routes than -2, -4 and -5; and Myrtleford-2 compared to -1. No appreciable difference in average speeds was observed for the Carabost blocks, but all Carabost blocks are serviced by major haul routes. Consequently, average speeds from these blocks are generally high.

Table 2.5 Parameter estimates (standard errors in brackets) for the 3-parameter log normal distribution for travel times from forest blocks to the mill

Forest block	Parameter estimates μ	σ	ε	observed minimum
Batlow-1	3.160 (0.128)	0.754 (0.082)	118.2 (2.486)	110
Batlow-2	3.855 (0.091)	0.519 (0.050)	117.2 (3.722)	122
Green Hills-1	3.469 (0.220)	0.586 (0.128)	126.0 (6.063)	132
Green Hills-2	3.367 (0.077)	0.591 (0.040)	126.0 (2.056)	108
Green Hills-3	3.466 (0.103)	0.604 (0.058)	121.8 (2.941)	111
Green Hills-4	3.106 (0.256)	0.717 (0.178)	115.6 (4.683)	114
Green Hills-5	3.405 (0.418)	0.470 (0.194)	97.22 (11.707)	102
Carabost-1	3.288 (0.168)	0.400 (0.062)	70.19 (4.318)	70
Carabost-2	3.490 (0.138)	0.343 (0.048)	64.05 (4.327)	70
Carabost-3	3.116 (0.118)	0.516 (0.057)	81.53 (2.430)	70
Shelley	3.179 (0.037)	0.417 (0.015)	71.3 (1.0)	67
Myrtleford-1	3.149 (0.110)	0.688 (0.066)	80.96 (2.071)	77
Myrtleford-2	3.461 (0.075)	0.815 (0.056)	82.51 (1.537)	82
Beechworth	2.568 (0.104)	1.130 (0.096)	72.85 (0.603)	69

All parameter estimates are significantly different from zero at the 0.05 probability level

Table 2.6 Means and standard deviations of the 3-parameter log normal distributions for travel times from forest blocks to the mill

Forest block	Mean		S.D.		Average
	Observed	Calculated	Observed	Calculated	Speed (km/h)
Batlow-1	152	149	46.4	27.1	63
Batlow-2	174	171	45.6	30.0	58
Green Hills-1	173	164	79.7	24.7	60
Green Hills-2	163	161	42.1	22.3	61
Green Hills-3	163	160	45.6	25.3	60
Green Hills-4	150	145	55.3	24.0	63
Green Hills-5	134	131	29.5	16.8	64
Carabost-1	101	99	28.6	12.1	68
Carabost-2	102	99	32.9	12.2	69
Carabost-3	110	107	37.4	14.5	68
Shelley	98	97	20.3	11.4	66
Myrtleford-1	110	109	23.9	19.9	59
Myrtleford-2	129	127	39.4	42.5	53
Beechworth	98	98	39.7	39.8	47

2.3.3 Loading Times of Trucks.

It was intended that the simulation model should handle queuing systems internally and thus, the data required was the loading time of a truck rather than time on the landing. Loading was defined as all operations necessary for the loader operator to load a truck including writing the docket and movement and delays by the loader during the loading operation.

ANM had no systematic information on the loading time of trucks and the required information was collected from truck drivers and loader operators by means of forms (Appendix 2.1). The forms were issued between 5th and 15th April 1982 and 26th May and 10th June 1982. The truck drivers and loader operators were asked to record the following information:

1. Time loading commenced on the truck
2. Time of departure of truck from the landing.

The procedure was not entirely successful for some truck drivers and loader operators refused to co-operate. However, enough data was collected for use in the model.

Analysis of variance was used to examine if the loading times at the different loaders were significantly different. The assumptions of normality and homogeneity were tested for each loader. The data were found to be normal and homogeneous, thus legitimizing an analysis of variance. The results of this analysis are given in Table 2.7 and show that the means of the loading times are significantly different from each other. It should be noted the data were classified by loader only

Table 2.7 Analysis of variance for times for loading trucks at landings under four loaders

Hypothesis	Analysis of Variance						Conclusion
		df	ss	ms	Fcalc	Ftab	
Individual loader means are equal	Loaders	3	250	83.2	3.92	=2.70	Four loader means are sign. diff. at the 0.05 prob. level
	Residual	95	2018	21.2			
	Total	98	2268				

and not by truck/trailer combination . As some truck drivers did not participate in the data collection, there was a lack of data for some combinations. This lack of data meant that theoretical distributions were not fitted to loading time data.

Examination of the observed data, together with the skewness and kurtosis tests for normality, showed no reason to reject the hypothesis that the data were normally distributed. Normal distributions were therefore assumed for application in the simulation model based on the observed means and standard deviations as given in Table 2.8.

Table 2.8 Times for loading trucks at landings

Loader	mean	S.D.
1	23.9	5.1
2	22.2	4.5
3	25.4	4.2
4	27.8	3.6

2.3.4 Travel Times by Trucks Between the Mill and the Landing

As with the loaded travel time by trucks to the mill, a large amount of data is needed to represent the travel time by trucks from the mill to the many landings in the forest blocks of the ANM supply area, but ANM did not record these times. Travel times by trucks to the landings were therefore synthesized from the data available from ANM records for travel times by trucks to the mill. The ANM weighbridge records enabled the cycle time to be obtained for a truck from the time when it left the weighbridge until it returned with a load to the weighbridge. Average cycle times were calculated for each of the forest blocks in the ANM supply area. The average time spent in the mill and the average time spent loading were calculated. The sum of this was between 34.5 and 42.1 minutes (depending on truck type in mill and loader number) and this was rounded off to 40 minutes which included an allowance of approximately 5 minutes for queuing at the landing. The average travel empty time to a forest block was then estimated as the respective cycle time, minus 40 minutes and minus the respective average travel time to the mill.

This of course gave a deterministic travel time to the landings. The average travel time to a forest block was then expressed as a percentage of the respective average travel time from the block to the mill and called the empty factor. Estimates of the travel time from the mill to the landing were calculated by randomly selecting from the appropriate distribution, a travel time to the mill from a particular forest block and multiplying this value by the empty factor. Table 2.9 shows the cycle times and empty factors for each forest block.

Table 2.9 Cycle times and travel times to and from the mill for forest blocks

Forest block	Average cycle time (mins)	Average time to mill (mins)	Average time to block (mins)	Empty factor
Batlow-1	332	152	140	.92
Batlow-2	364	174	150	.86
Green Hills-1	353	173	140	.82
Green Hills-2	341	163	138	.85
Green Hills-3	348	163	145	.89
Green Hills-4	320	150	130	.86
Green Hills-5	286	134	112	.83
Carabost-1	230	101	89	.88
Carabost-2	234	102	92	.90
Carabost-3	242	110	92	.84
Shelley	223	98	85	.86
Myrtleford-1	252	110	102	.93
Myrtleford-2	270	129	101	.78
Beechworth	220	98	82	.83

2.3.5 Frequency and Duration of Breakdowns to Trucks

Information on the frequency and duration of breakdowns to log trucks is an important factor in evaluating their performance. Baumgras (1978), Garner (1978) and Ada (1979) analysed data on the durations of breakdowns and intervals between them, although none fitted stochastic models for predictive purposes. This was seen as a significant deficiency in both the data and techniques used previously for modelling log hauling systems.

ANM had not started hauling to the mill at the beginning of this study. There was no large scale log hauling operation within Australia similar to the proposed ANM system and with reliable records of truck breakdowns. New Zealand Forest Products Ltd. agreed to provide access to records of breakdowns to their log truck fleet hauling to the Kinleith Mill at Tokoroa. The collection and analysis of these data is described in Chapter 3.

By the middle of 1981, ANM had determined that two haulage contractors would be used to deliver wood to the mill. Both contractors had other haulage contracts and scheduled trucks to the logging operations as required and as available. The problem in the modelling of the ANM hauling operation was therefore to determine the appropriate number of trucks on a daily basis and schedule these to the landings rather than determine the appropriate fleet size which would require information on the frequency of breakdowns of more than one day. Delays of less than one day are of course incorporated into the observed data collected from ANM.

2.3.6 Loadweights of Trucks

Data on the variability of the nett loads of the trucks were necessary to determine the wood input into the mill and a distribution for the loadweights was required for use in the simulation model.

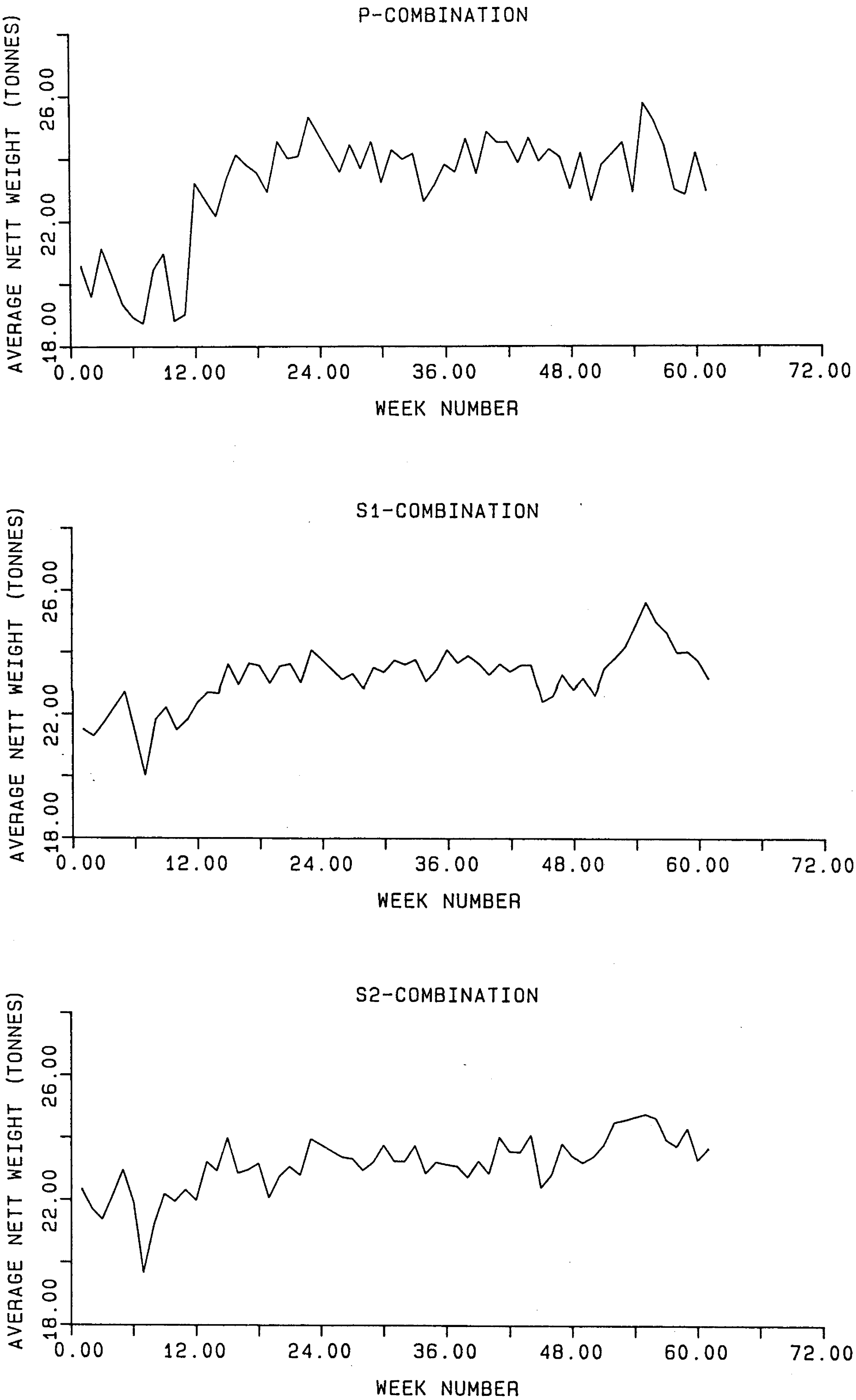
The nett weight of each truckload into the mill is recorded at the ANM weighbridge. Data on the nett loadweights were extracted from November 1981 to January 1983 inclusive. The loadweights were characterized by the truck/trailer combinations used by ANM. The average nett loadweights of each truck/trailer combination for each week are shown in Figure 2.5.

For the P-combination, the average nett loadweights for each week were very low during week 1 to 20 (November/December/January 1981/82) and rose rapidly in February 1982. This was followed by a gradual rise until the end of week 27 (May) when the loadweight seemed to stabilize. The initial low nett loadweights occurred when ANM was undertaking salvage operations in Victorian forests. The pig trailers were primarily involved in this work and it was concluded that this was the cause of the relatively low loadweights.

Figure 2.5 shows an initial gradual increase in the loadweights of the two semi-trailer combinations until week 20 (April 1982) when the loadweights seemed to stabilize.

Theoretical distributions for the loadweights delivered to the mill were therefore based on the period of apparent stability in loadweights, that is from week 27 (31st May 1982). Gross loadweight data were not recorded from the ANM weighbridge records. Data were

Figure 2.5 Average nett loadweights of each truck/trailer combination for each week of the data collection period

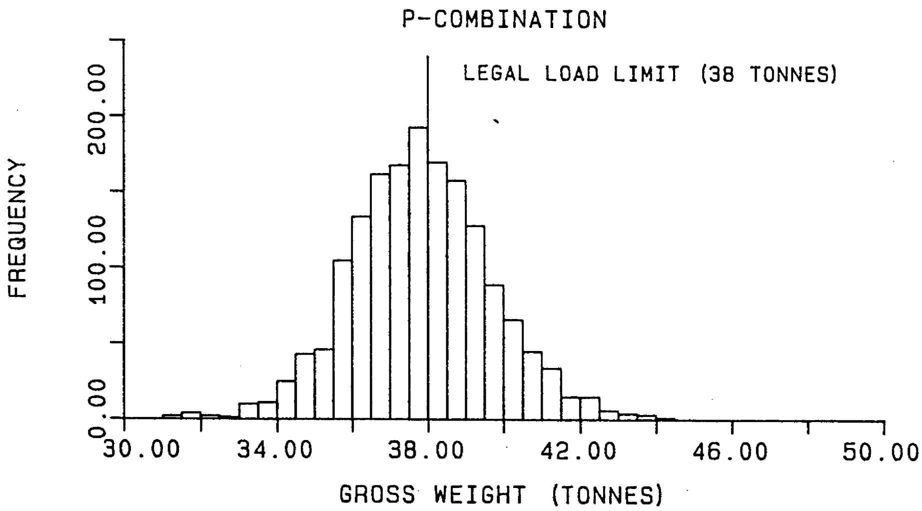


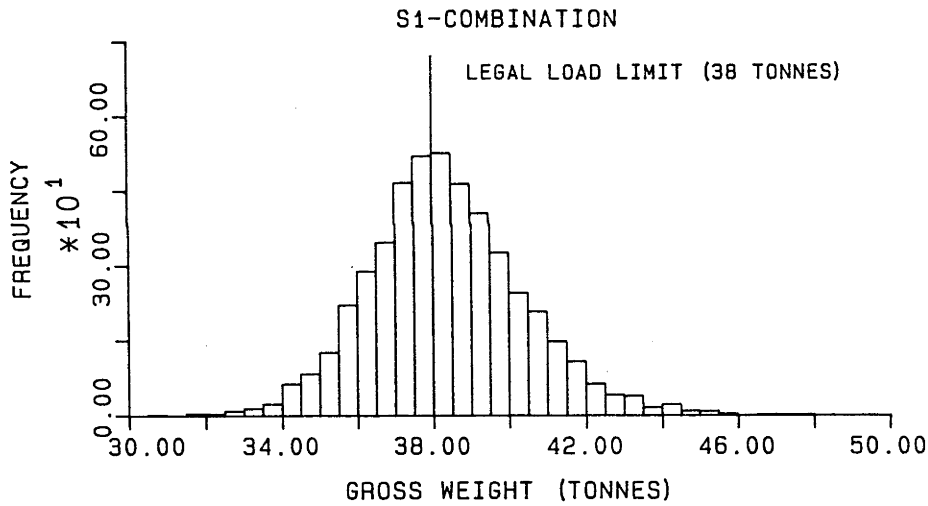
collected on the tare weight of every truck from 5 days of records, randomly sampled from the data collection period, to enable the gross loadweights of the trucks to be examined. The respective truck's average tare weight was added to each nett loadweight over the data collection period, to achieve the gross weight of the truck and load. Histograms of the gross weights for the truck/trailer combinations are shown in Figure 2.6, along with the 38 tonne gross vehicle weight limit imposed by legislation for the three truck/trailer combinations.

There was an extraordinary amount of overloading: 45% of the loads for the P-combination, 55% for the S1-combination and 57% for the S2-combination. While the policy of the company during the data collection period was to accept the load irrespective of gross weight, company staff cautioned drivers who grossly and consistently overloaded. Various distributions were fitted to the nett loadweight data from week 27 (31st May 1982) to the end of the data collection period. The results of the goodness of fit tests are shown in Table 2.10.

For the P-combination, the normal, 3-parameter log normal and gamma distributions were not significantly different from the observed data. However, estimates of some of the parameters of the latter two distributions were not significantly different from zero and the normal distribution was therefore chosen as the theoretical distribution representing the observed data. For the S1- and S2- combinations, all distributions except the 3-parameter log normal distribution were significantly different from the observed data by both the Chi-square and Kolmogorov-Smirnov tests.

Figure 2.6 Histograms of the gross vehicle weights for each truck/trailer combination





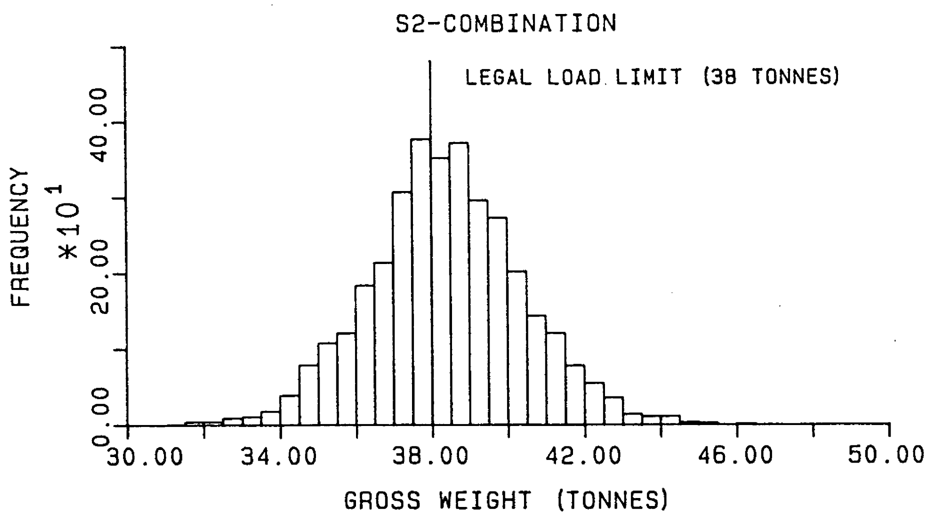


Table 2.10 Goodness of fit statistics for nett loadweights by truck/trailer combinations

Truck/trailer	Distribution	C-X^2	df	T-X^2	C-KS	T-KS
	normal	4.22	9	16.92	0.005	
P-	log normal[A]	4.18	8	15.51	0.005	0.034
	Weibull	183*	9	16.92	0.05*	
	gamma	2.32	9	16.92	0.005	
	normal	93.6*	6	12.59	0.025*	
S1-	log normal[A]	5.80	5	11.07	0.007	0.020
	Weibull	507*	6	12.59	0.063*	
	gamma	46.7*	6	12.59	0.017	
	normal	47.2*	6	12.59	0.022	
S2-	log normal[A]	6.89	5	11.07	0.004	0.023
	Weibull	350*	6	12.59	0.063*	
	gamma	22.8*	6	12.59	0.015	

* Significantly different at 0.05%

A 3 parameter log normal distribution

C-X^2 Calculated Chi-square value

df degrees of freedom

T-X^2 Tabulated Chi-square value

C-KS Calculated Kolmogorov-Smirnov value

T-KS Tabulated Kolmogorov-Smirnov value

The parameter estimates of the 3-parameter log normal distribution are shown in Table 2.11. The estimates are all significantly different from zero and in the case of the S1- and S2-combinations, the calculated minimum loadweights (12.9 and 10.1 tonnes respectively) are close to the observed minima (8.7 and 15.4 tonnes respectively). The 3- parameter log normal distribution was accepted as the appropriate theoretical loadweight distribution for the semi-trailer combinations. The parameter estimates were used to calculate the mean and standard deviation of the distribution functions for use in the simulation model. The values are shown in Table 2.12.

2.4 COSTS OF LOADERS AND TRUCKS

2.4.1 Introduction

The calculation of the cost of loading and hauling wood to the ANM mill requires cost information for the operation of the loaders and trucks. Specific costs for the ANM operation were not available and the loading and hauling contractors regarded this as confidential commercial information. Estimates of the unit costs required to calculate the cost of wood deliveries were therefore derived on the basis of information collected from other sources.

The two main approaches to equipment procurement in the forest industries in Australia, are purchasing and leasing. Both procedures are considered in this study, but inasmuch as the contractors for loading and hauling wood to the ANM mill mainly lease their equipment, unit costs in this study are generally calculated on the basis that equipment is leased. However, in Chapter 7, comparisons are made of

Table 2.11 Parameter estimates (standard errors in brackets) for the normal and 3-parameter log normal distributions for nett loadweights of truck/trailer combinations

Truck/ trailer	Theoretical Distribution	Parameter estimates			observed minimum
		μ	σ	ε	
P-	normal	23.995 (0.046)	1.830 (0.033)		11.70
S1-	log normal	2.362 (0.007)	0.182 (0.002)	12.913 (0.069)	8.68
S2-	log normal	2.598 (0.002)	0.130 (0.002)	10.082 (0.005)	15.42

All parameter estimates are significantly different from zero at the 0.05 probability level

Table 2.12 Mean and standard deviations of the normal and 3-parameter log normal distributions for nett loadweights of truck/trailer combinations

Truck/trailer	Distribution	Mean	S.D.
P-	normal	24.0	1.83
S1-	log normal	23.7	1.98
S2-	log normal	23.6	1.77

leasing and purchasing costs and so both methods are discussed here. Accounting procedures associated with purchasing equipment are more complicated than those associated with leasing.

2.4.2 Costs of Equipment

The total equipment costs may be subdivided into three parts:

1. Owning costs
2. Operating costs
3. Associated costs.

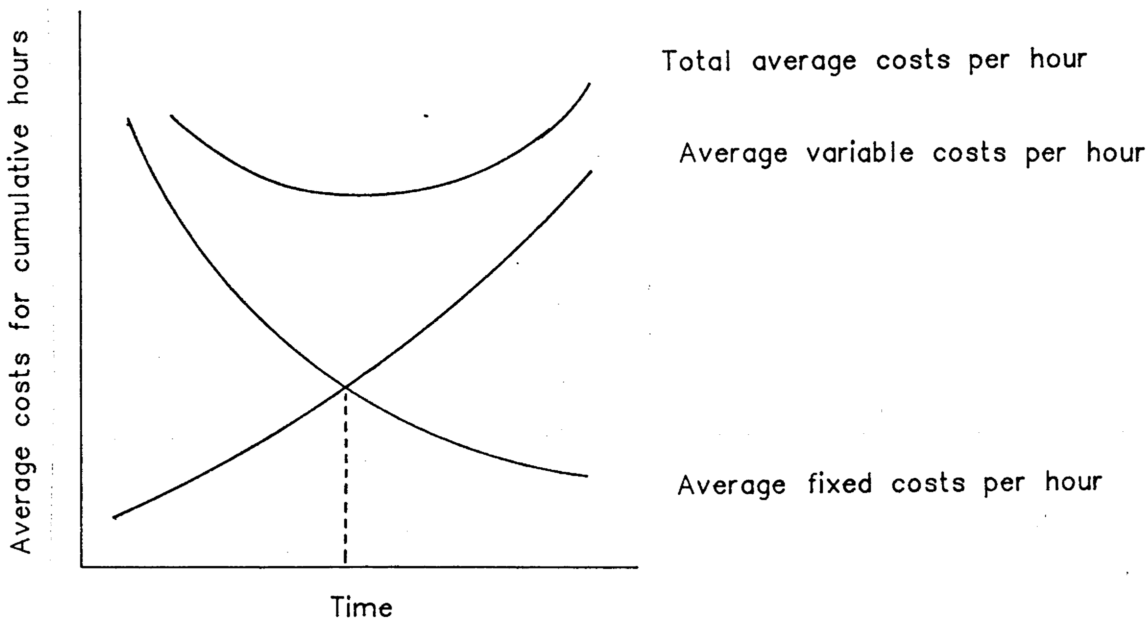
2.4.2.1 Owning costs

Owning costs are those costs incurred as a consequence of the decision to purchase equipment and by definition, occur irrespective of how long a machine is worked. The three components of owning costs are: depreciation, interest charges, insurance and registration.

Depreciation is the decline in the capital value of the machine with usage and obsolescence (De Vries 1973). The depreciation is thus the difference between the purchase price of the machine and its resale value at any time after purchase. Resale value depends on factors such as: the condition of the machine, kilometres travelled, age, machine specifications and technological improvements in new machines. Accounting for depreciation is one of the major problems in the costing of machines, for the appropriate period of depreciation is complicated by great variability in the use of equipment, difficulties in estimating future resale value and taxation regulations.

Ideally, machines should be replaced at the economic life of the machine as illustrated in Figure 2.7.

Figure 2.7 Economic life of a truck



Source: Adapted from De Vries (1973)

The minimum average total cost per cumulative hour coincides with the intersection of the variable cost and the fixed cost curves. As the machine becomes older and the hours of use increase, the average fixed costs per hour of use decrease. The average variable costs per hour of use increase with increasing costs of repair. Thus, the total average cost per hour of use of owning and operating a machine decreases from when it was bought to a minimum and then increases. De Vries (1973) suggests that the economic life of much of the equipment used in forestry is four to five years.

The costs must also cover the interest foregone on the money used to buy the machinery. The interest rate often adopted is that paid by low to medium risk investment packages. The interest charges are usually calculated on the average working capital, that is, half of the sum of the purchase price and resale value.

It is now common for contractors in the logging industry to lease machines from a finance company. The lessee maintains the machine and pays a monthly 'rental' to the lessor for the duration of the lease period. The rental is calculated by the finance company and is dependent on the prime cost of the equipment, the current interest rate charged by the finance company and the residual value.

For this study, leasing costs over four years for loaders and trucks in the ANM hauling operations were obtained from various leasing companies. The fixed costs of leasing are comparable to the owning costs of purchasing and include in addition to the leasing charges, the insurance and registration of the machine by the lessee or owner. The insurance premium insures the vehicle in case of accidents and is usually expressed as a percentage of the initial purchase price of the machine. Registration is compulsory in Australia for trucks and loaders and is dependent on the machine specifications. Registration and insurance costs were obtained from I. Macarthur (pers. comm.).

The assumptions and data used in the study for the determination of leasing and fixed costs are detailed in Table 2.13 and Appendix 3.1. The economic life for both trucks and loaders was taken as 4 years (after De Vries 1973), so leasing charges were calculated over 48 months.

Table 2.13 Summary of costs of trucks and loaders adopted for the simulation studies

Item	Truck		Loader	
	Fixed ($/day)	Variable ($/hour)	Fixed ($/day)	Variable ($/hour)
Leasing	129		140	
Insurance	18		16	
Registration	8		5	
Administration	18		18	
Tyres		5		0.1
Fuel		12		6
Oil		1		1
Repairs and M.		6		4
Total	173.13	25.11	178.70	11.79
Wages		8.00		8.00
Workers Comp		+15% of wages		+15% of wages

2.4.2.2 Operating costs

Operating costs are the costs of operating the machine, namely, purchasing tyres, fuel, oil and costs of repairs and maintenance. While often included in the purchase price of a vehicle, tyres are not treated as part of the fixed costs of a truck because they wear out much faster than the rest of the machine and are usually replaced before resale. Tyre life is dependent on the road surface and condition, with gravel roads increasing the costs per kilometre of tyres by a factor of three (De Vries op.cit.). Tyre life is also dependent on the condition and position of the tyre. Many truck owners use new tyres on the steer and drive axles, with recapped tyres for the trailer. The lives of truck tyres for calculating costs in this study were based upon unpublished and confidential reports and taken as 40 000 kms for truck steer and trailer tyres, 60 000 for truck drive tyres and 30 000 for loader tyres. Tyre costs were assumed to be $300 for new and $100 for recaps.

The fuel and oil consumption of a machine varies according to the machine specifications and the road conditions. In addition, driver characteristics can account for up to 10% change in fuel consumption for the same machine, over the same haul route and carrying similar loads (Ljubic 1982). Many references list fuel consumption for trucks, but these are usually theoretical and don't take into account the 'off-road' conditions that log trucks incur (De Vries 1973). The fuel and oil consumption of trucks for calculating costs in this study were based again on unpublished and confidential reports and taken as 50 litres/100 kms for trucks and 15 litres per hour for loaders. The cost of fuel adopted in this study was $0.43 per litre.

Reliable and accurate estimates of the costs of maintaining and repairing machinery are difficult to derive because good records of historical costs are not usually kept. Specific costs depend on the nature of the operations and the skill of the operator and mechanic. The usual method of expressing the maintenance and repair cost is as a percentage of the initial purchase price of the equipment. The following percentages, 50 and 30, were used for calculating costs for trucks and loaders respectively (Macarthur pers. comm.).

2.4.2.3 Associated costs.

Associated costs are those costs incurred by the owner or lessee in operating the machine but not directed to the machine, namely wages, workers compensation, insurance and administrative overheads.

In this study, wages of both truck drivers and loader operators were assumed to be $8 per hour with overtime at $12 per hour for the first two hours after an 8-hour day, and $16 per hour thereafter. Workers compensation is costed usually as a percentage of wages. The Australian Mutual Provident Insurance Society advised on the workers compensation insurance premium for truck drivers and loader operators. The percentage adopted for this study was 15%.

There are always administrative costs associated with commercial operations, for example, payment of clerical staff to pay salaries and accounts and keep records for taxation purposes. Advice was given that for every four employees, the equivalent of one extra staff person is required (Macarthur pers. comm). With a salary of $17 000 per year assumed, each truck and loader operator had administrative overheads of $4 250 per year.

CHAPTER 3

FREQUENCY AND DURATION OF LOG TRUCK BREAKDOWNS

3.1 INTRODUCTION

Information on the frequency and durations of breakdowns is required to evaluate the performance and operational availability of log trucks but there is little information in the literature.

Smith and Tse (1977) studied a fleet of trucks of three different bunk widths hauling timber over common haul routes in British Columbia. The effect of delays on the system were examined and they were able to differentiate between types of delays. Over one month, the mean time between repairs (MTBR) was 7.7 trips or approximately 2.6 days while the mean time to repair (MTTR) was 0.17 hours.

Baumgras (1978) studied four trucks belonging to two contractors in West Virginia for seven months. The trucks were of similar age, mechanical condition and load capacity. The effect of delays on log hauling was studied and delays were classified into eight categories of which breakdowns was one. Contractor A had a MTBR of 4.8 shifts while Contractor B had a MTBR of 9.1 shifts. The combined MTBR was 6.3 shifts. The MTTR for Contractor A was 1.5 hours and for Contractor B 4.3 hours. The combined MTTR was 2.6 hours. Baumgras was not able to explain the differences between the two contractors.

Garner (1978) studied for two months a large trucking fleet, hauling to a pulpmill in Nova Scotia. MTBR was 45 hours and MTTR 0.65 hours.

The studies showed a wide range of both frequencies and durations of breakdowns for log trucks, but it was not possible to compare the estimates of durations and frequencies of breakdowns in the above studies. The need for the systematic study of the frequency and duration of log truck breakdowns is apparent; for example, none of the studies mentioned the ages or distance travelled for any of the trucks.

There were no suitable truck fleets hauling logs in Australia with garage records for durations and frequency of breakdowns. New Zealand Forest Products Ltd. (NZFP) agreed to provide access to their records and the results of the study of durations and frequency of breakdowns of their log trucks is reported.

3.2 DATA COLLECTION AND ANALYSIS

The transport overseer at the Kinleith Mill had kept records of breakdowns of the trucks owned by New Zealand Forest Products Ltd. These records were the basis of the study.

Fourteen trucks were randomly selected and data on breakdowns extracted from the records. Data recorded on a daily basis for each truck over a ten month period included:

1. Date
2. Hours worked
3. Kilometres travelled

4. Hours the truck did not work, but was not broken down, e.g. when it was temporarily surplus to requirements
5. Duration of any breakdown
6. Cause of breakdown, if recorded.

Breakdowns had been recorded whenever the truck required attention in the workshop. However, the actual time at which a breakdown occurred was not recorded. For the purposes of the analysis, it was assumed that the hours recorded as worked on the day of the breakdown were prior to the breakdown. In practice, the breakdowns could have occurred before or within the hours worked.

In some cases, data for the hours worked and kilometres travelled for a particular day were missing from the NZFP records. For calculating the descriptive statistics and fitting of distributions, data on intervals between breakdowns with missing data were discarded from the analysis. Such data accounted for 2% of the total number of observations.

All of the selected trucks were of the same brand but not the same model. At the beginning of the data collection period, the ages of the trucks ranged from thirteen to just over seventy five months and the distances travelled from 79 000 to 508 000 kilometres.

3.3 DESCRIPTIVE STATISTICS OF FREQUENCY AND DURATIONS OF BREAKDOWNS

Descriptive statistics were calculated for the durations and times between breakdowns for each of the fourteen trucks. Age and distance travelled were the variables used to classify the data for calculation of the descriptive statistics.

The fourteen trucks were divided into two age classes, based on their date of purchase:

1. Average age 81 months and called 'old' trucks - nine trucks, purchased February or March 1973.
2. Average age 23 months and called 'young' trucks - five trucks, purchased November 1977 to April 1978.

The fourteen trucks were also divided into three classes based on distance travelled up to the midpoint of the data collection period:

1. Short distance travelled - five trucks with distances ranging from 109 000 to 131 000 kilometres. These trucks correspond with the 'young' trucks discussed above.
2. Medium distance travelled - three trucks with distances ranging from 370 000 to 412 000 kilometres.
3. Long distance travelled - six trucks with distances ranging from 483 000 to 542 000 kilometres.

Categories 2 and 3 were a further subdivision of the 'old' trucks.

3.3.1 Descriptive Statistics for Age Based Data

Descriptive statistics for the durations of breakdowns of trucks for the two age classes are presented in Table 3.1. The estimated population variances for the durations of breakdowns for the 'young' and 'old' trucks were found to be significantly different at the 0.05 probability level using the F-test. Therefore, these classes should be treated as separate populations. The mean duration of a breakdown increased from 9.7 to 13.0 hours with the increase in age. Although the minimum observed duration did not alter with increasing age, there was a marked increase in the maximum observed duration from 190 to 523 hours.

Table 3.1 Descriptive statistics for durations of breakdowns of two age classes of trucks

Age Class	Number of observations	Mean Hours	Standard deviation	Standard error	Kurtosis	Skewness	Minimum	Maximum
young	190	9.74	22.24	1.61	40.64	5.79	0.5	190.0
old	502	13.00	36.35	1.62	97.34	8.63	0.5	522.5

The variances of the intervals between breakdowns, by both time and distance, for the two age-classes were also significantly different at the 0.05 probability level; accordingly, the two classes should therefore be treated as separate populations (Table 3.2). The mean intervals between breakdowns for the two age classes were 112 and 64 hours and 1 733 and 1 006 kilometres respectively. Thus, intervals between breakdowns decreased with increasing age of the truck, that is, breakdowns became more frequent. The minimum observed interval between breakdowns by both time and distance decreased only slightly between classes, while the maximum observed interval between breakdowns decreased markedly from 958 to 369 hours and 16 184 to 6 650 kilometres.

3.3.2 Descriptive Statistics for Distance Based Data

Descriptive statistics for the duration of breakdowns for the three distance classes are presented in Table 3.3. The variances between each of the distance classes for the durations of breakdowns were significantly different at the 0.05 probability level. The classes must therefore be treated as separate populations in fitting probability density functions. The mean duration of breakdowns increased from 9.7 to 12.2 to 13.3 hours over the three distance classes. The maximum observed duration increased only slightly from the short to the medium distance class, but markedly increased to 523 hours for the long distance class.

The variances for the intervals between breakdowns for the three distance classes were also significantly different at the 0.05 probability level (Table 3.4). The mean interval between breakdowns for the three classes decreased from 112 to 77 to 59 hours and 1 733 to

Table 3.2 Descriptive statistics for intervals between breakdowns of two age classes of trucks

	Age Class	Number of observations	Mean hours	Standard deviation	Standard error	Kurtosis	Skewness	Minimum	Maximum
Intervals (hours)	young	187	111.65	111.15	8.49	15.05	2.90	3.5	957.5
	old	488	64.04	63.06	2.86	4.19	1.92	2.5	368.5
Intervals (kms)	young	167	1732.8	1912.73	148.01	19.66	3.37	44.0	16184
	old	453	1005.83	976.46	45.88	5.25	1.99	28.0	6650

Table 3.3 Descriptive statistics for durations of breakdowns of three classes of distance travelled by trucks

Distance Class	Number of observation	Mean hours	Standard deviation	Standard error	Kurtosis	Skewness	Minimum hours	Maximum hours
Short	190	9.74	22.24	1.61	40.64	5.79	0.5	190.0
Medium	137	12.23	27.86	2.38	21.11	4.40	0.5	192.0
Long	365	13.29	39.09	2.05	98.20	8.97	0.5	522.5

Table 3.4 Descriptive statistics for intervals between breakdowns of three classes of distance travelled by trucks

	Distance Class	Number of observations	Mean hours	Standard deviation	Standard error	Kurtosis	Skewness	Minimum	Maximum
Intervals (hours)	Short	187	111.65	116.15	8.49	15.05	2.90	3.50	957.50
	Medium	134	76.74	71.53	6.18	2.67	1.61	2.50	368.50
	Long	354	59.23	58.94	3.13	5.06	2.07	3.00	336.50
Intervals (kms)	Short	167	1732.8	1912.73	148.01	19.66	3.37	44.0	16184.0
	Medium	122	1250.13	1149.84	104.10	3.88	1.70	36.0	6650.0
	Long	331	915.78	889.37	48.88	5.62	2.07	28.00	5310.0

1 250 to 916 kilometres as the distance travelled increased. Although the minimum observed time between breakdowns decreased slightly over increasing time and distance, the maximum decreased from 958 to 337 and 16 184 to 5 310 kilometres.

3.4 FITTING PROBABILITY DENSITY FUNCTIONS FOR INTERVALS BETWEEN AND DURATIONS OF BREAKDOWNS

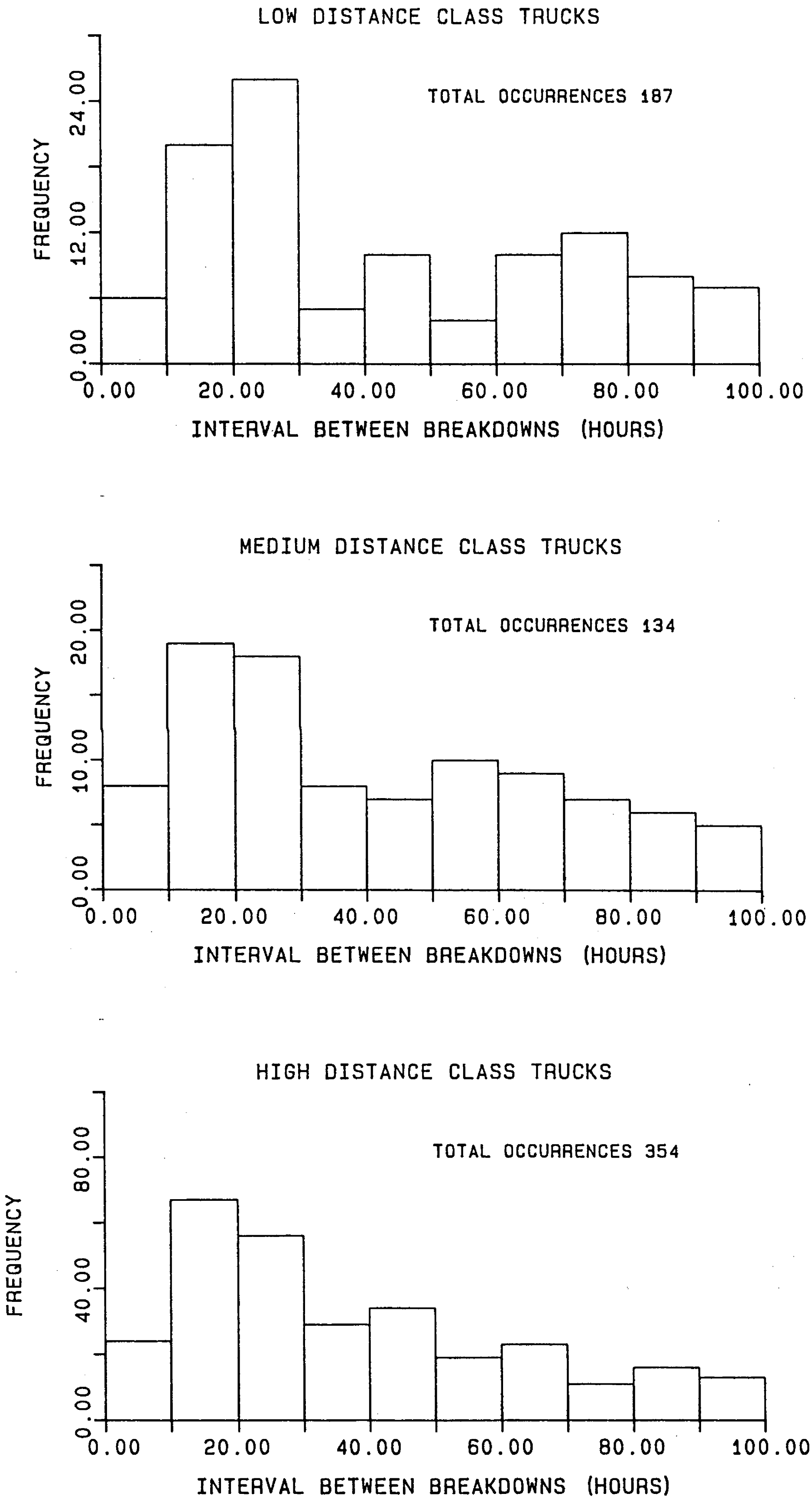
The more detailed classification of trucks by distance travelled was used in fitting separate probability density functions to the data in each class. Distance travelled is a more accurate indication of the amount of work done by a truck than is age since purchase.

Of the many possibilities, six probability density functions were chosen for testing of the data in this study: the normal, the log normal, the 3-parameter log normal, the Weibull, the gamma and the beta functions. The functions are defined in Appendix 2.2 and cover a wide range of potential shapes and characteristics.

3.4.1 Distributions for the Intervals Between Breakdowns (hours)

Data were grouped to achieve more than five observations in each class interval to satisfy the requirements of the Chi-square test. Histograms were plotted of the grouped data for the three distance classes (Figure 3.1) and some resemblance to positively skewed distributions was evident. Any of the five skewed distributions therefore seemed appropriate for matching to the data but all six distributions were fitted by maximum likelihood.

Figure 3.1 Histograms of the intervals between breakdowns (grouped data) for short, medium and long classes of distance travelled by trucks



The results of the goodness of fit tests for the fitted distributions are shown in Table 3.5. Using the Chi-square and Kolmogorov-Smirnov tests to assess the goodness of fit, the observed data distributions for the three distance classes were significantly different from the fitted normal distributions which were therefore rejected as appropriate distributions. Using the Chi-square test, the fitted Weibull and gamma distributions were significantly different from the observed data distribution for the long distance class at the 0.05 probability level. Due to the conflicting evidence between the Chi-square test and the Kolmogorov-Smirnov test for these distributions in the long distance class, they were rejected as unsuitable. That is, the tests indicated that any of the two log normal and beta distributions best represented the intervals between breakdowns.

The parameter estimates and their standard errors for both log normal distributions and for the beta distribution are given in Table 3.6. For the beta distribution, two of the three parameters for the medium distance class of trucks were not significantly different from zero. The estimates of the epsilon ( )parameter of the 3-parameter log normal distribution were not significantly different from zero for all three distance classes. Since estimates of both parameters of the 2-parameter log normal distribution were significantly different from zero, this distribution was accepted as best characterizing the intervals between breakdowns (hours).

3.4.2 Distributions for the Durations of Breakdowns

Histograms were plotted for the three distance classes (Figure 3.2) and indicated a positively skewed distribution. Five distributions

Table 3.5 Goodness of fit statistics for intervals between breakdowns of three classes of distance travelled by trucks

	Distance Travelled by Class														
	Short					Medium					Long				
Distribution	C-X^2	df	T-X^2	C-KS	T-KS	C-X^2	df	T-X^2	C-KS	T-KS	C-X^2	df	T-X^2	C-KS	T-KS
Normal	101.4*	9	16.92	0.119*		74.13*	11	19.68	0.121*		257.8*	13	22.36	0.145*	
log normal[A]	13.67	9	16.92	0.053		9.50	11	19.68	0.049		17.05	13	22.36	0.031	
log normal[B]	12.87	8	15.51	0.039	0.099	9.12	10	18.31	0.039	0.117	17.05	12	21.03	0.031	0.072
Weibull	13.48	9	16.92	0.039		11.74	11	19.68	0.047		42.33*	13	22.36	0.058	
gamma	12.45	9	16.92	0.044		10.84	11	19.68	0.054		36.11*	13	22.36	0.066	
beta	11.13	8	15.51	0.039		8.75	10	18.31	0.048		20.05	12	21.03	0.034	

* Significantly different at the 0.05 probability level
A 2-parameter log normal
B 3-parameter log normal
C-X^2 calculated Chi-square value

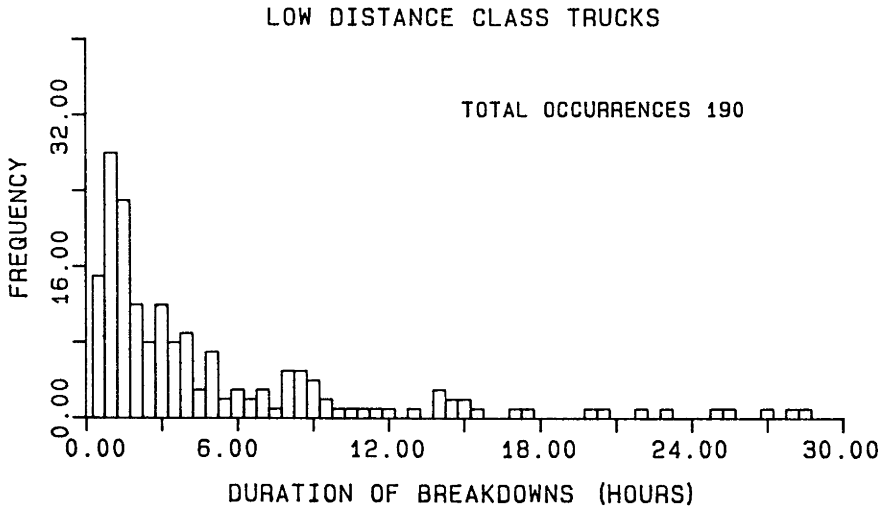
df degrees of freedom
T-X^2 Tabulated Chi-square value
C-KS Calculated Kolmogorov-Smirnov value
T-KS Tabulated Kolmogorov-Smirnov value

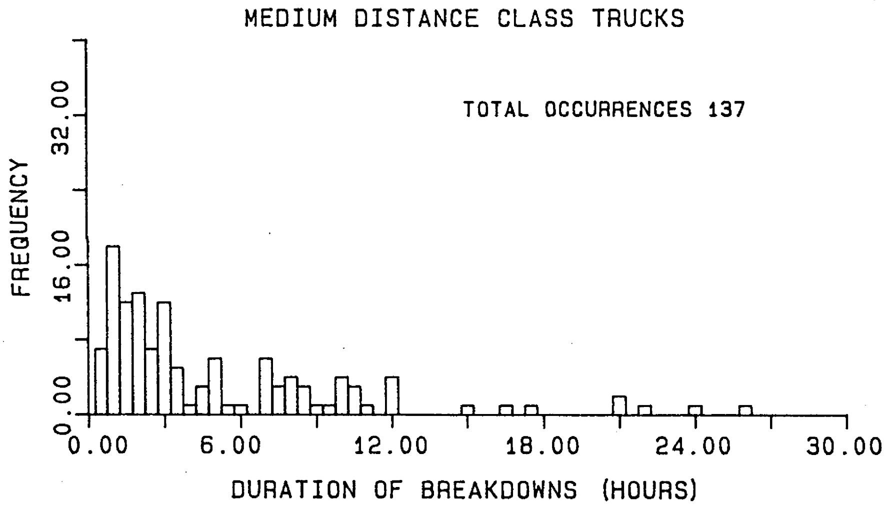
Table 3.6 Parameter estimates (standard errors in brackets) of three distributions of the intervals between breakdowns for three classes of distance travelled by trucks

Distribution	Parameter	Distance Travelled		
		Short	Medium	Long
log normal (2-parameter)	mu	4.274* (0.078)	3.920* (0.090)	3.660* (0.051)
	sigma	1.057* (0.060)	1.025* (0.069)	0.961* (0.038)
log normal (3-parameter)	mu	4.363* (0.128)	4.002* (0.163)	3.662* (0.076)
	sigma	0.967* (0.115)	0.950* (0.137)	0.959* (0.064)
	epsilon	-4.325 (5.632)	-2.972 (5.405)	-0.040 (1.447)
beta	p	1.432* (0.164)	1.561* (0.331)	2.326* (0.445)
	q	5.956* (1.831)	4.504 (2.600)	2.845* (0.689)
	b	0.003* (0.001)	0.006 (0.005)	0.020* (0.010)

* Significantly different from zero at the 0.05 probability level

Figure 3.2 Histograms for the durations of breakdowns for short, medium and long classes of distance travelled by trucks





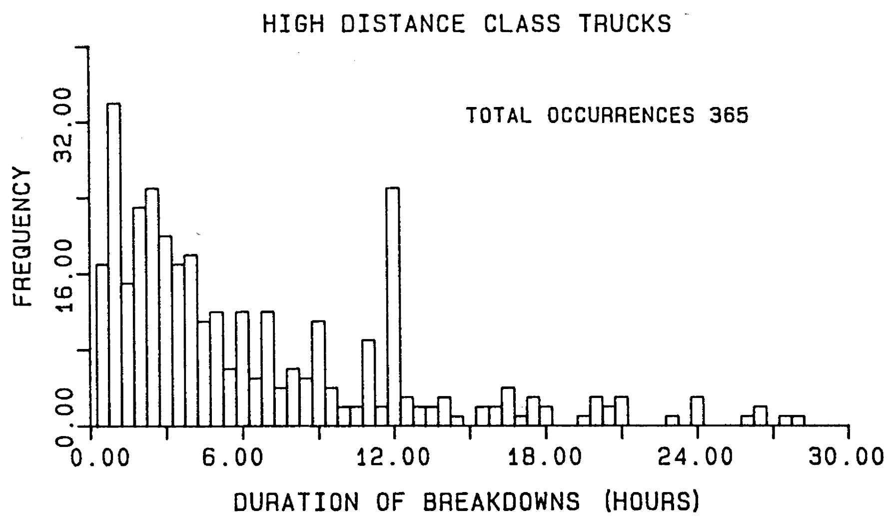


Table 3.7 Goodness of fit statistics for durations of breakdowns for three classes of distance travelled by trucks

	Distance Travelled by Class														
	Short					Medium					Long				
Distribution	$C\text{-}X^2$	df	$T\text{-}X^2$	C-KS	T-KS	$C\text{-}X^2$	df	$T\text{-}X^2$	C-KS	T-KS	$C\text{-}X^2$	df	$T\text{-}X^2$	C-KS	T-KS
log normal[A]	27.14*	13	22.36	0.056		26.85*	11	19.68	0.088		30.10*	16	26.30	0.030	
log normal[B]	6.09	12	21.03	0.017		8.81	10	18.31	0.031		23.64	15	25.00	0.032	
Weibull	69.20*	13	22.36	0.123*	0.099	61.44	11	19.68	0.127*	0.116	92.77*	16	26.30	0.083*	0.071
gamma	82.87*	13	22.36	0.126*		70.66*	11	19.68	0.141*		100.50*	16	26.30	0.080*	
beta	+					+					23.82	15	25.00	0.031	

* Significantly different at the 0.05 probability level
A 2-parameter log normal
B 3-parameter log normal
$C\text{-}X^2$ calculated Chi-square value

df degrees of freedom
$T\text{-}X^2$ Tabulated Chi-square value
C-KS Calculated Kolmogorov-Smirnov value
T-KS Tabulated Kolmogorov-Smirnov value

were fitted by maximum likelihood and the results of the goodness of fit tests for the fitted distributions are given in Table 3.7. The Chi-square and Kolmogorov-Smirnov tests were used to assess the goodness of fit. The fitted Weibull and gamma distributions are significantly different from the observed data distributions and these distributions were therefore rejected. Although the beta distribution was satisfactory for the long distance classes, it did not fit satisfactorily the short and medium distance classes. The two parameter log normal distribution showed conflicting results for goodness of fit to the observed data. The 3-parameter log normal was the only distribution to adequately characterize the durations of breakdowns for all classes of trucks.

The 3-parameter log normal distribution estimates and their standard errors are presented in Table 3.8. All three parameters are

Table 3.8 Parameter estimates (standard errors in brackets) of the 3-parameter log normal distribution for the durations of breakdowns for three classes of distance travelled by trucks

	Distance Travelled		
Parameter	Short	Medium	Long
mu	0.935 (0.146)	1.109 (0.162)	1.541 (0.087)
sigma	1.664 (0.134)	1.660 (0.151)	1.285 (0.080)
epsilon	0.757 (0.082)	0.799 (0.086)	0.451 (0.136)

All parameter estimates are significantly different from zero at the 0.05 probability level significantly different to zero for all three distance classes. Both mu and to a lesser extent sigma, have a trend. Mu increases as the distance travelled increases while sigma decreases. Epsilon on the other hand appears to have no trend. It was not possible to obtain a reliable estimate of the parameter trends over the distance classes.

3.5 TIME DEPENDENCE OF THE INTERVALS BETWEEN BREAKDOWNS (HOURS)

The descriptive statistics and distribution fitting clearly show differences between the classes of trucks based on age and kilometres travelled. Thus the data for the intervals between breakdowns may indicate a time-dependent process in the performance of the log trucks.

Time-dependent processes describe events with a tendency for successive intervals between failures to become either smaller or larger (Ascher and Feingold 1978). As such, the intervals between successive failures are not independent samples from any single distribution.

If no trend is apparent, then the intervals between successive failures for each truck can be assumed to be from the same distribution. While the intervals may not necessarily be independent, Ascher and Feingold (op.cit.) suggest that it is more usual for the intervals that are not time-dependent to be independent. Processes in which the intervals between failures are both identically distributed and independent are known as renewal processes and the machine is returned to a state regarded 'as new' after each failure. The most common renewal process is the Poisson process, that is, the intervals between failures are independently exponentially distributed (Cox and Miller 1968).

3.5.1 Testing for Time Dependence

If, in the fitting of distributions reported previously, there were missing data for either hours worked or kilometres travelled between breakdowns, then the data for the interval between two breakdowns were discarded. However, this is not permissible for time-dependent analyses since the time series would be broken.

Noting that breakdowns were not missing, two methods were used to generate approximate hours worked between the breakdowns when the actual hours were not recorded. Firstly, regression analysis was used to find a correlation between the hours worked and the kilometres travelled between breakdowns for all trucks. The hours worked could then be estimated from the number of kilometres travelled. Sometimes, information was missing for both the hours worked and kilometres travelled. In these cases, the hours worked daily about the missing data were examined for the particular truck and a determination made for the hours worked, usually 12 or 24 hours.

In the regression analysis to find the correlation between the hours worked and kilometres travelled between breakdowns, all the data for the fourteen trucks was pooled. The following relationship was found by the regression analysis:

$$\text{Hours} = \underset{(0.078)}{1.167} + \underset{(0.0)}{0.057} \times \text{kms} \qquad R^2 = 0.966$$

The above equation was used to generate hours worked between breakdowns for 12 cases. Another five missing values for hours worked were determined from the raw data.

The analysis of time trends for individual trucks followed Cox and Lewis (1966) and Ascher and Feingold (1978). The possibility of a time-dependent process was studied graphically by plotting the cumulative number of breakdowns against the cumulative operating time of each truck (Figure 3.3). There is no obvious evidence from the graphs of the intervals between breakdowns being a time-dependent process, that is, each graph appears to be linear.

Following Ascher and Feingold (*op.cit.*), data were tested for both serial correlation and ranked serial correlation. The estimate of the serial correlation coefficient ($\tilde{\rho}$) was calculated (Cox and Lewis 1966) and used in the following test against the upper 1/2 point of the unit normal distribution:

$$\left| \rho_1 \sqrt{(n-1)} \right| > c_{1/2\alpha}$$

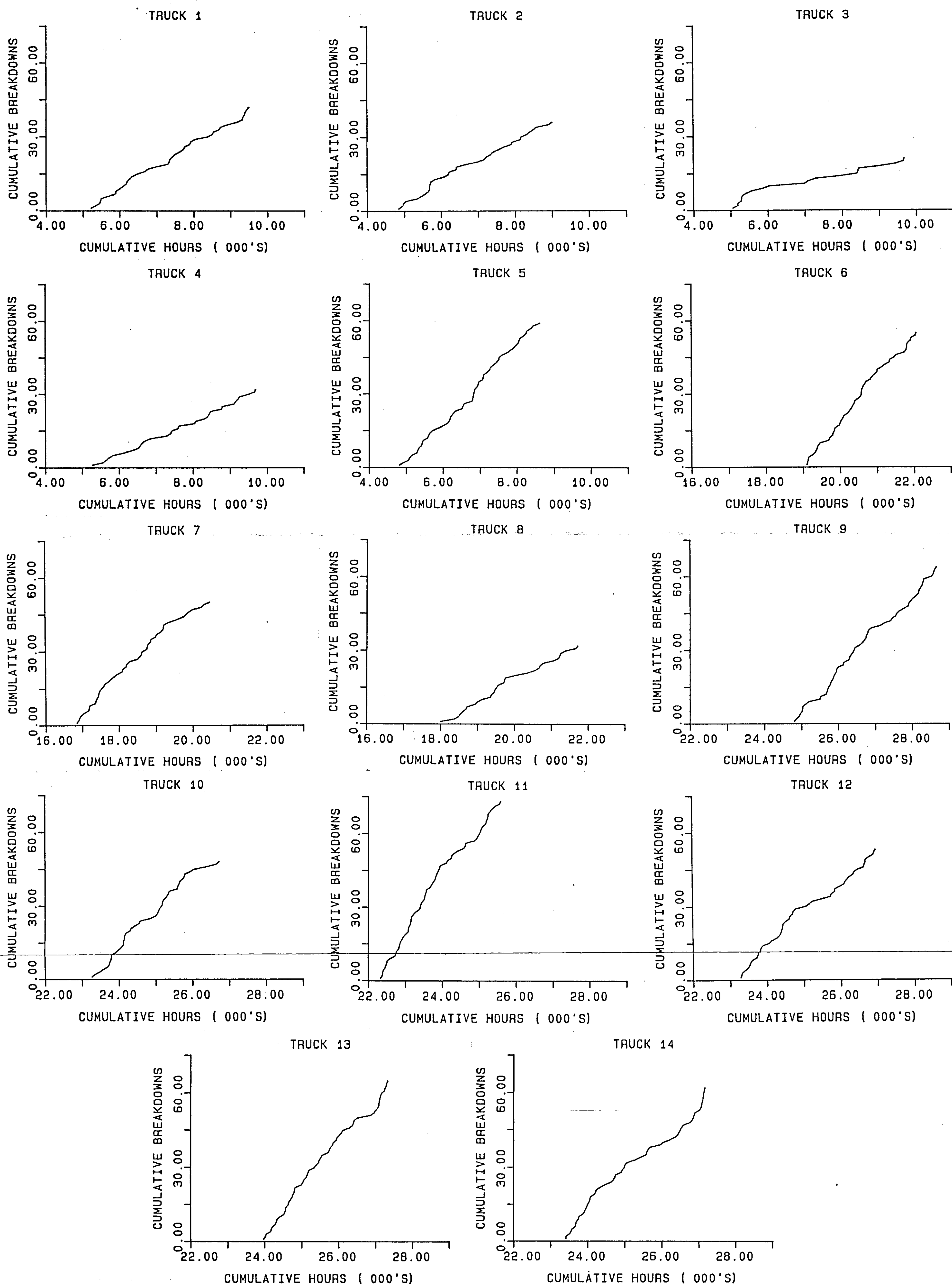
(Cox and Lewis *op.cit.*)

The null hypothesis was that $\tilde{\rho}_1 = 0$, that is, the events are independent.

The ranked serial correlation was also calculated, by replacing the events by the ranks and the above statistic again calculated.

The statistics for serial and ranked serial correlation are given for each truck in Table 3.9. One truck had significant serial correlation at the 0.05 probability level, indicating the dependence of

Figure 3.3 Cumulative number of breakdowns against the cumulative number of hours worked for each truck



an event on the previous event for only that truck. This single significant result could of course be a consequence of a Type I error, that is, a false rejection of the null hypothesis. The bulk of the evidence supports a conclusion that there is no reason to reject the null hypothesis. It could be assumed therefore that the intervals between breakdowns behave as a renewal process, that is, the trucks were repaired to a theoretically 'as new' state after each breakdown.

Table 3.9 Serial and ranked serial coefficients for the intervals between breakdowns for each truck

Truck	Standard normal variate	Ranked standard normal variate
1	1.063	1.565
2	0.040	0.706
3	0.431	0.887
4	1.300	0.683
5	0.332	0.888
6	1.228	1.593
7	0.409	0.251
8	0.367	0.178
9	0.004	0.995
10	2.104	0.274
11	0.638	1.657
12	1.037	0.003
13	0.855	0.711
14	1.880	2.567*

* Significantly different to upper 0.5 point of unit normal distribution at 0.05 probability level (Cox and Lewis 1966)

3.6 REVIEW

For the fourteen trucks sampled, the durations of breakdowns increased from 9.7 to 13.3 hours as kilometres travelled increased. The intervals between breakdowns decreased from 112 to 59 hours as kilometres increased, i.e. breakdowns became more frequent. This result supports the general trend in the failure of industrial equipment.

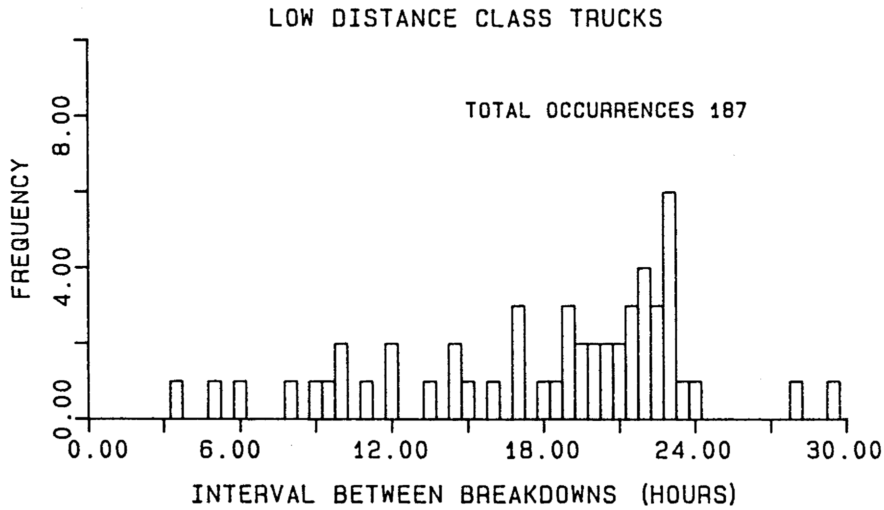
Data on the intervals between breakdowns showed marked peaks at certain periods (Figure 3.4). For the short distance travelled class, there was a peak at 23.0 hours, for the medium distance class peaks occurred at 12.0 and 22.5 hours, and for the long distance class at 12.0 hours. The majority of trucks worked two twelve hour shifts per day. When trucks work one shift per day, it is for twelve hours. The results suggest that drivers continue to use trucks with minor faults until either the end of shift or the end of day and then take the truck in for repairs.

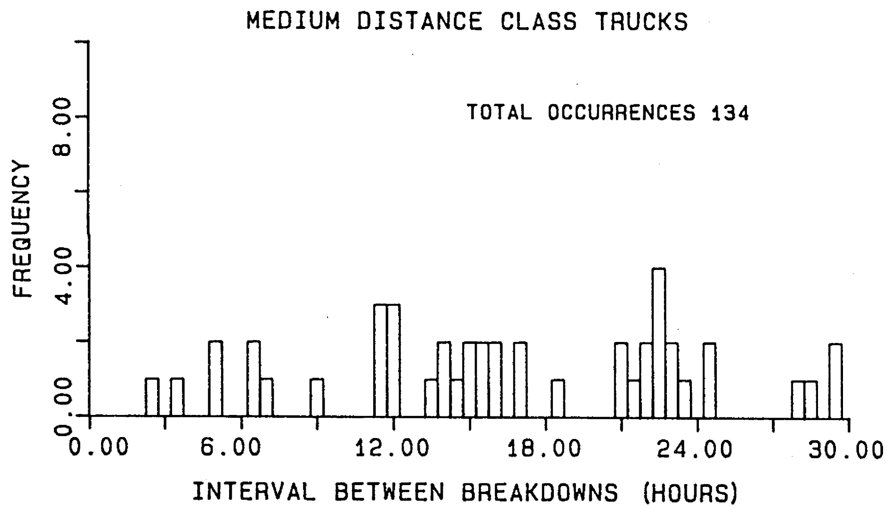
Durations of breakdowns (Figure 3.2) in the long distance travelled class exhibited a marked peak at the 12.0 hour period. There were spare trucks available to replace trucks in the workshop and the data suggests that the repairs are scheduled to make the truck available for the next shift. The shift time would therefore be important in determining the time between breakdowns and it should be noted that this study was associated with a twelve hour shift operation.

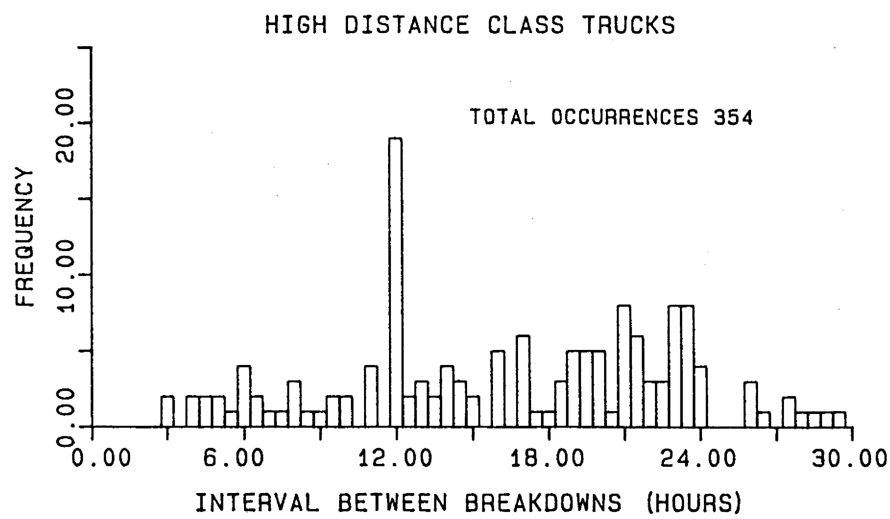
A log normal 2-parameter distribution provided the best fit for the intervals between breakdowns, while the durations of breakdowns were best characterized by a 3-parameter log normal distribution. These distributions are recommended for the modelling of the frequency and duration of log truck breakdowns in a stochastic simulation model.

Both the descriptive statistics and the fitting of distributions suggested the presence of a time-dependent process between the classes of trucks. However, analysis of the data on individual trucks following the procedure of Ascher and Feingold (1978), showed no suggestion of a time-dependent process in the intervals between breakdowns nor, except

Figure 3.4 Histograms for the intervals between breakdowns for short, medium and long classes of distance travelled by trucks







for one truck, of the intervals between breakdowns being serially correlated. It is inferred from this analysis that the intervals between breakdowns are representative of a renewal process in which the truck returns to an 'as new' condition after every repair. However, the time-dependent process may not have been observed in the data for individual trucks due to the short collection period.

Thus, the results of the analysis of the data in terms of a time-dependent process conflict with the evidence from the descriptive statistics and the fitting of distributions, for these point to a time-dependent process. Also, in Figure 3.3, the slopes of the lines of the short distance class trucks are less steep than the long distance class trucks and this is evidence of a time-dependent process over the lifetimes of trucks.

Both the descriptive statistics and trends in the parameters of the distributions were based on trucks in groups differing widely in ages and kilometres travelled. Thus, broad differences in each class are likely and this could affect the analysis. Another explanation for the different slopes of lines between short and long distance class trucks would be technological advances in the truck manufacture and resulting performance. The two age groups of the fourteen trucks were nearly five years apart and advances to improve the reliability of the trucks would be expected during that period.

The conflicting evidence from the analyses suggests that analysis of truck breakdowns for the determination of a renewal process may require data on the breakdown of components of trucks. The New Zealand Forest Products Ltd. data did not always specify the cause of the machine failure or the component that failed and this approach was not feasible. Future analyses on the breakdown of log trucks could examine the reliability of components rather than an aggregation of components. In addition, it is very desirable that data for analysis of a renewal process in log trucks be far longer than ten months.

The results obtained from the analysis of the data are applicable to stochastic simulation of the availability of the New Zealand Forest Products truck fleet. For example, as each truck commences work in a simulation run, the interval to a breakdown could be predicted by random selection from the probability density function. When the truck accumulates hours of operation in the simulation equal to the selected interval to the breakdown, the breakdown would be simulated in the model. The duration of the breakdown would then be predicted by again randomly selecting from a probability density function.

It must be emphasized that the data presented and the results of the analysis are specific to the New Zealand Forest Products Ltd. operation at the Kinleith mill. However, there are no published data on frequency and duration models of log truck breakdowns and in that context, the results of this study provide a quantitative guide for the simulation of breakdowns in the simulation of log hauling operations.

CHAPTER 4

THE SIMULATION MODEL

4.1 INTRODUCTION

There is no well defined theory of simulation which would provide guidelines for organising the data and model formulation (Emshoff and Sisson 1970). Nevertheless, the steps outlined in Chapter 1 can assist in defining aspects of a computer model which would enable manipulation of a conceptual model identifying the variables, parameters and interrelationships of a system.

Flow diagrams or charts are helpful in developing a computer simulation model from the conceptual model. They show the sequence of movement of items or information through the processes or activities in the conceptual model. At a macro level, the charts can show the complete simulation model and at a micro level, represent every step in one activity or process within the model. They have the advantage that the modeller may show them to those familiar with the real system and receive criticism of the assumptions and hypotheses of the abstract model, before any computing is accomplished.

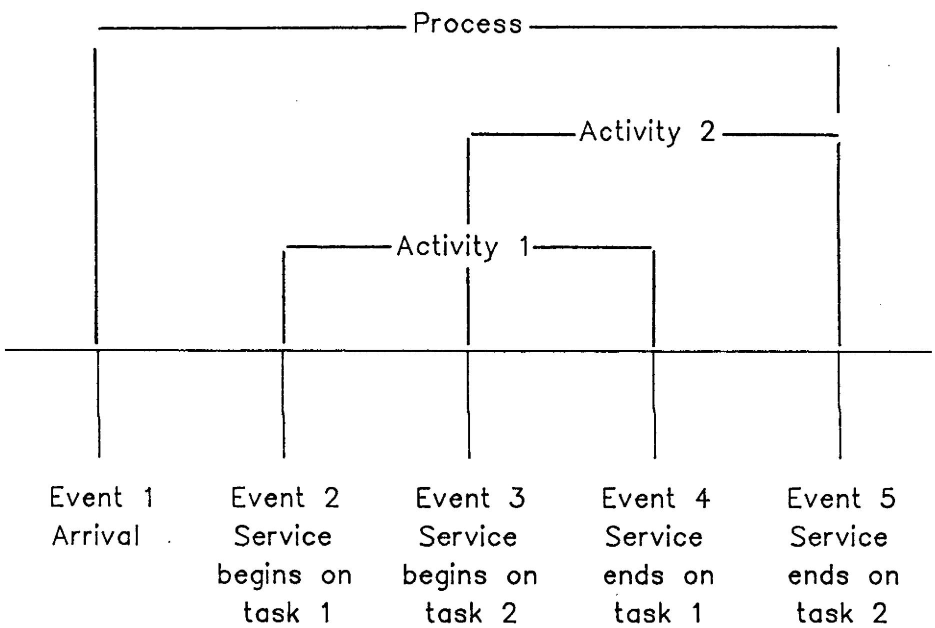
A flowchart also assists in identifying subsystems within the system modelled. The advantages of dividing a system into subsystems is that they are usually less complex and more amenable to description by mathematical relationships.

The formulation of flow charts and sub systems also determines the modelling techniques for time-advance within discrete simulation models. There are two methods for advancing time: by unit and by event. In the former, time is advanced unit by unit throughout the simulation run, with the unit of time as small or as large as the modeller wishes. In event-time advance, time is advanced in variable steps with the step being the time to the occurrence of the next scheduled event. Many studies have considered which is the more appropriate technique to use when systems have both periodic and random occurring elements (Conway et al 1959, Gafarian and Ancker 1966 and Nance 1971). Conway et al (op.cit.) suggest that as the mean time between events becomes larger, the event-time technique becomes more advantageous, but that there are no basic rules.

Sequences of events in discrete simulation models can be characterised as to whether they are oriented by event, process or activity. Events are points where a change in a system entity occurs; a process is a chronologically ordered sequence of events; and an activity is a collection of events or operations that change the state of an entity (Fishman 1973). The relationships between the concepts are presented in Figure 4.1.

In event-oriented simulation, an event occurs when there is a change in the status of an entity. In a simple job queuing problem, changes in the status of an entity (or job) occur when the job arrives, when it begins, when tasks are finished and when the job departs. In the activity-oriented approach, time is advanced to the next event when each job passes through the system and the activities of each job must be scanned to determine whether a current event is the beginning or the completion of a job. In process-oriented simulation, the progress of an entity is followed through the system from its arrival to its departure (Fishman 1973).

Figure 4.1 The relationship between the event, process and activity oriented mechanisms for scheduling the next event.



Source: Fishman (1973)

The conceptual model described in Chapter 1 specifies the basic nature of the proposed simulation model which is discrete and stochastic and the state-change approach was adopted to assist in identifying the variables, parameters and logical relationships that exist in the system. This also assisted in identifying the type of time-advance suitable for the proposed model.

The state-change approach showed that the states of the entities of the system, such as trucks and loaders, only changed at discrete points in time and that the state was constant between these events. Therefore, the next-event approach in time-advance mechanisms could be used to advance time within the simulation model. That is, the model skips over the time a truck spends travelling from the landing to the mill for the state of the truck does not change during this time. The next-event time-advance mechanism is also appropriate if scheduling of trucks by a 'despatcher' at the mill is necessary.

4.2 CHOICE OF LANGUAGE

The choice of computer language is a critical aspect of model formulation. The choice is based on many factors including the sophistication of the computer available, the amount of time for model construction and verification and the application of the model (Lientz 1975). Kreutzer (1983) describes four levels of modelling languages. The lower level includes the general programming languages such as FORTRAN and PASCAL; the middle levels include the simulation-oriented languages such as SIMULA and GASP; and the higher level includes the specialized simulation packages such as DRAFTS and SIMWAP. Kreutzer (op.cit.) states that raising the level of a language increases the simplicity of programming, the ease of learning and the speed of model development and reduces error rates. However, higher level languages decrease the flexibility of the model.

The rapid growth in simulation modelling has resulted in the development of many simulation-oriented languages at Kreutzer's middle levels, such as SIMULA, Simscript and GPSS. These languages offer ease of modelling and reduced programming effort while utilizing capabilities such as time-advance, structured data organisation, ease of statistical compilation, ease of reporting results and random number generation. Their use assists a modeller by providing 'building blocks' which correspond to subsystems within the real world system (Thesen 1978). Adam and Dogramaci (1979) suggest one of the most important advantages of using a simulation language is the reduction in time required for verification since they often provide for interactive compilation and provide exhaustive error diagnostics. Although the number of simulation oriented languages is large, each language has features that make it suitable for only a few classes of simulation problems.

Since the conceptual model specified a discrete event model, only those languages that are suitable for this approach are discussed here. GASP and Simscript use the event-oriented scheduling approach. The former is not a formal language itself, but comprises FORTRAN subroutines especially written for discrete simulation. Simscript, although developed in the 1960s, has been continually updated and now represents one of the most advanced of the simulation languages. GPSS and SIMULA are appropriate for process oriented approaches. The former is problem related although it still allows a wide range of situations to be modelled. Usually, they are used to model a system in terms of predefined blocks which perform specific functions (Phillips et al 1976). SIMULA is an ALGOL based language which describes and generates processes that can conceptually operate in parallel (Dahl and Nygaard 1966 and Fishman 1973). Activity oriented approaches can be modelled with CSL which stops and starts a process rather than concentrating on the flow of items through a process (Emshoff and Sisson 1970).

Two simulation oriented languages that use the next-event time-advance mechanism were available on the Univac 1100/82 at the Australian National University computer facility: GASP and Simscript II. The latter was chosen because it is a formal simulation language.

The simulation mechanism of Simscript II is defined in terms of entities, resources, attributes and sets. The components of the system are the entities and resources; the properties and characteristics of the entities and resources are the attributes; and a group or groups of entities are called sets. In the conceptual model, trucks can be distinguished as entities, attributes are for example, the loadweight of a truck. Sets are collections of entities and in the conceptual model, the truck queue at the landing is a set. Resources are components within the system which can be requested and relinquished by entities. Thus, in the conceptual model, the loaders and the weighbridge are resources which can be requested by the trucks. In Simscript, the system changes when an entity or resource is created or destroyed, when attribute values of entities or resources are changed or when entities arrive or depart from sets (Adam and Dogramaci 1979).

4.3 THE CORE MODEL AND ITS ANCILLARY ROUTINES

4.3.1 The Core Model

Constraints are placed on users of the Univac 1100/82 computing facilities at the Australian National University in respect of time to run programmes and storage available. While some of the constraints may be eased for special purposes, it soon became clear that there would be difficulties in running a large generalised model. A core model was therefore developed for manipulation by ancillary programmes for particular tasks, for example, verification and validation of the model, experimentation with system changes and costing of wood haulage. The core model was essentially the routines that transposed the trucks from the mill to the loader at a landing and then back to the mill and calculated travel time on a stochastic basis.

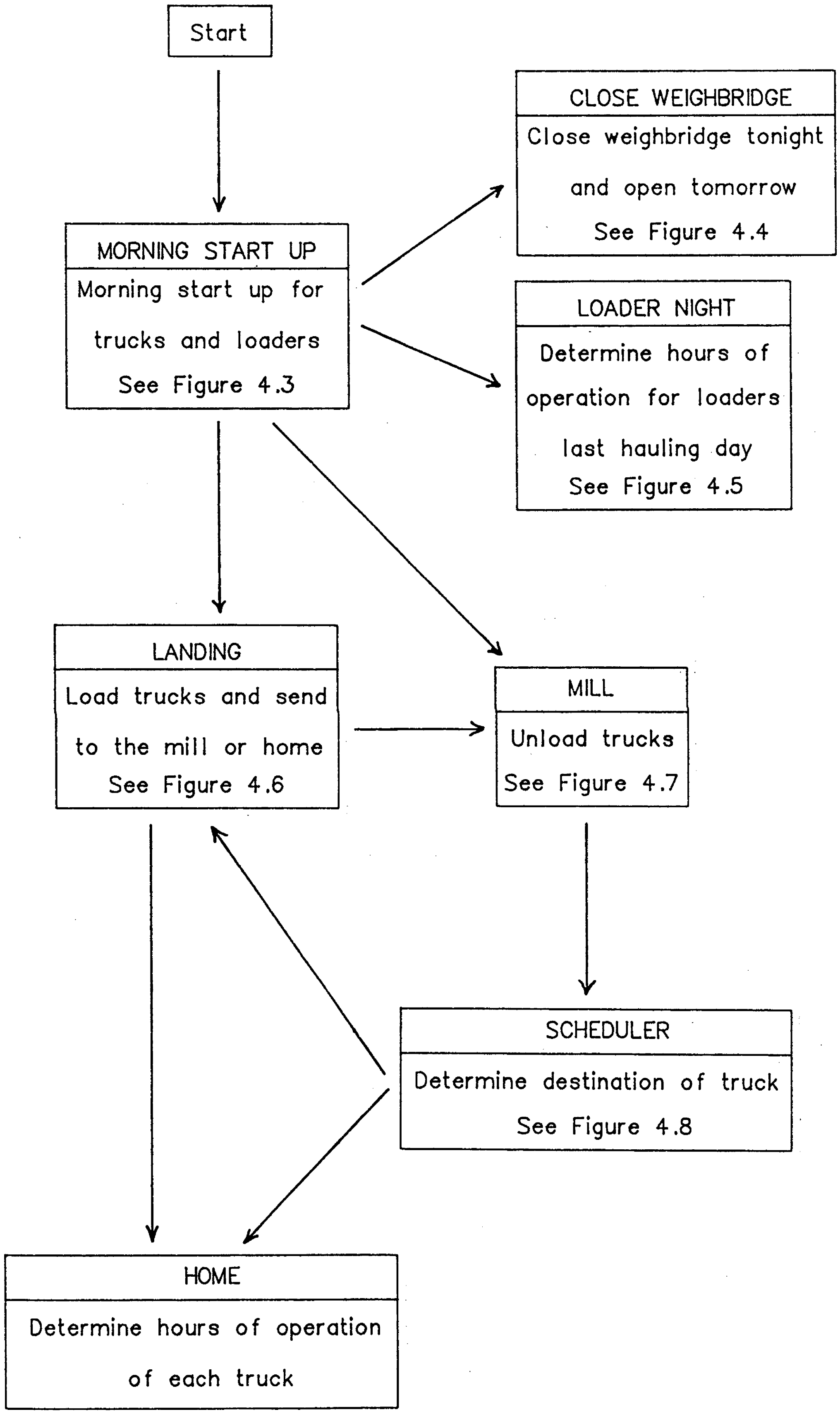
The state-change approach was used to construct a flow diagram (Figure 4.2) of the core model from the conceptual model detailed in Chapter 1. A general description of the core model follows.

The model routines first determine for the morning of every haul day of the week, the number of trucks and loaders working on each day and allocate them to a loader and forest respectively. Trucks are sent either to the landing if they were empty overnight or to the mill if they were loaded overnight. The weighbridge is scheduled to close later that day and reopen the next haul day. The operating hours of each loader and truck are calculated for the previous hauling day.

When a truck arrives at the landing, it waits until the loader is available, spends time getting loaded and travels to the mill. At any time, if the truck cannot get back to the mill, it goes 'home'. 'Home' represents the time that the truck stops work, rather than the physical home of the driver.

Once the truck arrives at the mill, it is weighed, unloaded in the mill and reweighed on return to the weighbridge. If a truck arrives at the weighbridge when the mill is not open, it goes 'home' to return to the mill at a suitable time.

Figure 4.2 Flowchart of the core model components



When a truck is ready to depart the mill, the model determines if it is possible to get another load. If it is, the truck returns to the landing, if it is not, it goes 'home'.

The entire core model can be envisaged as a number of subsystems each modelling various aspects of the ANM system. The following subsystems are examined in detail:

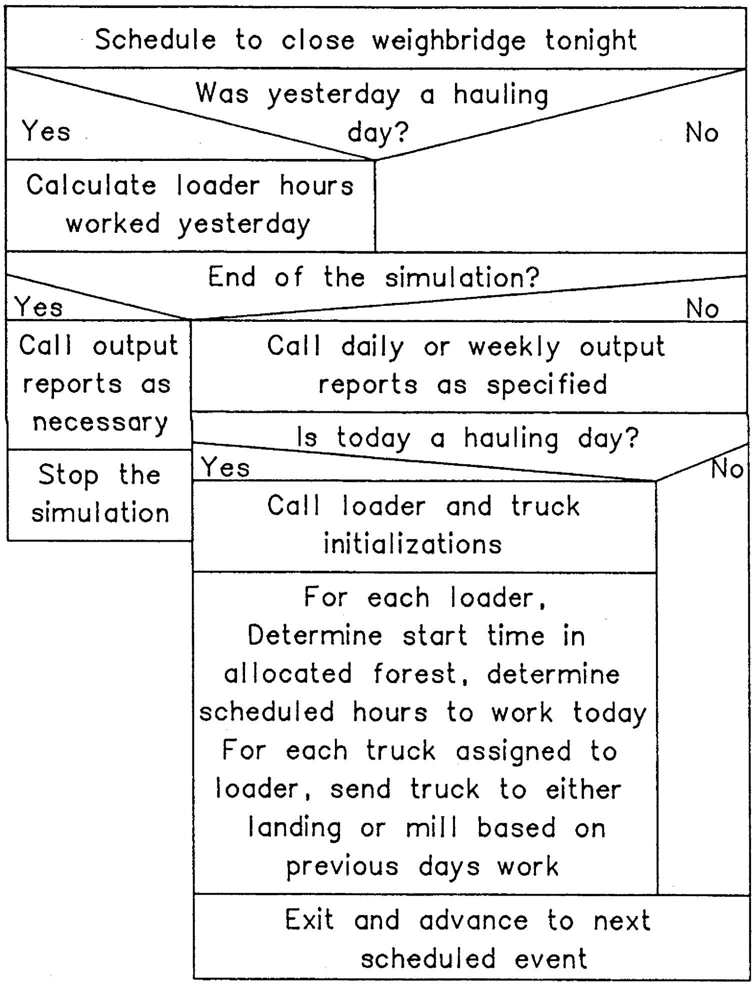
1. Morning start up
2. Close weighbridge
3. Loader night
4. Landing
5. Mill
6. Scheduler
7. Home.

4.3.1.1 Morning start up subsystem

A flowchart of the subsystem is presented in Figure 4.3. The subsystem or routine:

1. Schedules the weighbridge to close at the end of the working day (close weighbridge 4.3.1.2).
2. Determines if the previous day was a hauling day and if so, updates the loader operational statistics for the work of the previous day (loader night 4.3.1.3).
3. Determines if the end of the simulation run is due and if so, calls specified output reports and stops the simulation. If the end of the simulation is not due then reports are accessed if specified.

Figure 4.3 Flowchart of the morning start up subsystem



4. Determines the status as a hauling day. If today is not a hauling day, the routine is exited and the simulation is advanced to the next scheduled event. If today is a hauling day, the number of loaders and trucks to be used are determined. Since these routines are specifically linked to the validation phase, they are discussed in section 5.4.
5. Determines for each working loader a starting time in the allocated position and the hours the loader is scheduled to work.
6. Determines for each of the trucks assigned to the loader, the destination of either the landing or the mill from the previous day.

The routine is then terminated.

4.3.1.2 Close weighbridge subsystem

A flowchart of the subsystem is presented in Figure 4.4. The routine closes the weighbridge at night and reopens it the next morning. Observations at the weighbridge showed that the bridge was opened usually between 7.10 and 7.30am rather than at 7.30 sharp and the weighbridge opening time was therefore selected from a distribution determined from observations of arrival times of the first truck at the weighbridge.

4.3.1.3 Loader night subsystem

The subsystem is presented in Figure 4.5. The operating and idle times at the landing are calculated for each loader that worked the previous day. If a daily report is needed, then the report is accessed.

Figure 4.4 Flowchart of the close weighbridge subsystem

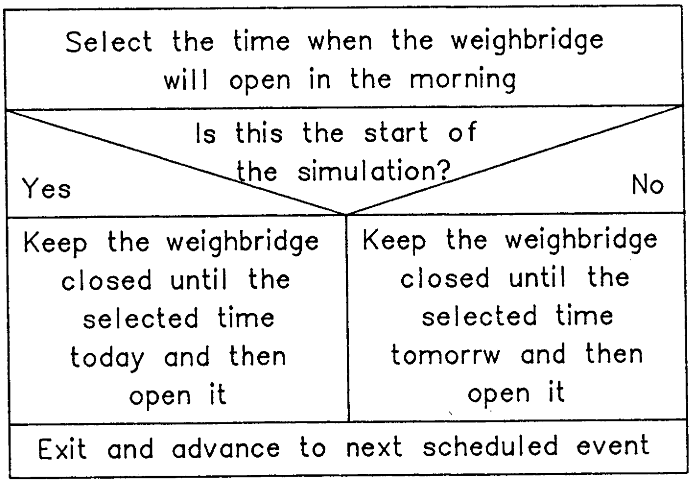
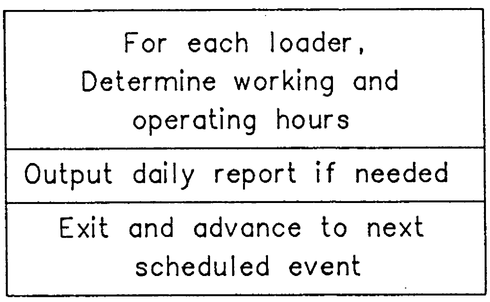


Figure 4.5 Flowchart of the loader night subsystem



4.3.1.4 Landing subsystem

A flowchart of the subsystem is presented in Figure 4.6. The routine represents the arrival of a truck at the allocated landing, the servicing by a loader and the departure of the truck for the mill.

When the truck arrives at the landing, the service of the loader assigned to the landing is requested. If the loader is not available, the truck queues until it is. When the loader is available, it is determined if the truck can get back to the mill before it shuts. If it cannot, then in simulation, it goes 'home', that is stops work and is loaded at the landing on the next hauling day.

If the truck can make it to the mill before it closes, a loading time and loadweight are selected and the truck relinquishes the loader. The loader is then available for the next truck. A travel time to the mill is selected for the truck and it is determined if it will get there before closing time. If not, the truck goes 'home' and then to the mill the next hauling day. If it is determined that the truck can get to the mill before closing then it travels to the mill.

The routine is then terminated.

4.3.1.5 Mill subsystem

A flowchart of the subsystem is presented in Figure 4.7. The routine represents the arrival of the truck at the weighbridge, the time spent in the mill unloading and the return to the weighbridge.

Figure 4.6 Flowchart of the landing subsystem

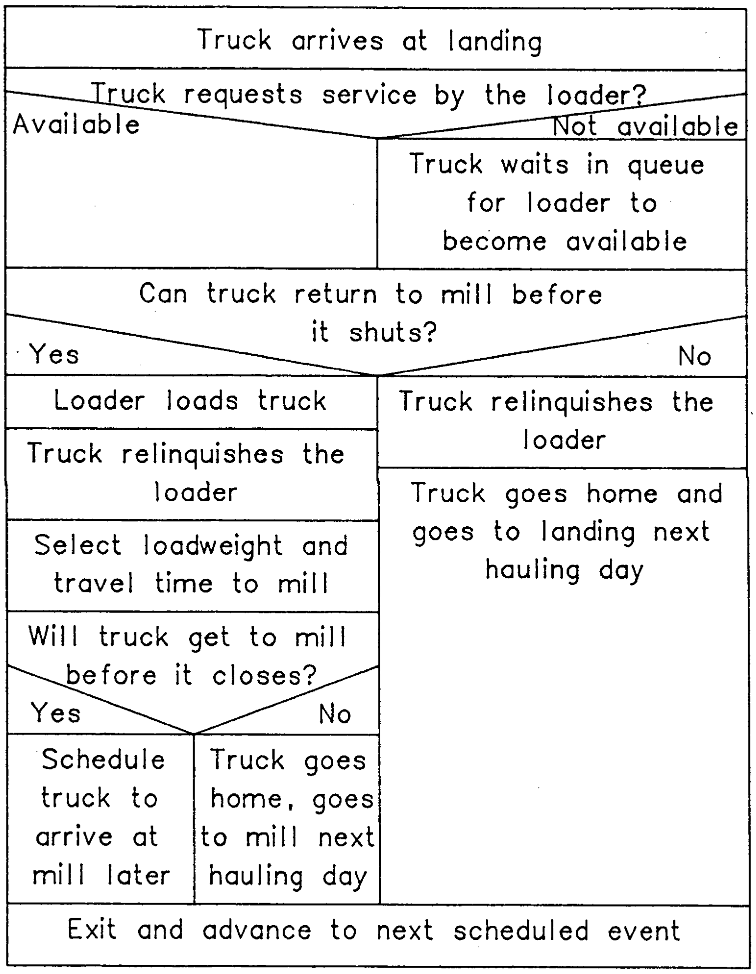
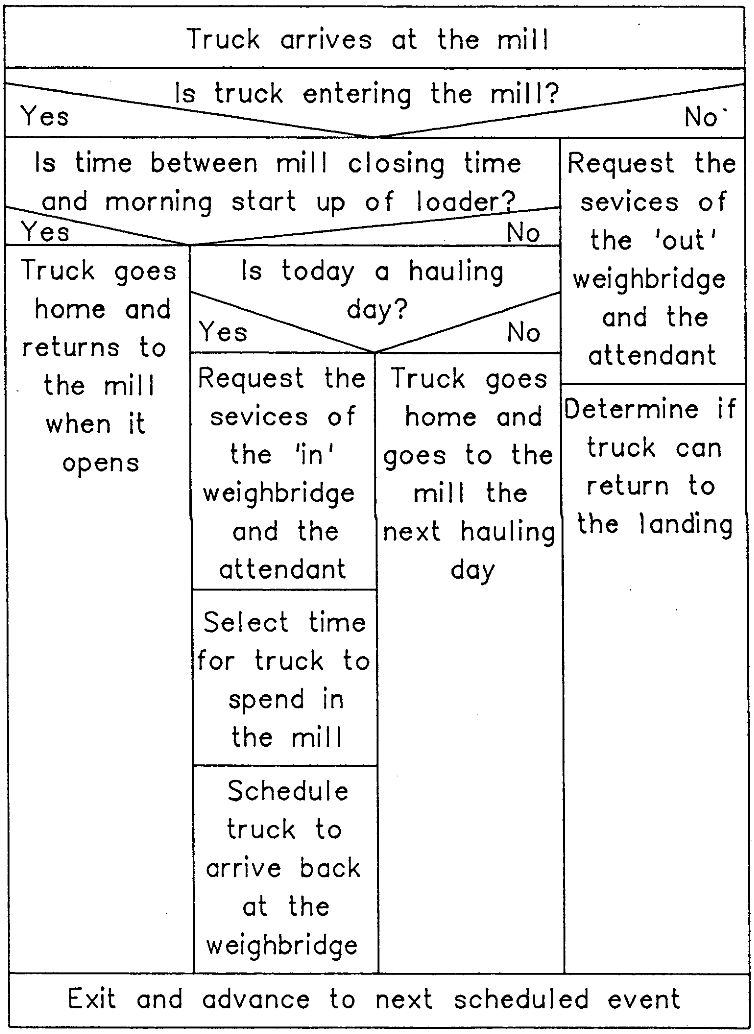


Figure 4.7 Flowchart of the mill subsystem



When a truck arrives at the weighbridge, the routine determines if the time of arrival is between the closing time and the start up of trucks and loaders the next hauling day. If it is, the truck is sent 'home' and returns when the mill opens. If the time of arrival is on a day the mill is open and just prior to the opening, the truck requests the services of the 'in' weighbridge and waits until the mill opens.

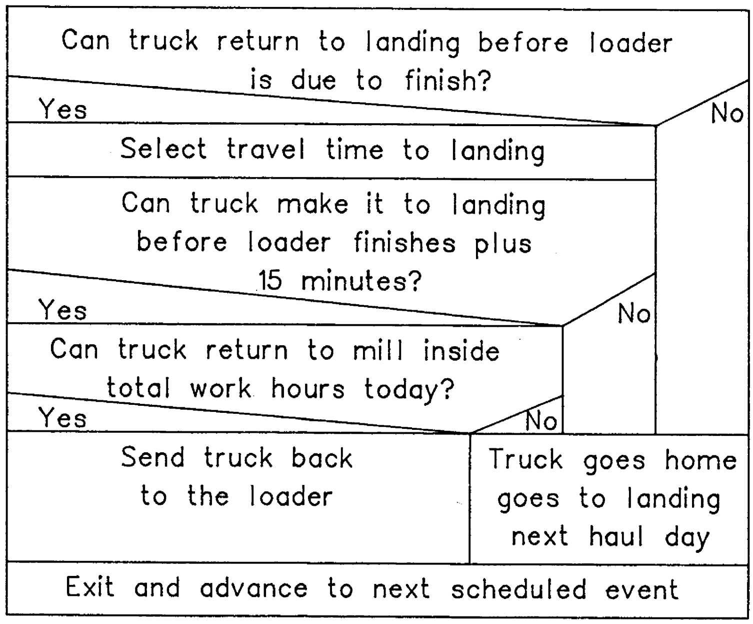
Once the mill opens, the services of the weighbridge attendant are requested. After weighing, a time for unloading in the mill is selected, the truck then exits from the routine and is returned when unloading is finished. If the mill is not open when the truck arrives and is not due to open, the truck is sent 'home' and resumes at the mill on the next hauling day.

When a truck arrives at the weighbridge after unloading and is going out of the mill, a request is made for the 'out' weighbridge and attendant for weighing. The truck then exits from the routine to determine if it can return to the landing for another load (Scheduler 4.3.1.6).

4.3.1.6 Scheduler subsystem

The subsystem is presented in Figure 4.8. The routine determines whether with faster than average travel times a truck can return to the landing before the loader is scheduled to finish work. If it cannot, the truck goes 'home' and then starts at the landing on the next hauling day. It should be noted here that this programming is related only to validation of the model. In experimentation, the trucks are programmed to start from the mill. These points are discussed in Section 6.3.3.

Figure 4.8 Flowchart of the scheduler subsystem



If the truck can get to the landing, a travel time to the assigned landing is selected. The routine then determines if the truck can reach the landing assuming that the loader operator will stay approximately 15 minutes longer if the truck is coming. If the truck would not reach the landing in time, it goes 'home' and starts at the landing on the next hauling day. If the truck will reach the landing in time, the routine determines if after loading, it can return to the mill before the mill closes. If not, the truck goes 'home' and starts at the landing on the next hauling day. If it can, the truck goes to the landing for another load.

The routine is then terminated.

4.3.1.7 Home subsystem

The home subsystem represents the time that trucks stop work rather than the physical home of the truck. The routine determines the travelling and standing hours of each truck at the end of its working day.

4.3.2 Ancillary Routines

The ancillary routines of the model are those associated with the input of data to the model, the output of daily, weekly or periodic reports and the costing of the truck and loader operations. These routines were changed depending upon the purpose of simulation runs; validation, verification or experimentation. Details of the routines are given in Appendix 5.2 and 6.1 which contain the listings of the models used for validation and experimentation.

4.3.3 Control Checks in the Model

Checks were incorporated into the simulation model in many areas to control the simulated activities of the trucks and loaders as realistically as possible. For example, many are made in the scheduler subsystem before sending a truck back to the landing, since it was not realistic for trucks to arrive at the landing after the loader operator had departed.

At the landing, checks are made by the loader before a truck is loaded to make sure the loader does not work unacceptable hours. After being loaded, trucks were programmed to check they could arrive at the mill before the mill closed.

At the weighbridge, arriving trucks are programmed to check to make sure the mill was opening today or not and whether to stay until it opened or go 'home' and return when it was opened.

That programmed checks functioned correctly was of course an important aspect of model verification.

4.4 APPLICATION OF THE CORE MODEL TO THE ANM SYSTEM

The core model and its ancillaries become of course a simplified model of a real operating system such as the ANM haulage system. Application of the core model to for example the ANM system therefore requires that the real system be simplified without compromising simulation studies.

The following assumptions were made to simplify the ANM system for modelling purposes. The assumptions also have the effect of reducing the data required for a model of the ANM system and the time required to build a workable model.

Loader Operations:

- A loader does not spend any significant time moving between compartments or forests in the simulation of one day. That is, in simulation, when loaders move between landings within a forest block during one day, they do so during tea breaks or when there are no trucks to load.
- In simulation, loaders travel to the next location after ceasing to load trucks and this time is not included in the operating hours of the loader.
- In simulation, loaders operate at a rate independent of the number of trucks in a queue.
- Loader breakdowns and maintenance are not modelled. Reliable records of loader breakdowns were not available and in practice, trucks would be directed to other loaders when breakdowns of over one hour's duration occurred. The collection of data on the ad hoc operational procedures adopted by ANM for replacing broken down loaders with another loader was not feasible in this study. Observations suggest that delays due to breakdowns were infrequent but a future study for say scheduling of the loaders, should collect data on the frequency and duration of breakdowns and delays at the landing while a broken down loader is replaced.

Truck Operations:

- Breakdowns during the day are incorporated in the travel time data. In simulation, all loads are delivered to the mill and breakdowns greater than one day would reduce the number of trucks available for allocation to the loader.
- A truck always returns to the landing for another load if it can reach it before the loader finishes work.
- A truck operates independently of how many loads it has delivered. For example, trucks do not speed up to reach the landing or the mill before loading or weighing operations cease.
- In the programming for validation a truck starts at the allocated landing in the morning in time for the first truck to arrive at the mill when the weighbridge opens.
- Each truck operates from only one loader on any day and when there is insufficient time to make a return trip to that loader, it goes 'home'. This is called a 'shuttle service'.
- After the incoming weighbridge closes, the outgoing weighbridge remains open to let trucks out of the mill.
- There are not more than three truck types.

General:

- There is always wood at the landing to which loaders are allocated.
- In simulation, operations can be undertaken in up to five forest blocks in every forest.
- Components of the cycle time, for example loading or travel full times, are selected from the distribution of times for that component determined from analysis of data from the ANM system.

4.5 DATA INPUTS REQUIRED FOR THE CORE MODEL

4.5.1 Data Inputs from Field Operations

The core model requires the input of values for the exogenous parameters of the system to be modelled, in this study, the ANM system. The following are required.

Parameters of distributions representing the performance of the real operations:

- For the times spent in the mill for unloading each of the three truck types
- For the travel-full time from the forest blocks
- For the loadweights of each of the three truck types
- For the loading times for all loaders
- For the opening hours of the weighbridge.

Specification of truck operations:

- Maximum hours worked each day
- Number of haulage days per week
- Maximum number of trucks available to the model
- Relative ratios of the numbers of the three truck types (summing to one)
- Maximum numbers of the truck/trailer combinations
- Scheduled interval between the arrival of trucks on the landing.

4.5.2 Data Inputs as Managerial Specifications

The model also requires the input of values to specify the management of the model. The following are required:

- A random number seed for the pseudo-random number generator.
- A random number stream.
- The number of days to be simulated, including non-hauling days.
- The length of a period to be reported, for example, seven days for a weekly report.
- A decision on the need for a daily report (yes or no).
- A decision on the need for a report at the end of the simulation (yes or no).

Examples of two input data decks used for the validation and experiment phases are detailed in Appendix 5.3 and 6.2 respectively.

CHAPTER 5

VERIFICATION AND VALIDATION OF THE SIMULATION MODEL

5.1 INTRODUCTION

Acceptance of the results and conclusions drawn from simulation studies requires that the modeller establish the credibility of the model. While it is important that practitioners associated with the real system for which the model is developed be convinced of the credibility and reliability of the model, it is essential that the modeller be satisfied from a very critical viewpoint of the performance of the model. The processes to establish credibility are commonly called verification and validation and in these processes, both the data structure and the logical structure are critically assessed (Fishman and Kiviat 1968).

Verification is the checking that the responses of the model are those actually intended by the algorithmic structure of the model. As Mihram (1972) noted:

> "Verification can be likened to the calibration of a scientific apparatus, in which one makes certain that the apparatus (the model) performs (or behaves, or measures) in accordance with certain more elementary situations before being applied in a subsequent scientific investigation. In this manner, certain fears that the model's structure may be inadequate are overcome and elementary features, such as pseudo-random number generators may be employed with confidence".

Validation is "the process of building an acceptable level of confidence that an inference about a simulated process is a correct or valid inference for the actual process" (Van Horn 1971).

Stochastic simulation requires a mechanism for generating independent random variates which are values from a specified distribution (Emshoff and Sisson 1970). The random variates represent uncontrollable factors in the system and are described statistically by distributions. Random variates are generated from the specified distribution by a process involving random numbers. Simulation oriented languages usually provide for generating independent random numbers by using mathematical recursive relationships. These relationships are deterministic and the random numbers, not truly random, are called pseudo-random numbers. Crookes (1981) states that there are many defective generators in use and that it is desirable to statistically check the generator for departures from randomness.

Fishman (1973) describes six well known statistical tests to verify a pseudo-random number generator but verification should also include a check that the distributions generated from the simulation oriented language using the random numbers are correct.

The verification that the assumptions of independence hold for the generated random numbers in a computer simulation model is the first step in the verification of the model (Fishman and Kiviat 1968). Other stages of verification involve the examination of the structure of the model to check its internal validity (Reynolds et al 1981) and the location and correction of syntactical and semantic errors within the computer simulation model by detailed critical review. If a model fails a verification test, then it is necessary to return to the formulation of the computer model or subsystem. Fishman and Kiviat (1968) state that verification can identify unwanted system behaviour and assist the replacement of complicated algorithms by less complicated ones. They also stress the need to verify a number of models representing the system and then to select the simplest of the acceptable ones.

Once verification has ensured that the algorithmic structure of the model is performing as expected, the model must be subjected to validation 'tests'. Validation is a difficult procedure. It is confused by theoretical, practical and philosophical complexities and there is no standard universal test (Naylor et al 1966 and Van Horn 1971).

Naylor and Finger (1967) discussed different philosophies for validation and how they relate to methods of validation. They suggest a new approach to validation and their multistage verification has become the basis for all computer simulation validation methodologies (Van Horn 1971). The first stage seeks to validate the face validity of the internal structure of the model by checking the building blocks or subsystems of the model to ensure that they are necessary and that no erroneous hypothesis is incorporated. The second stage seeks to empirically test the hypotheses or assumptions in the model. The final stage seeks to verify the ability of the model to predict the behaviour of the real world system by comparing the input-output transformations generated by the model to those generated by the real world. This is undertaken by comparing from identical inputs, the outputs of the model to that of the real world. A range of statistical tests are available for the comparison. Van Horn (op.cit.) suggests that simple comparisons of means, variances and distributions will often be suitable to validate a model.

Simulation models often generate sets of time series and certain statistical methods must then be used to compare the time behaviour of the model and real world. Jenkins (1961) and Fishman and Kiviat (1967) developed procedures for using spectral analysis for the comparison of time series and these are suitable for model validation. Time series generated by models are usually highly autocorrelated that is, the occurrence of an event is in part determined by the occurrence of a previous event. Spectral analysis takes into account the autocorrelation of the output and provides a means to objectively compare the two time series and construct confidence bands. However, Van Horn (1971) suggests that if the spectra are not equivalent, the interpretation of the modelled output is unclear. Spectral analysis also requires a large number of observations and is costly and should only be applied to models that reach steady state conditions.

While there is no apparent validation procedure or test that can be used to validate all computer simulation models and validation is therefore problem dependent, McKenney (1967), Shannon (1975) and Grieg (1979) suggest a broad validation 'test' can be used to compare the input-output transformations of a model and the real world when statistical tests cannot be used. The test is called a Turing test and seeks to see if experienced people with a knowledge of the real world system can differentiate between the modelled results and the real world results. If the results cannot be differentiated, then the model is assumed to be validated.

Careful consideration must be given to the results of the chosen validation procedures. For example, Reynolds et al (1981) state that if the test accepts the null hypothesis that the model is correct, the result does not mean that the model is correct or even the best possible model of the real system. Conversely, if the test rejects the null hypothesis, it is not necessarily a useless model.

Thus, validation is not about absolute degrees of valid or invalid models, but about the usefulness of the model. Shrank and Holt (1967) suggest that validation should be concerned with the question of whether the errors in the model make it unsuitable for its intended purpose. The question of the model's usefulness has also been taken up by Lehman (1977). He suggested that while 'indistinguishability tests' are adequate to establish the validity of the simulation, they make no evaluation of the theory or conceptual model that is the basis of a computer simulation model. Lehman suggests that if the theory is not adequately represented in the model, the model cannot be considered valid, no matter how close the agreement of the input-output transformations of the model and real system. He goes on to say that there is no single appropriate test to validate the theory of the model and it is necessary for the modeller to document both the theory of the real world and the conceptual model. Others may then also judge the adequacy of the program as an expression of the real world.

Naylor et al (1966) suggest that the most important validation test for a computer simulation model is the degree of accuracy with which the model predicts the response of the system in the future. They see two validation tests as necessary: (1) an historical validation of the input-output transformations of a period covered in the data collection period, and (2) another validation for the input-output transformations of a period later than the data collection period that represents the future for the simulation model.

It is seldom possible to validate entirely a computer simulation model since the models are usually simplified abstractions of the real system (Shannon 1975). In fact, the validation demonstrates only that for one alternative of the simulated system and one set of conditions, the simulation generates results that are not inconsistent with the known performance of the real system (Conway et al 1959). However, it may be noted that this occurs not just for simulation, but is common to all decision-aiding procedures. The ultimate validation criterion is the manager's belief that the model is useful and makes sense (Emshoff and Sisson 1970), but the use of the model should also conform with the validation of the model (Karplus 1977).

There are particular problems with the validation of simulation models which exhibit transient state behaviour and those models which exhibit steady state behaviour after a period of transient behaviour. The problems are associated with the selection of the simulation responses for comparison with the real system. Under steady state conditions, the probabilities associated with the predictions of the model do not change, but steady state may occur only after the model has been running for a long time and the performance of the model has become independent of the starting conditions (Kleijnan 1974). Many systems never reach steady state, for example some that periodically shut down and then start up.

A problem in validating many models for the steady state condition is in determining when the transient stage has ended. The system responses during the transient stage should not of course be used at all. There is no completely satisfactory method of deciding when a model has reached steady state conditions (Conway et al 1959, Emshoff and Sisson 1970 and Shannon 1975). Emshoff and Sisson (1970) suggest computing a moving average of the output and when it no longer changes significantly, steady state conditions are assumed. Crane and Iglehart (1974) suggest dividing the simulation run ito a series of cycles so that the behaviour of the system during different cycles is both statistically independent and identically distributed. The observations from the cycles can be used to assess for steady state behaviour.

Validation of a model in a transient or nonstationary state must be particularly concerned with the starting conditions for the model. The easiest procedure is to start the model 'empty and idle'. Mize and Cox (1968) suggest that starting conditions should be based on the experience and judgement of the modeller while Tocher (1963) suggests that the model should be run for some time and the final conditions used to start the genuine run.

The core model developed for this study exhibits transient state conditions. A combination of the methods outlined was adopted for its validation and is discussed later.

5.2 VERIFICATION OF THE CORE MODEL

5.2.1 Pseudo-random Number Generator

Simscript has a multiplicative pseudo-random number generator. Fishman (1973) tested the random number generators in three simulation oriented languages including Simscript. He found that of the ten possible random number streams in Simscript, only stream 1 had poor sampling properties and suggested that the seed value of this stream be changed to a sequence with acceptable sampling properties. The Simscript language used in the computer simulation model incorporated this change. It was not necessary therefore to run verification tests on the pseudo-random number generator.

5.2.2 Structure of the Model

Verification of the structure of the model was carried out simultaneously with the construction of the model. The model comprised several subsystems. These were developed and verified separately and then combined in the core model. In addition, many check runs were conducted and detailed reports of changes in the status of trucks produced. These check runs were run initially for day length duration and then weekly. The core model showed no inconsistencies with the conceptual model. An example of the output from a check run is in Appendix 5.1.

5.2.3 Data Verification

The means and standard deviations calculated from the simulation outputs of the times to load a truck, the times spent in the mill, the loadweights, the travel-full times and the travel-empty times were compared to the means and standard deviations of the fitted theoretical model. The comparisons are based on eight weeks' simulation of the ANM system.

Table 5.1 shows the means and standard deviations of the times spent in the mill by the three truck types. There is virtually no difference between the model input data and the model outputs.

Table 5.2 shows the means and standard deviations of the loadweights carried by the three truck types. Again, there appears no reason to reject that the model is not behaving as intended in terms of loadweights.

Table 5.3 shows the means and standard deviations of the loading times for each of the loaders. Except for loader one, the model outputs do not differ greatly from the inputs. The distribution was generated again for loader 1 using a different random number stream and a mean of 24.0 and a standard deviation of 4.98 was obtained. Thus, the differences in these times may be largely due to random fluctuations.

Table 5.4 shows the mean and standard deviations of the inputs and model outputs for travel-full times and the input and simulation outputs of the empty factors for all forest blocks. Again there is no reason to suggest that the model is not behaving as intended for both the travel-full times and empty factors.

Table 5.1 Comparison of the means and standard deviations used as input for the distribution and the simulated output for the time spent by trucks in the mill

Truck/ trailer	INPUT		OUTPUT	
	Mean (mins)	S.D.	Mean (mins)	S.D.
P-	14.7	3.24	14.7	3.15
S1-	13.1	2.67	13.2	2.80
S2-	12.7	2.64	12.7	2.77

Table 5.2 Comparison of the means and standard deviations used as input for the distribution and the simulated output for nett load weight of trucks

Truck/ trailer	INPUT		OUTPUT	
	Mean(tonnes)	S.D.	Mean(tonnes)	S.D.
P-	24.0	1.83	24.0	1.82
S1-	23.7	1.98	23.7	1.98
S2-	23.6	1.77	23.7	1.77

Table 5.3 Comparison of the means and standard deviations used as input for the distribution and the simulated output for loading times of trucks

	INPUT		OUTPUT	
Loader	Mean (mins)	S.D.	Mean (mins)	S.D.
1	23.9	5.06	24.3	4.72
2	22.2	4.48	22.5	3.72
3	25.4	4.22	25.5	4.16
4	27.8	3.63	27.8	3.83

Table 5.4 Comparison of the empty factors and the means and standard deviations used as input for the distribution and the simulated output for travel-full times

	Travel-full time (mins)				Empty factor	
	Input		Output		Input	Output
	Mean	S.D.	Mean	S.D.		
Batlow-1	149	27.1	150	28.5	.92	.91
Batlow-2	171	30.0	170	29.0	.86	.85
Green Hills-1	164	24.7	161	19.8	.82	.83
Green Hills-2	161	22.3	160	26.4	.85	.86
Green Hills-3	160	25.3	162	24.8	.89	.88
Green Hills-4	145	24.0	144	22.2	.86	.87
Green Hills-5	131	16.8	133	18.7	.83	.81
Carabost-1	99	12.1	99	11.7	.88	.89
Carabost-2	99	12.2	98	11.6	.90	.90
Carabost-3	107	14.5	107	14.2	.84	.83
Shelley	97	11.4	98	11.3	.86	.86
Myrtleford-1	109	19.9	110	20.8	.93	.92
Myrtleford-2	127	42.5	126	40.1	.78	.79

All the comparisons indicate that the distributions were generating acceptable variates and it was determined therefore to accept that both the structure and the data of the core model were as verified.

5.3 VALIDATION OF THE MODEL

5.3.1 Starting Conditions for Simulation Runs

The ANM hauling system shuts down at the close of operations on each hauling day and recommences on the morning of the next hauling day. Kleijnan (1974) describes models and systems that periodically shut down and start up again as being of transient state.

Since the model is of a transient state nature, it is appropriate for validation purposes that the model be run for the same period as the input provided from the real system. That is, there was no start up period for the model. It is essential that the model performs satisfactorily when operated in this way because while log hauling systems can be readily seen as shutting down and starting up, they also change from day to day in for example the number of trucks operating, the number of loaders operating and the location of the loaders. Thus, the model does not require running for a long period before simulated observations are made.

The starting conditions chosen for the validation were 'empty and idle' since most resources within the model and the real world system started in this condition. For example, loaders start a new day 'empty and idle' because trucks do not queue overnight and it is not the usual custom for trucks to keep a load overnight and therefore not go directly to a landing in the morning.

5.3.2 Data Periods for Validation

Three periods were chosen in the ANM operation to validate the simulation model. The first, November 1982 was within the data collection period and comprised 29 days of which 21 were hauling days. It was chosen because it was towards the end of the data collection period and outside the learning curves for some of the operations described in Chapter 2. The second period chosen, February 1983, provided data that were independent of any of the data used in the building of the model. February 1983 comprised 28 days, of which 20 were hauling days. The third period, June 1983, comprised 14 days of which 10 were hauling days and also represented an independent data source.

February and June were chosen for two reasons. Firstly, it was practical and convenient to obtain data for these two periods. Secondly, they represented both a summer (February) and winter (June) period.

The performance of the model was examined for validity over several periods, called period validation and over one day, called daily validation.

5.4 PERIOD VALIDATION

5.4.1 Data

The procedure for the validation of the period model was to compare the input-output transformations of a period in the real system to those generated by the model for the same period. The following information was collected for the three validation periods:

1. How many days in the period each loader worked
2. How many hours each loader worked in a day
3. When and to where loaders were shifted
4. How many trucks were used each day.

5.4.1.1 Days worked by loaders

This information was collected from the daily weighbridge records. For each loader, the ratio of the number of days the loader did not work over the total number of hauling days in the period was calculated. In the simulation model, at the start of each day, a random number between zero and one was produced. In simulation, if this number was less than the ratio calculated, then the loader did not work on that day. However, there was never more than one loader idle on any day throughout the data collection period and therefore, in simulation, only one loader was allowed to be idle on any one day.

5.4.1.2 Hours worked by loaders

This information was also collected from the ANM weighbridge records. The hours worked each day by a loader were calculated from truck records as the time from when the first truck left the landing to the time that the last truck left the landing plus a mean loading time. If either of the times was missing, a time was substituted based on known mean travel times to particular forest blocks and experience.

A mean and standard deviation was calculated for each loader for the times worked on each day during the period. The limited sample size was not sufficient to satisfactorily fit any of the distributions usually fitted and it was assumed by inspection of the data that the hours worked by each loader could be represented by a normal distribution. In simulation, for each day that a loader worked, a time was selected from the normal distribution. This selected time was programmed as the scheduled hours of work on that day. The model could then determine if trucks could return to the landing before the loader was due to finish.

The hours actually worked by the loader on any day were generated by the model and are based on the scheduled time and the interaction of the trucks assigned to the loader and may be either less or greater than the scheduled hours, although usually not greatly different.

5.4.1.3 Movement of loaders

Loaders move from landing to landing in response to a variety of constraints and requirements, for example, stock depletion, landing conditions, road conditions, age of wood and managerial decisions. While the loader movements could be examined from the ANM weighbridge records, the reasons for the movements were not recorded and it was not possible to rationalize the scheduling of the loaders in the real system.

Therefore, in simulation, loaders were assumed to stay within the one forest block for one day and then have the opportunity to shift. At the end of the day or the beginning of the next day, the model determined if the loader had to shift and if so, to which landing.

The landings in the simulation model represented forest blocks in the real world - one landing for each forest block since there was one travel time distribution for each forest block. Each block was given a priority which provided for the programme to determine which landing the loader would attend the next day. The priority was based on the actual loads delivered from all forest blocks in the period compared with the total simulated loads delivered by the loader from that forest block over the simulated total loads delivered from all forest blocks. Thus, the priority of the ith forest block would be calculated as:

$$P_i = \left(\frac{\Sigma \text{ actual loads}_i}{\sum_{i=1}^{n} \text{actual loads}_i} \right) - \left(\frac{\Sigma \text{ simulated loads}_i}{\sum_{i=1}^{n} \text{simulated loads}_i} \right)$$

where n = total number of forest blocks

When the simulated load ratio is less than the actual, the priority for the forest block is positive. Conversely, if the simulated ratio is greater than the actual, the priority will be negative. The forest blocks or landings are sorted into descending order based on the calculated priorities and the loaders allocated on the priority basis.

Loaders do not usually attend any landing, for example, the loader positioned in Victoria would rarely visit New South Wales and the loader near Batlow and Green Hills rarely visits Carabost. The weighbridge records showed the landings attended by each loader and these records were used to constrain the loader positions in the simulation runs carried out for validation of the model. In experimental runs, these constraints must be specified. In simulation, when a selection is being made for allocating each loader, the landing with the highest priority is accessed first. If the loader is not constrained from attending the selected landing, that selection is accepted. If it is constrained, the selector moves to the landing with the next highest priority and repeats the operation.

Once a landing is selected, it cannot be attended by another loader until the first loader has moved. In addition, no more than two loaders are permitted in a forest at any one time.

5.4.1.4 Number of trucks

The number of trucks used for log hauling on any one day depends for a particular operation on many factors, including for example, the number of trucks available the number of loaders to be serviced, the location of the loaders and how much wood is required. In this study, it is assumed that the number of trucks available for despatch to the loaders is a management decision and an input to the simulation model. Later, in Chapter 6, a method for determining the number of trucks to be assigned to a loader is discussed.

For the period validation, the average number of trucks allocated to that loader was determined from the mean number of trucks per day that had serviced loaders in that location. The number allocated must of course be an integer and in modelling, a random number between zero and one was added to the mean and then the answer truncated to an integer. This procedure was adopted to ensure that the mean number of trucks assigned to a loader would converge on the mean for the validation period in the real system.

The above routines are listed with the core model in Appendix 5.2 while an example of a data deck used in the period validation is in Appendix 5.3.

5.4.2 The Assumptions for the Period Validation

The following assumptions were made for assigning loaders to landings and trucks to loaders. The constraints imposed by the assumptions encompass the ANM operation and it may be necessary to review them if the simulation model is applied to other large hauling operations:

1. A maximum of two loaders within a forest on any one day
2. A total of fourteen landings
3. A minimum of three loaders must work on any day (in the ANM operation, there are four loaders)
4. Only one loader can service a landing on any one day.

5.4.3 Outputs of the Model Runs for the Period Validation

The aim of the period validation was to show that the input-output transformations of the simulation model were not significantly different to the input-output transformations in the real world. The transformations are compared for a specific period in the period validation.

The period validation model predicts the number of loads, the weight of wood (tonnes) delivered to the mill and the hours the trucks worked to deliver the loads. These are the endogenous variables generated within the model. It is also important to validate that the correct number of trucks were used, that the mix of loads from landings was maintained and the simulated hours worked by the loaders was realistic. Thus, for validation testing, five factors were compared between the simulated and the real world over the specified period:

1. The mean and standard deviation of the number of loads delivered per day
2. The mean and standard deviation of the number of tonnes delivered per day
3. The mean and standard deviation of the number of trucks used per day
4. The mean and standard deviation of the hours worked for all trucks each day
5. The mean and standard deviation of the hours worked for each loader each day.

Simscript has ten random number streams and all ten sequences were used for the validation. Thus, for each of the three periods selected for period validation, the model was run ten times with a different random number sequence. The output generated for each run was compared to the real system output using Van Horn's (op.cit.) suggestion of testing the variances and means for significance using the F-test and t-test.

The tests were made with the SPSS^X package, the latest version of the 'Statistical Package for the Social Sciences'. The package calculates the F-test statistic and two t-test statistics, one based on equal or pooled variances the other on unequal or separate variances. The null hypothesis for the F-test is that the two variances estimate the same parametric variance. If there is no reason to reject the null hypothesis, then the t-statistic based on the pooled variances is used to test the means. If the null hypothesis in the F-test is rejected, then the t-statistic based on separate variances is used. The null hypothesis for the t-tests is that the two sample means are equal. The probability level for both tests was 0.05.

Both the F-test and t-test assume that the underlying distribution is normal (Steele and Torrie 1960). However, it is often not easy to specify the underlying distribution and two nonparametric or distribution-free tests were also calculated, viz. the Mann-Whitney and Kolmogorov-Smirnov tests. These statistics compare the distributions rather than the parameters estimating the mean and variance.

The Mann-Whitney test yields the same statistic and the same result as the Wilcoxon two-sample test (Sokal and Rohlf 1969). The null hypothesis is that the two independent samples are from the same population. The Kolmogorov-Smirnov two-sample test is also a test of whether two independent samples are from the same population. The test is sensitive to any type of difference in the two distributions, such as the median, dispersion and skewness (Siegel 1956).

The SPSS^X package computes both the Mann-Whitney and Wilcoxon two-sample test. Only the Mann-Whitney statistic is quoted since the tests have the same result. For the Kolmogorov-Smirnov test, the SPSS^X package transforms the Kolmogorov-Smirnov statistic to a Kolmogorov-Smirnov Z statistic based on Smirnov (1948). Smirnov's tables are used to calculate the probabilities.

The Kolmogorov-Smirnov statistic is only applicable to continuous distributions (Sokal and Rohlf 1969) and this test is not used when comparing the number of loads delivered or the number of trucks used on any day.

5.4.4 Results for the Period Model Validation

5.4.4.1 November 1982: period I

Tables 5.5 to 5.13 show the comparison between the actual outputs from the real system and the outputs from the simulation model over the period for the following factors:

1. Average loads delivered per day (Table 5.5)
2. Average tonneage delivered per day (Table 5.6)
3. Average number of trucks employed per day (Table 5.7)
4. Average hours worked by trucks per day (Table 5.8)
5. Average hours worked by loader 71 per day (Table 5.9)
6. Average hours worked by loader 72 per day (Table 5.10)
7. Average hours worked by loader 73 per day (Table 5.11)
8. Average hours worked by loader 74 per day (Table 5.12)
9. Percentage of loads delivered from New South Wales and Victoria (Table 5.13).

Although there are a few significant differences (in Tables 5.7, 5.8, 5.10, 5.11 and 5.12), nearly all the statistical tests show no evidence to suggest the null hypothesis, that the simulated outputs are not significantly different to the real system outputs, should be rejected.

Table 5.5 Results for period I validation: number of loads delivered per day (No random streams are significantly different from the observed data)

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]
Actual	63.05	3.612	21			
Stream						
1	61.48	4.008	21	1.23	-1.33	151.0
2	62.90	3.833	21	1.13	-0.12	212.5
3	62.52	3.076	21	1.38	-1.47	176.0
4	62.52	3.642	21	1.02	-0.47	206.0
5	60.81	4.854	21	1.81	-1.70	160.5
6	61.91	2.488	21	2.11	-1.19	162.0
7	61.57	3.682	21	1.04	-1.31	177.5
8	61.90	5.585	21	2.39	-0.79	206.0
9	60.71	4.349	21	1.45	-1.89	171.0
10	62.86	3.468	21	1.08	-0.17	212.5

Table 5.6 Results for period I validation: number of tonnes delivered per day (No random streams are significantly different from the observed data)

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	1488	93.79	21				
Stream							
1	1456	96.70	21	1.06	-1.09	170.0	0.926
2	1498	92.40	21	1.03	-0.34	197.0	0.772
3	1464	69.83	21	1.80	-0.94	207.5	0.772
4	1485	86.56	21	1.17	-0.09	212.0	0.463
5	1446	116.2	21	1.54	-1.28	210.0	1.234
6	1468	61.97	21	2.29	-0.83	185.0	0.926
7	1458	87.72	21	1.14	-1.07	157.0	1.234
8	1468	130.0	21	1.95	-0.57	203.0	0.926
9	1440	103.3	21	1.21	-1.58	186.5	0.772
10	1493	86.03	21	1.19	-0.19	150.0	0.772

* Significantly different at the 0.05 probability level
1 Mann-Whitney U Statistic
2 Kolmogorov-Smirnov Z statistic

Table 5.7 Results for period I validation: number of trucks used per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]
Actual	25.14	1.276	21			
Stream						
1	24.81	0.814	21	2.46	-1.01	130.0*
2	25.05	1.071	21	1.42	-0.26	169.5
3	25.14	0.727	21	3.08*	0.00	164.0
4	25.43	0.746	21	2.92*	0.89	207.0
5	24.71	0.845	21	2.28	-1.28	121.0*
6	25.24	0.889	21	2.06	0.28	191.5
7	24.76	0.944	21	1.83	-1.10	143.0*
8	25.0	1.00	21	1.63	-0.40	164.0
9	24.67	0.913	21	1.95	-1.39	120.0*
10	25.33	0.856	21	2.22	0.57	189.0

Table 5.8 Results for period I validation: hours worked by trucks per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	9.61	0.377	21				
Stream							
1	9.68	0.470	21	1.55	0.47	187.5	0.463
2	9.83	0.427	21	1.28	1.76	159.0	0.926
3	9.53	0.425	21	1.27	-0.65	197.0	0.617
4	9.58	0.413	21	1.20	-0.27	162.5	0.463
5	9.57	0.557	21	2.18	-0.32	183.5	0.617
6	9.58	0.340	21	1.23	-0.30	176.5	0.617
7	9.75	0.514	21	1.86	0.99	213.0	0.772
8	9.66	0.627	21	2.77*	0.30	154.5	0.926
9	9.57	0.476	21	1.59	-0.32	188.5	0.463
10	9.71	0.459	21	1.48	0.73	168.0	0.617

* Significantly different at the 0.05 probability level
1 Mann-Whitney U Statistic
2 Kolmogorov-Smirnov Z statistic

Table 5.9 Results for period I validation: hours worked by loader 71 per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	9.50	0.826	21				
Stream							
1	9.62	0.614	21	1.81	0.53	147.5	0.772
2	9.79	0.982	21	1.41	1.00	172.0	0.772
3	9.37	0.611	21	1.83	-0.62	202.5	1.080
4	9.57	0.635	21	1.69	0.27	203.5	0.772
5	9.51	0.874	21	1.12	0.02	204.5	0.772
6	9.35	0.727	21	1.29	-0.65	213.5	1.080
7	9.70	0.843	21	1.04	0.74	159.5	0.463
8	9.54	0.870	21	1.11	0.15	211.0	0.463
9	9.43	0.747	21	1.22	-0.29	202.5	0.772
10	9.41	0.622	21	1.76	-0.42	210.0	0.772

Table 5.10 Results for period I validation: hours worked by loader 72 per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	10.08	1.168	21				
Stream							
1	10.20	1.635	21	1.96	0.27	164.5	0.772
2	10.36	1.020	21	1.31	0.82	174.5	0.617
3	10.12	0.919	21	1.62	0.13	192.5	0.617
4	10.22	1.569	21	1.80	0.33	140.5*	0.772
5	10.16	1.110	21	1.11	0.23	186.0	0.617
6	9.90	1.294	21	1.23	-0.46	197.5	0.463
7	10.57	1.062	21	1.21	1.41	195.5	0.772
8	10.43	1.234	21	1.12	0.95	151.5	0.463
9	10.10	1.102	21	1.12	0.05	168.0	0.463
10	10.57	1.015	21	1.32	1.45	136.0*	0.926

* Significantly different at the 0.05 probability level
1 Mann-Whitney U Statistic
2 Kolmogorov-Smirnov Z statistic

Table 5.11 Results for period I validation: hours worked by loader 73 per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	10.61	1.268	21				
Stream							
1	10.38	1.227	21	1.07	-0.61	218.5	0.463
2	10.90	1.105	21	1.32	0.79	173.5	0.926
3	10.83	0.899	21	1.99	0.63	173.0	1.080
4	10.52	1.011	21	1.57	-0.27	188.0	0.617
5	10.21	1.593	21	1.58	-0.91	182.0	0.772
6	10.40	0.589	21	4.63*	-0.70	157.5	0.926
7	10.40	1.257	21	1.02	-0.55	212.0	0.617
8	10.60	1.527	21	1.45	-0.03	196.5	0.309
9	10.65	1.101	21	1.33	0.09	210.5	0.463
10	10.99	1.026	21	1.53	1.04	177.0	0.926

Table 5.12 Results for period I validation: hours worked by loader 74 per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	9.58	1.537	19				
Stream							
1	9.08	1.477	20	1.08	-1.06	156.5	0.739
2	8.84	1.637	17	1.13	-1.42	102.0	1.465*
3	9.05	1.671	17	1.18	-0.99	103.5	1.113
4	8.68	1.224	19	1.58	-2.01	120.0	1.622*
5	8.71	1.255	20	1.50	-1.96	116.5*	1.380*
6	9.29	1.315	20	1.37	-0.65	166.0	0.732
7	8.63	1.030	21	2.23	-2.32*	121.0*	1.234
8	9.54	1.801	18	1.37	-0.07	157.0	0.702
9	8.69	1.395	20	1.21	-1.92	116.5*	1.347
10	8.89	1.292	18	1.41	-1.47	115.0	1.040

* Significantly different at the 0.05 probability level
1 Mann-Whitney U Statistic
2 Kolmogorov-Smirnov Z statistic

Table 5.13 Results for period I validation: percentage of loads delivered from NSW and Victoria

	NSW	Victoria
Actual	72.6	27.4
Stream		
1	73.4	26.6
2	71.3	28.7
3	70.7	29.3
4	72.1	27.9
5	73.1	26.9
6	72.2	27.8
7	73.4	26.6
8	72.2	27.8
9	72.2	27.8
10	70.7	29.3

However, while nearly all of the statistical tests indicate no significant differences, the result of the statistical analysis in Tables 5.5 to 5.12 suggest there may be bias. Tables 5.5 and 5.6 show that for all ten random streams, the model underestimates the number of loads and tonneages with respect to the actual values. There is no clear explanation for this. One explanation is that the model is based on a combination of winter and summer haul times and is therefore quite likely to underestimate for summer conditions. The simulated average hours worked by loader 74 are also underestimated (Table 5.12), while overestimated for loader 72 (Table 5.10).

In the case of the simulated average number of trucks in use per day (Table 5.7), the simulated average hours worked by trucks (Table 5.8), and the simulated average hours worked by loaders 71 and 73 (Tables 5.9 and 5.11) exhibit no bias (neither under- nor overestimation of the actual results).

The general conclusion is that the model satisfactorily represents the ANM system for the November 1982 period.

5.4.4.2 February 1983: period II

Tables 5.14 to 5.22 compare the simulated outputs with the recorded performances for the same factors as above for period I. The tests, as for period I, generally indicate that except for loader 74 (Table 5.21), there is no evidence to suggest that the null hypothesis should be rejected. In general, the comparisons indicate for period II that there is no bias associated with the simulated number of loads and tonnes delivered, that the number of trucks employed and the average

Table 5.14 Results for period II validation: number of loads delivered per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]
Actual	59.15	5.743	20			
Stream						
1	59.05	4.861	20	1.40	-0.06	198.0
2	58.05	5.586	20	1.06	-0.61	183.0
3	58.20	5.357	20	1.15	-0.54	175.0
4	59.85	4.171	20	1.90	0.44	131.0
5	57.90	5.350	20	1.15	-0.71	183.5
6	58.60	5.365	20	1.15	-0.31	168.0
7	61.40	4.558	20	1.59	1.37	106.0*
8	59.40	3.575	20	2.58*	0.17	130.0
9	60.70	4.669	20	1.51	0.94	139.5
10	59.80	4.980	20	1.33	0.38	197.5

Table 5.15 Results for period II validation: number of tonnes delivered per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	1398	137.1	20				
Stream							
1	1400	117.9	20	1.35	0.04	197.0	0.632
2	1378	133.5	20	1.05	-0.48	179.0	0.474
3	1382	129.1	20	1.13	-0.37	173.0	0.632
4	1414	100.5	20	1.86	0.43	177.0	0.791
5	1368	124.8	20	1.21	-0.72	163.0	0.791
6	1394	129.3	20	1.12	-0.10	186.0	0.632
7	1458	112.6	20	1.48	1.51	139.5	1.265
8	1409	79.51	20	2.97*	0.29	182.0	0.791
9	1436	109.8	20	1.56	0.95	180.5	0.949
10	1419	122.9	20	1.25	0.51	158.0	0.474

* Significantly different at the 0.05 probability level
1 Mann-Whitney U Statistic
2 Kolmogorov-Smirnov Z statistic

Table 5.16 Results for period II validation: number of trucks used per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]
Actual	24.80	1.196	20			
Stream						
1	24.95	1.356	20	1.28	0.37	155.0
2	24.60	1.273	20	1.13	-0.51	194.0
3	24.80	1.361	20	1.29	0.0	176.0
4	24.80	1.056	20	1.28	0.0	197.0
5	25.00	1.170	20	1.05	0.53	191.0
6	24.60	1.231	20	1.06	-0.52	191.0
7	25.20	1.399	20	1.37	0.97	146.0
8	24.80	1.361	20	1.29	0.0	158.0
9	24.90	1.119	20	1.14	0.27	170.0
10	24.85	1.387	20	1.34	0.12	185.0

Table 5.17 Results for period II validation: hours worked by trucks per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	9.48	0.435	20				
Stream							
1	9.49	0.373	20	1.36	0.08	168.5	0.560
2	9.52	0.588	20	1.83	0.24	116.0*	0.791
3	9.50	0.509	20	1.37	0.13	189.0	0.474
4	9.66	0.452	20	1.08	1.28	159.0	0.632
5	9.39	0.416	20	1.09	-0.71	185.0	0.474
6	9.45	0.653	20	2.25	-0.20	191.0	0.819
7	9.75	0.416	20	1.09	1.97	175.0	1.423*
8	9.60	0.318	20	1.87	1.00	149.0	0.791
9	9.82	0.411	20	1.12	2.50*	179.5	1.265
10	9.66	0.307	20	2.01	1.47	182.0	0.632

* Significantly different at the 0.05 probability level
1 Mann-Whitney U statistic
2 Kolmogorov-Smirnov Z statistic

Table 5.18 Results for period II validation: hours worked by loader 71 per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	9.89	0.538	20				
Stream							
1	10.07	0.670	20	1.55	0.94	125.5*	0.632
2	10.16	0.641	20	1.42	1.47	143.5	0.791
3	9.92	0.606	20	1.27	0.17	150.5	0.316
4	9.91	0.531	20	1.03	0.12	136.5	0.474
5	10.05	0.497	20	1.17	0.98	197.5	0.474
6	9.93	0.458	20	1.38	0.25	174.5	0.316
7	10.04	0.450	20	1.43	0.96	138.0	0.791
8	9.98	0.484	20	1.24	0.56	122.0	0.474
9	10.16	0.586	20	1.19	1.52	137.0	0.791
10	10.04	0.616	20	1.31	0.82	143.0	0.474

Table 5.19 Results for period II validation: hours worked by loader 72 per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	9.67	1.189	20				
Stream							
1	9.84	1.290	20	1.18	0.45	193.0	0.474
2	9.68	1.235	20	1.08	0.04	186.5	0.632
3	9.75	1.205	20	1.03	0.22	197.5	0.632
4	9.69	0.915	20	1.69	0.07	172.0	0.632
5	9.65	0.874	20	1.85	-0.06	197.0	0.632
6	9.77	1.354	20	1.30	0.26	194.5	0.632
7	10.26	0.999	20	1.42	1.71	197.5	1.423
8	9.82	0.888	20	1.80	0.45	190.0	0.791
9	10.04	0.879	20	1.83	1.12	193.0	1.107
10	9.91	1.140	20	1.09	0.67	169.0	0.949

* Significantly different at the 0.05 probability level
1 Mann-Whitney U Statistic
2 Kolmogorov-Smirnov Z statistic

Table 5.20 Results for period II validation: hours worked by loader 73 per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	10.35	0.855	17				
Stream							
1	10.38	0.838	16	1.04	0.07	99.5	0.644
2	10.78	0.970	16	1.29	1.33	131.5	0.739
3	10.81	1.135	16	1.76	1.30	127.5	1.098
4	11.10	0.879	19	1.06	2.58*	120.5	1.224
5	10.42	0.886	14	1.07	0.22	106.0	0.419
6	10.75	0.855	17	1.07	1.34	110.0	0.857
7	10.74	0.770	19	1.23	1.44	146.0	0.751
8	10.77	0.549	20	2.43	1.79	155.0	1.070
9	10.89	0.820	19	1.09	1.92	148.0	0.909
10	10.86	0.642	16	1.78	1.93	106.0	0.971

Table 5.21 Results for period II validation: hours worked by loader 74 per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	8.79	1.086	15				
Stream							
1	7.93	0.852	15	1.63	-2.39*	61.5*	1.643*
2	7.79	0.795	15	1.86	-2.88*	48.5*	1.643*
3	7.93	0.921	13	1.39	-2.23*	51.0*	1.678*
4	7.70	0.599	14	3.29*	-3.37*	37.0*	1.973*
5	8.18	1.108	18	1.04	-1.57	107.5	1.081
6	7.64	0.914	17	1.41	-3.24*	55.0*	1.804*
7	8.48	1.273	14	1.37	-0.70	69.0	1.397*
8	7.61	0.488	8	4.95*	-3.57*	17.5*	1.846*
9	8.25	1.177	14	1.17	-1.28	62.0	1.371*
10	8.09	0.846	16	1.65	-1.99	71.0	1.727*

* Significantly different at the 0.05 probability level
1 Mann-Whitney U statistic
2 Kolmogorov-Smirnov Z statistic

Table 5.22 Results for period II validation: percentage of loads delivered from NSW and Victoria

	NSW	Victoria
Actual	66.2	33.8
Stream		
1	67.4	32.6
2	68.1	31.9
3	67.9	32.1
4	65.3	34.7
5	68.0	32.0
6	67.2	32.8
7	66.3	33.7
8	64.8	35.2
9	68.0	32.0
10	65.1	34.9

hours worked by the trucks are overestimated by the model and that the hours worked by loaders 71, 72 and 73 are overestimated.

The comparisons in respect of loader 74, suggest that the simulated hours worked are significantly different and underestimated to the actual hours worked. The variation of the simulated outputs and the actual performance appear similar, but the simulated mean hours worked seem to be underestimated. Review of the data for this period revealed inconsistencies between the data and the assumptions made for the validation of the model. In the model, trucks arrive on the landing every twenty minutes when first allocated in the morning. This did not occur at loader 74 on approximately half of the days in the period and in some cases, the interval was in excess of one hour. This would extend the number of hours that the loader needed to stay on the landing to load the trucks. Also, trucks allocated to loader 74 changed with trucks allocated to other loaders after delivering one load. These reasons were accepted as explanations of the relatively poor performance of the model in respect to loader 74.

The comparison of the actual and simulated percentages of loads delivered from NSW and Victoria in period II (Table 5.22) indicate that the simulated percentage of loads from each of the two states for the ten streams is 'close' to the actual.

Thus, the period II validation provides further support for the validity of the simulation model.

5.4.4.3 June 1983: period III

Tables 5.23 to 5.31 compare the simulated outputs with the recorded performances for the same factors as in periods I and II. The same tests, again indicate generally that there is no reason to reject the null hypothesis that the actual performances are not significantly different to the model's output.

Tables 5.23 and 5.24 compare respectively, the simulated and the actual number of loads and tonnes delivered to the mill. The F-test indicates that the simulated and actual populations are significantly different. A very wide range of loads was delivered in the real system on the ten hauling days, between fifty and seventy-five loads per day. The model does not produce this relatively large variation, due to the modelling method of using a mean number of trucks to a loader and truncating after adding a random number between zero and one. Thus, only two numbers of trucks to a landing can be selected and much higher or much lower numbers do not occur in the validation runs. The routine for selecting truck numbers in the validation runs is thus deficient when large variations of truck numbers occur. However, these differences were not indicated in the other periods of validation and in view of the unusual variation, the validity of the model as a whole was accepted.

Tables 5.25 to 5.31 show no bias in the model towards either over or underestimating the actual results and again, provide support for the validity of the model.

Table 5.23 Results for period III validation: number of loads delivered per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]
Actual	61.30	8.166	10			
Stream						
1	59.60	2.171	10	14.15*	-0.64	46.0
2	58.40	3.836	10	4.53*	-1.02	44.5
3	61.70	3.093	10	6.97*	0.14	49.0
4	58.70	6.499	10	1.58	-0.79	45.0
5	63.30	3.945	10	4.28*	0.70	47.5
6	60.90	5.705	10	2.05	-0.13	48.0
7	60.70	3.860	10	4.48*	-0.21	36.5
8	58.00	5.142	10	2.52	-1.08	45.5
9	60.40	5.420	10	2.27	-0.29	49.5
10	58.80	4.566	10	3.20	-0.85	49.5

Table 5.24 Results for period III validation: number of tonnes delivered per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	1441	194.3	10				
Stream							
1	1415	56.29	10	11.91*	-0.40	38.0	0.894
2	1385	80.78	10	5.79*	-0.84	42.5	0.671
3	1467	71.44	10	7.40*	0.41	34.0	1.118
4	1398	150.3	10	1.67	-0.55	35.0	0.671
5	1503	93.62	10	4.31*	0.91	28.0	1.118
6	1441	129.5	10	2.25	0.01	40.0	0.671
7	1439	89.13	10	4.75*	-0.03	48.0	0.671
8	1382	120.8	10	2.59	-0.81	49.0	0.671
9	1428	119.0	10	2.67	-0.17	47.0	0.671
10	1394	114.5	10	2.88	-0.66	48.0	0.447

* Significantly different at the 0.05 probability level
1 Mann-Whitney U statistic
2 Kolmogorov - Smirnov Z statistic

Table 5.25 Results for period III validation: number of trucks used per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]
Actual	26.80	2.530	10			
Stream						
1	26.90	2.132	10	1.41	0.10	33.0
2	26.40	1.647	10	2.36	-0.42	33.5
3	26.70	1.767	10	2.05	-0.10	32.0
4	26.50	1.581	10	2.56	-0.32	29.0
5	27.00	1.944	10	1.69	0.20	22.0*
6	27.90	1.853	10	1.86	1.11	25.0
7	26.60	1.776	10	2.03	-0.20	28.5
8	27.50	1.269	10	3.97	0.78	31.0
9	27.40	2.413	10	1.10	0.54	21.5*
10	27.40	2.413	10	1.10	0.54	27.5

Table 5.26 Results for period III validation: hours worked by trucks per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	9.54	0.430	10				
Stream							
1	9.48	0.520	10	1.46	-0.28	43.5	0.671
2	9.34	0.552	10	1.65	-0.90	29.5	0.671
3	10.00	0.432	10	1.01	2.39*	42.0	1.118
4	9.49	0.831	10	3.73	-0.17	42.0	0.671
5	10.10	0.302	10	2.03	3.37	33.0	1.565
6	9.56	0.692	10	2.59	0.08	43.5	0.224
7	9.73	0.787	10	3.35	0.67	39.0	1.118
8	9.20	0.720	10	2.80	-1.28	45.0	0.671
9	9.62	0.671	10	2.44	0.32	39.5	0.671
10	9.33	0.570	10	1.76	-0.93	42.5	0.894

* Signifcantly different at the 0.05 probability level
1 Mann-Whitney U statistic
2 Kolmogorov-Smirnov Z statistic

Table 5.27 Results for period III validation: hours worked by loader 71 per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	10.49	0.723	10				
Stream							
1	10.76	0.740	10	1.05	0.83	24.5	0.894
2	10.43	0.618	10	1.37	-0.20	45.5	0.447
3	10.95	0.700	10	1.07	1.45	32.0	0.671
4	10.47	0.793	10	1.21	-0.06	46.5	0.671
5	10.53	0.803	10	1.23	0.12	42.0	0.224
6	10.65	0.578	10	1.57	0.55	49.5	0.447
7	10.10	0.392	10	3.41	-1.50	42.5	0.894
8	10.83	0.769	10	1.13	1.02	39.0	0.671
9	10.44	0.544	10	1.77	-0.17	43.0	0.671
10	10.37	0.672	10	1.16	-0.38	47.5	0.447

Table 5.28 Results for period III validation: hours worked by loader 72 per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	10.81	0.928	7				
Stream							
1	10.24	0.907	8	1.05	-1.22	26.5	0.966
2	11.24	1.080	7	1.35	0.80	22.0	0.535
3	11.04	0.609	9	2.33	0.60	14.0	0.693
4	11.70	0.800	7	1.35	1.91	15.5	1.069
5	11.53	0.775	9	1.44	1.69	20.5	0.850
6	10.91	0.911	8	1.04	0.21	22.0	0.449
7	11.50	1.015	9	1.20	1.39	28.0	1.039
8	10.63	0.967	6	1.09	-0.34	17.0	0.599
9	10.81	1.097	8	1.40	0.00	24.5	0.690
10	10.68	1.044	8	1.27	-0.27	26.5	0.483

* Signifcantly different at the 0.05 probability level
1 Mann-Whitney U statistic
2 Kolmogorov-Smirnov Z statistic

Table 5.29 Results for period III validation: hours worked by loader 73 per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	9.70	1.018	8				
Stream							
1	9.84	0.226	8	20.24*	0.37	21.0	0.750
2	9.94	1.224	9	1.44	0.44	18.5	0.457
3	9.53	0.924	9	1.17	-0.35	20.0	0.600
4	9.33	0.918	8	1.23	-0.77	17.5	1.000
5	9.95	0.838	8	1.48	0.54	24.0	0.500
6	8.32	2.139	6	4.41	-1.62	20.5	0.772
7	9.79	1.162	8	1.30	0.16	20.5	0.250
8	9.81	0.552	7	3.40	0.26	22.5	0.483
9	9.06	1.131	7	1.23	-1.16	21.0	0.932
10	8.77	1.216	7	1.43	-1.61	23.0	0.932

Table 5.30 Results for period III validation: hours worked by loader 74 per day

	Mean	S.D.	Days	F-statistic	T-statistic	M-W U[1]	K-S Z[2]
Actual	9.52	1.179	9				
Stream							
1	9.15	0.987	8	1.43	-0.70	33.0	0.686
2	8.99	1.404	7	1.42	-0.83	29.0	1.039
3	9.79	1.302	8	1.22	0.44	30.5	0.829
4	8.93	0.680	8	3.01	-1.26	32.5	1.086
5	9.58	1.537	8	1.70	0.473	35.5	0.600
6	10.34	1.583	10	1.80	1.26	29.0	0.846
7	9.03	1.189	8	1.02	-0.86	26.0	0.857
8	9.38	1.194	10	1.03	-0.26	40.5	0.822
9	10.30	1.647	8	1.95	1.13	33.5	0.800
10	9.38	1.187	9	1.01	-0.26	36.5	0.707

* Significantly different at the 0.05 probability level
1 Mann-Whitney U statistic
2 Kolmogorov-Smirnov Z statistic

Table 5.31 Results for period III validation: percentage of loads delivered from NSW and Victoria

	NSW	Victoria
Actual	85.3	14.7
Stream		
1	83.9	16.1
2	80.3	19.7
3	84.8	15.2
4	84.2	15.8
5	85.5	14.5
6	90.8	9.2
7	85.5	14.5
8	86.0	14.0
9	87.3	12.7
10	88.1	11.9

Table 5.31 shows for the loads delivered from New South Wales and Victoria, the actual and simulated percentages of the total loads. There appears to be more variation among the random streams than in the previous period but the comparisons still indicate that the model is allocating loaders to achieve the required percentages from New South Wales and Victoria. The high variation is likely to be due to the algorithm which schedules the loaders to a forest block. This algorithm converges when large sample sizes are taken, that is, as the sample size increases, the estimated variance produced decreases. Thus, in the ten days of period III, the high variation produced by the algorithm due to small sample sizes could explain the variation among the random number streams.

5.4.4.4 Discussion

The tests undertaken to compare the actual and simulated performances over the selected validation periods strongly indicate, with the few exceptions discussed previously, that the model satisfactorily simulates the actual performance.

The model does appear to underestimate slightly the number of loads, tonnes delivered to the mill and hours worked by some of the loaders. There are a number of reasons why this could be so:

1. The periods selected for validation are some months after the collection of data for specific components such as loading times and travel times and these may have decreased with time as the learning process and training procedures within the ANM operation brought increased efficiency.

2. In running the model to test for its validity, the trucks were scheduled to commence work at the landing at exactly twenty minute intervals. In practice, this did not occur because truck drivers did not always meet their scheduled instructions. For example, if the truck that was scheduled to be at the landing at the start time of the loader was late, then there would have been the tendency for the formation of queues in the real system. In simulation, trucks were never late.

The model also appears to slightly overestimate the time worked for loaders 71 and 72. However, there are few significant differences between simulated and actual performances and modifications of the model were deemed unnecessary.

The model did have difficulties in adequately simulating the performance of loader 74. However, in period II, the trucks did not operate in a 'shuttle service' to this loader as was assumed for all simulation runs. Furthermore, the interval between scheduled trucks arriving on the landing was much longer than the twenty minutes programmed in the model. While such events and operating procedures occurred in the two other periods selected for validation, they were not as frequent. Although these anomolies were not frequent enough to lead to significant differences between the actual and simulated performance, they would cause a slight underestimate of loader hours.

5.5 DAILY VALIDATION

5.5.1 Introduction

The validation of the daily performance of the model was undertaken to provide further assessment of the performance of the model before reaching a conclusion as to its validity and applying it for predictive and experimental purposes. It involved comparison of the loads and tonnes delivered and the hours worked by loaders and trucks for a particular day.

The following information was collected to specify the inputs to the model for each day selected for a validation run:

1. Number of trucks scheduled to each loader
2. Number of loaders working
3. Hours worked by each loader which became the scheduled hours of operation of the loader
4. Location of each loader in a forest block
5. Time loader began in the morning
6. Time weighbridge opened.

The first five of these categories of data were extracted from the data used in the reported period validation of the model and are of course, the major influences on the amount of wood hauled in one day by the trucks. The fifth category was incorporated to check the ability of the model to predict the tonneage delivered to the mill within that constraint. Lastly, it was observed on some days, that the weighbridge opened prior to the usual time of approximately 7.30 am. The early opening time was usually 6.00 am. The model had to simulate the early opening times to match the early loader and truck start times.

5.5.2 Comparison of the Real and Simulated Daily Performance

The aim of the validation was to compare the daily deliveries and hours worked for each individual day for the months of November 1982, February 1983 and June 1983 with those predicted by the model. Ten random number streams were again used for each day. Since there was only one daily result in the real world for any variable such as loads delivered, statistical comparisons between the simulation output and the real world were not possible and these validations were by study of the comparative performances.

The comparisons are listed in Appendix 5.4. The worst comparisons for each month are presented in Tables 5.32 to 5.34. Each of them are examined in detail.

5.5.2.1 November 22nd 1982

The comparisons of the actual and simulated performance for November 22nd are presented in Table 5.32. The simulation model overestimates both the NSW and Victorian loads delivered. Examination of the data of the actual performances showed vehicles were not returning to the landing for extra loads, even when there was sufficient time to do so. The reasons are not known. The overestimation of the loads in simulation would consequently lead to the higher hours worked by the trucks.

Table 5.32 Daily validation November 22nd 1982: comparison of loads delivered and hours worked

	NSW loads	Vic loads	Total loads	Tonnes	Truck hours	Loader 71		Loader 72		Loader 73		Loader 74	
						Loads	Hours	Loads	Hours	Loads	Hours	Loads	Hours
Actual	42	24	66	1585	10.1	21	11.0	21	12.0	24	12.2	0	0.
Stream													
1	46	27	73	1714	10.9	23	11.4	23	11.7	27	12.9	0	0.
2	43	25	68	1642	10.7	22	10.5	21	11.4	25	12.8	0	0.
3	45	27	72	1701	10.8	23	11.7	22	12.0	27	12.6	0	0.
4	44	26	70	1657	10.4	22	10.1	22	11.3	26	12.4	0	0.
5	46	26	72	1681	11.0	23	11.4	23	12.3	26	12.7	0	0.
6	46	27	73	1739	11.1	24	11.8	22	12.1	27	13.0	0	0.
7	46	27	73	1705	11.2	23	11.1	23	12.2	27	13.4	0	0.
8	46	28	74	1777	11.3	24	11.7	22	11.7	28	12.9	0	0.
9	44	27	71	1693	10.5	22	9.9	22	12.1	27	12.6	0	0.
10	45	25	70	1657	10.6	23	10.9	22	11.6	25	12.3	0	0.

Table 5.33 Daily validation February 11th 1983: comparison of loads delivered and hours worked

	NSW loads	Vic loads	Total loads	Tonnes	Truck hours	Loader 71		Loader 72		Loader 73		Loader 74	
						Loads	Hours	Loads	Hours	Loads	Hours	Loads	Hours
Actual	37	20	57	1343	9.2	19	10.0	18	9.0	20	11.0	0	0.
Stream													
1	36	24	60	1419	9.6	18	9.9	18	9.3	24	11.4	0	0.
2	36	23	59	1406	10.2	18	11.0	18	10.0	23	11.2	0	0.
3	36	24	60	1419	9.6	18	9.5	18	8.8	24	11.6	0	0.
4	36	24	60	1431	9.8	18	9.9	18	9.5	24	11.5	0	0.
5	36	25	61	1437	9.8	18	9.8	18	9.4	25	11.8	0	0.
6	36	24	60	1413	9.7	18	9.5	18	9.3	24	11.9	0	0.
7	36	22	58	1341	9.5	18	9.5	18	9.5	22	11.0	0	0.
8	37	23	60	1448	9.7	18	10.4	18	9.0	23	11.5	0	0.
9	36	23	59	1384	9.7	18	9.7	18	9.5	23	11.4	0	0.
10	36	23	59	1420	9.6	18	9.9	18	8.9	23	11.7	0	0.

Table 5.34 Daily validation June 2nd 1983: comparison of loads delivered and hours worked

	NSW loads	Vic loads	Total loads	Tonnes	Truck hours	Loader 71		Loader 72		Loader 73		Loader 74	
						Loads	Hours	Loads	Hours	Loads	Hours	Loads	Hours
Actual	59	14	73	1727	10.0	21	11.1	24	10.8	14	10.0	14	8.4
Stream													
1	56	12	68	1588	9.6	20	9.8	22	11.4	12	10.1	14	9.0
2	54	12	66	1604	9.9	21	11.8	21	11.4	12	10.6	12	8.9
3	58	14	72	1726	10.3	22	11.9	23	12.0	14	11.4	13	8.3
4	56	12	68	1621	9.5	22	11.5	21	10.8	12	10.1	13	9.2
5	57	13	70	1661	9.9	21	11.4	22	11.4	13	10.4	14	9.0
6	56	13	69	1631	9.9	20	10.3	22	11.2	13	9.3	14	9.1
7	56	13	69	1652	9.8	21	11.0	22	11.3	13	9.5	13	9.0
8	55	13	68	1647	9.8	20	10.2	21	11.1	13	9.6	14	9.0
9	56	13	69	1657	9.7	21	10.8	22	11.4	13	9.8	13	8.5
10	57	13	70	1659	10.1	21	11.2	22	11.2	13	10.6	14	9.1

The higher times worked by the loaders can also be related to the higher number of loads delivered.

5.5.2.2 February 11th 1983

The simulated and actual performances for February 11th are presented in Table 5.33. The simulated NSW loads are very close to the actual loads delivered. Both loader 71 and 72 (in NSW) are delivering the correct number of loads, although in nine cases, loader 71 is one below the actual. The simulated hours worked by the two loaders are also similar to the actual hours worked.

However, the simulation model has again overestimated the number of loads delivered from Victoria (loader 73). Examination of the records showed that loader 71 and 73 swapped some trucks on that day with the effect of reducing the loads delivered from Victoria, but due to the long haul, not affecting NSW's output. Some trucks had taken one load from each of loader 71 and 73, with no time for a third load. The simulator scheduled eight trucks to loader 73 in a 'shuttle' service, each truck achieving nearly three loads. As a result of the increased loads delivered, the hours worked by loader 73 are also greater than the actual hours worked.

5.5.2.3 June 2nd 1983

The simulated and actual performances are presented in Table 5.34. The simulated NSW loads fall short of the actual loads delivered. Of the three loaders in NSW (71,72,74) it is loader 72 that is the cause of the underestimation. This is inexplicable, but there may have been exceptionally quick loading and travel times on this day or there could have been an error in the records. For example, if the loader hours worked for loader 72 were 11.8 instead of 10.8, the correct number of loads may have been simulated.

In all other cases, it was accepted that the model adequately represents the log hauling on June 2nd 1983.

5.5.3 Review of Daily Validation

The results cited were chosen as the worst of the comparisons undertaken. All the comparisons made are shown in Appendix 5.4 and for most days, the simulation model output is very close to the actual performances.

Table 5.35 shows the total bias for the loads delivered for each of the four loaders over the 51 individual days simulated for the daily validation. Loads delivered by loader 71 do not seem to be biased either way. Loads for both loaders 72 and 74 appear to be overestimated while the model underestimates the number of loads delivered by loader 73. Table 5.35 suggests that a difference between the actual and simulated loads delivered of less than or equal to one will occur 78% of the time for loaders 72 and 73, 81% for loader 74 and 89% for loader 71. Thus, this suggests that the bias is not substantial and it was accepted that the comparison suggests that the model is realistic and reliable.

Table 5.36 shows the total bias for both the truck hours and loader hours worked. In all cases, the model underestimates the time

Table 5.35 Number of occurrences for various differences between actual and simulated loads delivered per day

Number of occurrences

Loader	Difference between actual and simulated loads								
	≤-4	=-3	=-2	=-1	= 0	=+1	=+2	=+3	≥4
71	0	4	30	98	230	127	20	1	0
72	2	22	20	59	194	143	51	18	1
73	9	24	66	103	229	64	14	1	0
74	2	17	7	44	260	108	70	1	1

1 The total number of days simulated for each loader was 510, that is, ten random number streams for each of 51 days.

Table 5.36 Number of occurrences for various differences between actual and simulated hours worked per day

Number of occurrences

Loader	Difference between actual and simulated loads									
	≤-.8	≤-.6	≤-.4	≤-.2	= 0	>0	≥.2	≥.4	≥.6	≥0.8
Truck hours	26	46	56	124	69	108	51	14	12	4
Loader 71	38	64	61	91	47	72	43	27	27	40
Loader 72	33	58	84	108	52	94	33	6	19	23
Loader 73	39	90	70	96	52	97	17	12	14	23
Loader 74	27	29	26	33	19	113	36	20	48	159

spent on the landing by the loaders and the hours worked by the trucks. The tables suggest that for loader 74, the difference between the actual and simulated hours worked will be less than 0.6 hours 48% of the time, 67% of the time for loaders 71 and 73 and 74% for loader 72. In the case of truck hours, the actual versus simulated difference will be less than 0.6 hours 83% of the time. However, again, there was no reason to suggest that the bias is substantial or that the model is unrealistic and unreliable. There is some indication that generally either mean travel times or mean loading times may be slightly lower than they should be.

5.6 CONCLUSION

The comparisons and assessments of the results of the simulation runs made to validate the model all indicate that the model is adequately representing actual performances. The model was therefore accepted as validated for experimental simulations.

CHAPTER 6

EXPERIMENTAL APPLICATION OF THE SIMULATION MODEL

6.1 INTRODUCTION

In experiments with simulation models, the performance of the real system is 'observed' under combinations of controllable variables and parameters which are called factors (Emshoff and Sisson 1970 and Hunter and Naylor 1970). However, investigation of the response of a system to changes to a few factors but at various levels, that is a sensitivity approach to experimental study, may involve a high number of combinations. One aim of experimental design is to reduce the number of combinations of factors and still achieve the 'best' results from the experiments. The experiments are of course often directed towards problem solving and achieving efficient operation of the system.

The factors associated with the experiments can be changed in either a continuous or discrete fashion. If a factor is taken as continuous, then an infinite number of outcomes would be possible, but not of course feasible. If factors are taken as discrete, that is they take on only specific values, there will be a finite number of outcomes or alternatives, but the number may still be very large.

The experimental design should ensure that all possible information is incorporated in the model (Kleijnan 1977) and then the experiment run to determine efficiently the most appropriate inputs and constraints on the system to achieve the objective function. There are often difficulties in determining the objective function and the criteria to evaluate the system performance, but there are further difficulties, particularly where the variables are continuous, in reaching a determination of the solution to be accepted as the best, for there are usually many combinations which would produce results approaching the 'best'.

When factors take on only discrete values, the most common approach to find the 'best' solution is factorial analysis. In a full factorial design, each factor has a number of levels associated with it. The outcome of the response variable is attributed both to the factor levels themselves (main effects) and to the combined effect of the factors (interactions). The optimum combination of factor levels can then be found. However, even if the number of factors and their levels is small, a full factorial design may produce an unmanageable number of outcomes (Hunter and Naylor 1970). Kleijnan (1974) lists a number of methods for screening a full factorial design to obtain a reduced experiment.

The design of simulation experiments and assessment of the experimental results of simulation runs also presents some theoretical and practical problems. The theory behind the design of simulation experiments is largely based on the theory of physical experimental design (Biles and Swain 1980 and Hillier and Leiberman 1980). The analyst must establish both the simulation run length and the initial set of random number seeds for the experimental design (Biles and Swain op.cit.).

The simulation run length determines the sample size which in turn affects the 'statistical reliability' of the simulated estimated response (Kleijnan 1974). The reliability of the estimate can be increased by increasing the simulation run length. However, this also increases the computer costs. Shannon (1975) suggests a method based on the known variability in the system, the risks the analyst wishes to take in making the wrong prediction and the difference allowed between the estimate and the true parameter.

The analyst must also decide whether to use a constant random number seed or to replicate experiments with different random number seeds. Kleijnan (1974) suggests the use of replicated experiments such that each run yields an independent observation and classical statistical techniques can be used to analyze the results. On the other hand, Hillier and Lieberman (1980) suggest that the same random number seed be used throughout the experiment, for this ensures that experimental conditions are held constant. The difference between the alternatives is then due to the input changes rather than random fluctuations and the approach is particularly useful for the comparison of alternatives.

Simulation experiments are often concerned with finding the optimum response for certain inputs or outputs and this is the case for the simulation model of log haulage. For example, what is the best number of trucks to deliver the required tonneage of wood per day to a paper mill from various forest blocks? Clearly, the optimization aspect of experimental studies is a critical aspect of experimental design and is discussed in detail.

6.2 OPTIMIZATION OF SIMULATED SYSTEMS

Optimization is the process of finding the 'best' or optimal solution to a problem (Biles and Swain 1980 and Foulds 1981). Optimization entails the manipulation of quantifiable and controllable variables to maximize or minimize a function which represents the performance of the system.

Biles and Swain (op.cit.) classify optimization problems into three categories:

1. Analytical methods
2. Numerical methods
3. Mathematical programming.

Analytical methods are based on the concept of the derivative from calculus. The idea is to equate the derivative to zero and solve for the stationary point. The analytical methods used are called 'Classical Optimization' techniques.

Numerical methods are more commonly used, since many relations are not amenable to analytical methods. There are two main techniques for optimization of both single- and multi-variable functions. Gradient methods use partial derivatives of the function to obtain an optimal solution, while direct search techniques make no assumptions about the function being optimized. These methods have been mainly developed to deal with unconstrained problems.

Mathematical programming uses computational procedures to systematically find optimal solutions to multivariable constrained problems.

The operations of the simulation model developed for this study are not determined by relationships expressed as functions and analytical and numerical methods are not therefore appropriate for its application. Mathematical programming methods are briefly examined in the following sections.

6.2.1 Mathematical Programming

Mathematical programming techniques are used to solve problems that have several independent variables and several dependent variables or responses (Foulds 1981). The techniques can be classified on the following lines:

1. Linear
2. Nonlinear

6.2.1.1 Linear programming

The objective of linear programming is to optimize a linear objective function which is subject to linear constraints (Eldin 1981 and Foulds (op.cit.). Components of the objective function are usually dollars and optimization involves either maximizing revenue or minimizing costs.

Linear programming was developed over 50 years ago, but it was not until Dantzig developed in 1947 an efficient algorithm, the 'simplex method' and the development of efficient computer solutions, that it became widely used (Dantzig 1963). The simplex method is not the only algorithm that can be used, but it has proved to be the most efficient (Williams 1978). Linear programming is one of the most widely used techniques in mathematical programming (Hall 1967). Foulds (op.cit.) describes a wide variety of problems solved by linear programming; from resource allocation to network analysis to transport distribution systems.

Other than the requirement of linearity in both the objective function and the constraints, linear programming has important assumptions:

1. Additivity requires that all activities are independent and that there are no interactions between activities. Thus, the sum of the outputs of independent activities equals the output of the combined activities.

2. Divisibility assumes that any activity can be divided into any fractional level so that non integer answers are possible.

3. Certainty assumes that the model is deterministic and that outcomes occur with certainty.

Only one objective function can be solved at a time in linear programming. Many critics of linear programming see this as a significant disadvantage for in many industrial processes, it is difficult to isolate a single objective function.

Charnes and Cooper (1961) presented an approach called goal programming where multiple objectives could be solved. It has the same assumptions of additivity, divisibility, non-negativity and linearity as linear programming. Goal programming involves multiple objective functions in which priorities and weightings are attached to each objective or goal. Unlike linear programming which finds a feasible or optimal solution only if all constraints are satisfied, goal programming need not satisfy all objectives completely (Field 1977). A solution is found that minimizes the weighted sum of deviations of the objective functions from their respective goals.

Linear programming assumes divisibility for all activities, but in many cases, the decision variables can only take on integer values, for example, men or machines assigned to various activities. This additional restriction led to integer linear programming (IP). If a model consists entirely of integer values, then it is pure integer programming (PIP). It is more usual to have the continuous and discrete variables present and this is called mixed-integer programming (MIP) (Williams 1978).

One method of solving integer problems is to solve the problem by linear programming and round off the values to an integer solution (Bell 1977). Although sometimes useful, many authors are critical of this method (Newnham 1973, Mital 1976, Williams 1978 and Foulds 1981).

Unlike linear programming, there is not one single efficient algorithm that can be used to solve integer programming (Bare and Norman 1969). A frequently successful algorithm used in most commercial packages is the branch and bound technique (Williams op.cit.). The problem is solved first as a linear programming problem by relaxing the integer constraints. The algorithm systematically searches through the solution set for an improvement to either a lower or higher bound, depending on whether maximizing or minimizing.

The main problem with integer programming is the lack of a universal efficient algorithm. It involves many more calculations than does a similar linear programming problem and even with high speed computers, it is not always possible to solve an integer problem in a reasonable time.

6.2.1.2 Nonlinear programming

In linear programming, there are constant returns to scale, for example, every unit of product 1 will yield for example $50, regardless of how many units are produced. However, in nonlinear programming, the objective function and constraints may be nonlinear. Thus, the unit yield of product 1 will depend on how many units are produced; and there can be increasing or decreasing returns to scale. Finding solutions to nonlinear problems is much more complicated than for linear problems. There are a number of techniques to solve problems with specific mixtures of objective functions and constraints in the non-linear form:

1. Quadratic programming. The method extends linear programming techniques to objective functions which are quadratic in nature, but the constraints must remain linear (Eldin 1981).

2. Separable programming. Each function of the problem may be expressed as the sum of a number of functions of one variable and an appropriate solution can be obtained by making each function a linear approximation and using linear programming (Foulds 1981).

3. Geometric programming. This technique deals with both constrained and unconstrained minimization and the nonlinearities take the form of polynomials.

In experimental studies with the simulation model, which seeks an optimal allocation of discrete numbers of items of equipment, division of a piece of equipment or combinations of equipment is obviously precluded. Therefore, neither linear or nonlinear programming are applicable and integer programming must be used to determine optimum allocation of these resources in the experimental studies.

6.3 OUTLINE OF THE EXPERIMENTAL STUDIES

6.3.1 Experimental Design

It is clear that the design of experiments with simulation models requires careful planning. It is equally clear that the selection of the experiments and in particular, the specification of the objective function, is also important.

The aim of the studies was to use the validated simulation model in conjunction with an optimization model to minimize the loading and hauling cost of a log hauling operation when the following factors were changed:

1. Gross vehicle weight limits for trucks
2. Number of shifts for both trucks and loaders
3. Time to load a truck.

The studies were also seen as a demonstration of the application of the simulation model.

The literature shows many cases of substantial savings when payloads are increased. However, as payloads increase, so do factors such as load time, travel time, fuel consumption and others. It is therefore difficult to gauge (without simulation) the extent, if any, of cost savings when gross vehicle weight limits are increased, especially when one way haul distances of the magnitude present in the ANM operation are involved. The simulation model was therefore used to determine the cost savings with increased gross vehicle weight limits.

Since much of the equipment in the ANM operation is leased, any increase in the hours worked by trucks and loaders reduces the average hourly fixed costs of the leased equipment. However, unless the extra hours enable the delivery of sufficient extra loads, the total unit costs may not be reduced for the additional variable costs may be relatively high, for example, overtime to drivers. The simulation model was therefore used to determine if cost savings could occur by double shifting trucks and loaders.

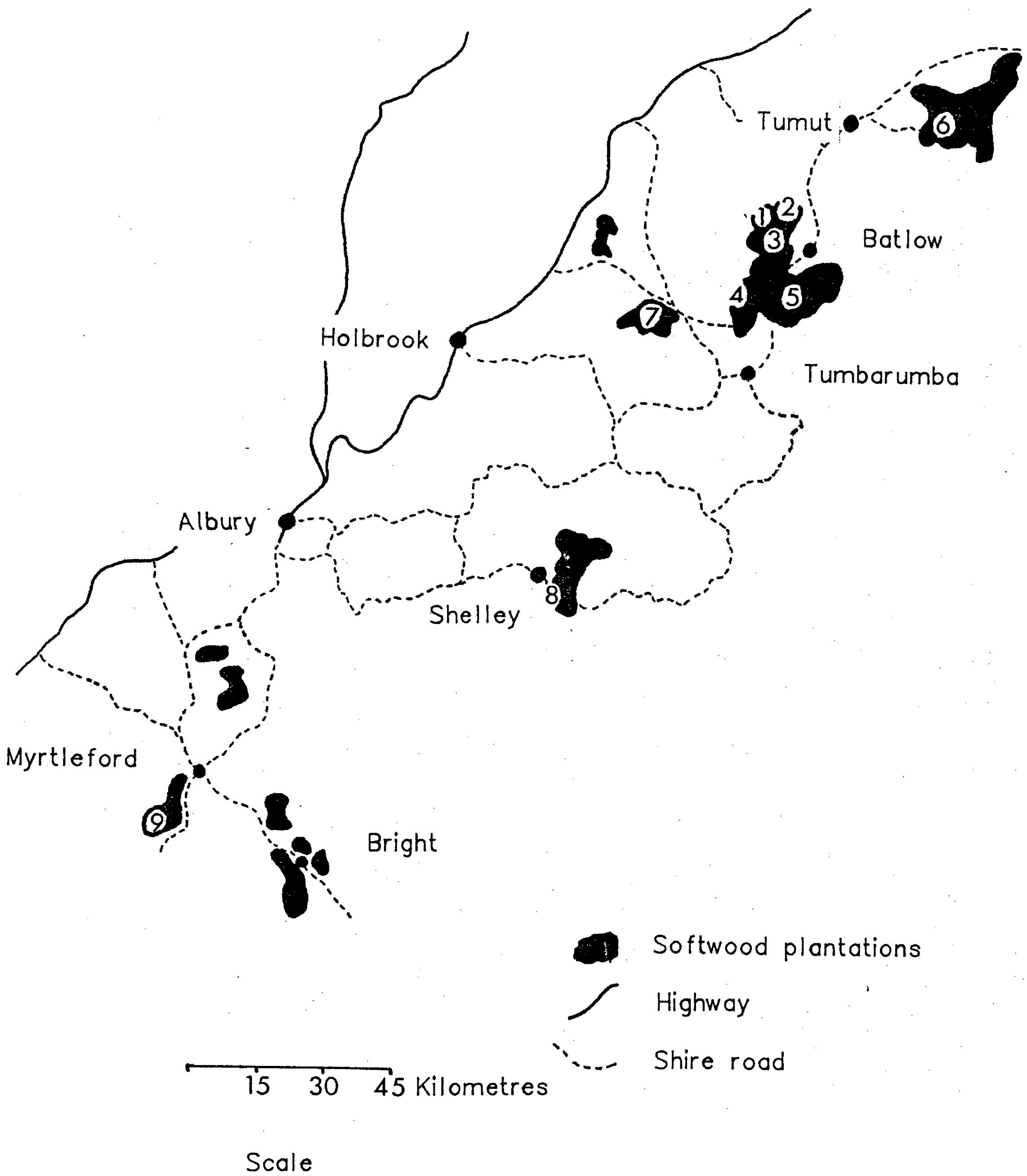
There was approximately five minutes difference between the mean times to load a truck by the fastest and slowest of the ANM loaders respectively and there are other types of mobile cranes available which may substantially reduce the loading times of trucks. The simulation model was therefore used to determine to what extent, substantial reductions in mean loading times would reduce the costs of the log hauling operations.

All three studies required a defined transport task and it was determined that the optimization process involve the distribution of trucks to loaders at minimum costs, while delivering at least 8 000 tonnes of wood per week from nine locations to the Albury mill. The nine locations are shown in Map 6.1. These locations were specified since they broadly represented the average positioning of harvesting contractors throughout the year. Each location had a specified quota to supply per week. The specified tonneages and one way haul distances from each location are shown in Table 6.1.

Table 6.1 Specified haulage quotas (tonnes per week)

Location	Distance (km)	Quota	Location	Distance (km)	Quota
Green Hills-1	165	700	Bondo	220	1050
Green Hills-2	164	700	Carabost-2	114	1050
Green Hills-3	160	700	Shelley	107	1400
Green Hills-5	158	1050	Myrtleford-1	108	700
Batlow-1	137	700			

Map 6.1 Location of harvesters



6.3.2 Simulation Methodology

The simulation model was run for haulage from the nine forest blocks specified in Table 6.1. For each forest block, truck numbers and scheduled loader hours were varied. A listing of the experimental simulation model and corresponding example of a data deck are given in Appendices 6.1 and 6.2.

Since the number of trucks is a discrete variable, a factorial design was adopted. The number of trucks was varied from three to eighteen and the scheduled loader hours from six to twelve hours. Less than three trucks was not simulated since ANM records showed that three trucks was the minimum number ever allocated to a loader. Although ANM records showed that eleven trucks was the maximum ever allocated to a loader, it was decided to oversupply the system with trucks to assess the change in the tonneage of wood delivered with increased truck numbers. A maximum of eighteen trucks was therefore adopted for the study.

Although the scheduled hours for loaders is not a discrete variable, it can be made so in simulation and the scheduled hours worked by each loader was varied by increments of one hour. Thus, for each set of trucks, scheduled loader hours from six to twelve were simulated. There were thus 112 responses or strategies simulated for each of the nine locations in the experiments.

Since the experiments were to compare alternatives and to distribute trucks amongst loaders in an optimal way, following Hillier and Liebermann (1980), only one random stream was used for all runs of the model. Hence, differences between alternatives are due to the inputs rather than random fluctuations.

The simulation model had to be run for an appropriate period of time to estimate the average daily response for each specified location, number of trucks and scheduled loader hours. Shannon's (1975) formulae was used to calculate the necessary sample size (Appendix 6.3). Twenty days was selected as an appropriate sample size.

Rather than expand the number of strategies from 112 to 448 for each location by simulating each of the four loaders, a single loader was used with a loading rate representative of all the loaders used at the time in the ANM operation. A mean and standard deviation of 24.0 and 4.8 minutes respectively for all loading times was calculated. Another advantage of using a single loader was that the responses to the varied factors of gross loadweights, double shifts and loading times would not be attributable, in part, to different performances of the loaders. Thus, assessment of the results was simplified. In addition, only one type of truck was used in the simulation runs rather than the three used in the ANM operation. The Fleetxpress semi-trailer combination was the most common, its payload and time spent in the mill was close to the average for all trucks and this combination was adopted for the study.

The appropriate travel time distributions described in Chapter 2 were used for each of the locations. However, no data were available for travel times from the Bondo forest block. The block requires a long cycle time for the trucks and in a normal day, only one load per truck would be delivered. Discussions were held with Greenfreight Pty Ltd and a mean loaded travel time of 225 minutes and a standard deviation of 25.0 were assumed. Since all the other loaded travel time distributions were three parameter log normal distributions, this was also used for the Bondo forest block.

The simulation model produced the following per day averages for the twenty day period:

1. Number of loads and tonnes delivered per day
2. Total hours, operating and idle hours of each loader
3. Total hours, travelling and standing hours of trucks
4. Loader and truck costs
5. Total cost and cost per tonne.

6.3.3 Assumptions and Constraints

The following assumptions and constraints were determined to contain the study to the available time, to restrict computation costs and to ensure that the simulated operations were feasible in practice.

1. All trucks started and finished at the mill. Although this was not the case for ANM, it was a reasonable assumption on which to base costs. In reality, trucks start from home and finish at home. Since in all cases, home was between the mill and the forests, this assumption should not significantly affect results, for driving time is transferred from one day to the next in the simulation.

2. Loaders commenced work at the assigned landing at specified times. The first truck was scheduled to depart from the mill in

the morning in order to arrive at the landing at the specified starting time of the loader. It was assumed that the truck would use the fastest empty travel time between the mill and particular forest block.

3. The trucks assigned to a loader started from the mill every twenty minutes. This is the interval allowed between arrivals by ANM when preparing instructions to the truck drivers for their arrival time at the landing in the morning. Due to the stochastic nature of the travel times, interarrival times of trucks on the landings will not equal twenty minutes, but over time, should approach a mean of twenty minutes.

4. Each truck was assigned to a loader and delivered wood only from that loader, that is, a 'shuttle service' was assumed.

5. The maximum length of a working day, that is maximum shift time was fourteen hours for trucks and twelve hours for loaders. These figures were based on information obtained from the ANM records.

6. Trucks always returned to the assigned loader as long as the loader was available and the maximum length of working day was not likely to be exceeded.

7. Operating costs derived in Chapter 2 were used to calculate loading and hauling costs.

8. The costs of moving loaders were excluded as in the simulation this operation was outside the scheduled loader hours and unit costs for this operation were not available.

6.3.4 Programming and Optimization Procedures

The aim was to determine the appropriate number of trucks required, 'x', and allocate them between 'y' loaders located in specified forest blocks, such that each loader delivered the specified tonneage at the minimum loading plus hauling cost.

To accomplish the hauling task, a weekly loader schedule was compiled to allocate the loaders day by day to forest blocks. Convenient and feasible loader schedules were formulated on a heuristic basis with both three and four loaders in service. All nine forest blocks were allocated a loader within a five day period. The schedules were changed as different experimental runs were conducted.

The heuristic formulation of the loader schedules was based on the experience with the ANM system. The method adopted for assigning the loaders involved assessment of the quota of each block and the distance from the mill. Loaders were kept within geographical limits as much as possible. Loader I was normally assigned to Bondo, the northern blocks of Green Hills and Batlow; loaders II and III the blocks of Green Hills, Batlow and Carabost and loader IV, the Victorian blocks of Shelley and Myrtleford. When only three loaders were in operation, the third loader was assigned to Carabost as well as the Victorian forests. Minor changes to the loader schedules were necessary because of the change in production rates over the different experiments.

Mixed-integer programming was used to optimize the number of trucks and allocate them to the loaders, because some variables such as tonnes delivered were continuous while others for example, the combination of trucks and loaders servicing a forest block and constituting a strategy, were declared integer. The package, Functional Mathematical Programming System (FMPS) available on the Univac 1100/82 computer and with capabilities for linear and mixed-integer programming, was selected for the optimization procedure. The FMPS package uses a branch and bound algorithm to solve specified problems.

The objective function was the total cost of the loading and hauling strategies with the constraints being the number of loaders used, the tonneage delivered and the number of trucks allocated. The aim was to minimize the cost of wood deliveries subject to these constraints. The tableau for one forest block is presented in Table 6.2 and described below.

Each column represents a simulated strategy of a number of trucks servicing a loader schedule for a particular number of hours in a forest block. The column headings in the tableau are as shown below:

0
) The forest block
1

T
)
1 Number of trucks
)
8

S
)
0 Scheduled hours of the loader in the forest block.
)
6

Thus, the column 01T03S06 represents forest block 01, with 03 trucks and a loader scheduled to work 06 hours, while 01T18S09

Table 6.2 Program tableau for optimization model

	01T03S06	01T03S07	01T03S08	01T03S09	01T03S10	01T03S11	01T03S12	01T04S06	01T04S07	01T04S08	01T04S09	01T04S10	01T04S11	01T04S12	01T05S06
NL01	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NL02															
NL03															
NL04															
MINT01	123	139	143	142	140	142	139	148	185	188	188	191	186	189	169
MINT02															
MINT03															
MINT04															
TNTKS	6	7	8	9	10	11	12	6	7	8	9	10	11	12	6
COST	1714	1859	1899	1884	1894	1885	1872	2109	2391	2398	2428	2428	2426	2435	2465

	01T10S09	01T10S10	01T10S11	01T10S12	01T11S06	01T11S07	01T11S08	01T11S09	01T11S10	01T11S11	01T11S12	01T12S06	01T12S07
NL01	1	1	1	1	1	1	1	1	1	1	1	1	1
NL02													
NL03													
NL04													
MINT01	451	464	473	471	282	367	429	474	508	513	516	308	386
MINT02													
MINT03													
MINT04													
TNTKS	9	10	11	12	6	7	8	9	10	11	12	6	7
COST	5639	5725	5765	5828	4468	5084	5575	5943	6263	6320	6307	4854	5442

	01T17S10	01T17S11	01T17S12	01T18S06	01T18S07	01T18S08	01T18S09	01T18S10	01T18S11	01T18S12
NL01	1	1	1	1	1	1	1	1	1	1
NL02										
NL03										
NL04										
MINT01	589	632	692	406	490	518	561	592	648	700
MINT02										
MINT03										
MINT04										
TNTKS	10	11	12	6	7	8	9	10	11	12
COST	8186	8690	9263	6915	7507	7771	8161	8428	8952	9558

represents forest block 01, 18 trucks servicing a loader scheduled to work 09 hours.

Each row represents a constraint applied to a strategy represented by a column. Thus, row NL01, which represents the constraint on the number of loaders in forest block 01, indicates that 1 loader was used in each of the column strategies. In addition, row MINT01 indicates the tonneage delivered from the loader in forest block 01 for each particular strategy, while TNTKS indicates the number of trucks used to deliver the wood.

A summarized tableau is presented in Table 6.3. Each forest block follows the pattern detailed in Table 6.2. The column RHS indicates the equalities or inequalities that must be met in relation to the resource constraints. For example, in Table 6.3, there are four loaders available that day, which are situated in forest blocks 1 to 4, one in each. In addition, each forest block must deliver at least the specified tonneage while the total specified number of trucks must be allocated to the landings in each forest block.

The output from the programme incorporating the optimization model was as follows:

1. Number of trucks assigned to each loader
2. Scheduled period each loader should work
3. Tonneage delivered from each loader
4. Total cost for each loading and hauling operation.

Table 6.3 Summary program tableau for optimization model

Resource Constraints	Forest block 1 3 -- 18 trucks[1] 6 -- 12 hours[2] (112 strategies)	Forest block 2	Forest block 3	Forest block 4	RHS[3]
NL01[4]	1 1 1 1				=1
NL02		1 1 1 1			=1
NL03			1 1 1 1		=1
NL04				1 1 1 1	=1
MINT01[5]					≥
MINT02					≥
MINT03					≥
MINT04					≥
TNTKS[6]	3 -- 18	3 -- 18	3 -- 18	3 -- 18	=
Objective function[7] (cost)					

1 Range of numbers of trucks simulated

2 Range of scheduled hours of loader simulated

3 Constraint (equality or inequality)

4 Numbers in row represent number of loaders used in each strategy

5 Numbers in row represent tonneage delivered by each strategy

6 Numbers in row represent number of trucks used in each strategy

7 Cost for each strategy

6.4 EXPERIMENT 1 : STUDIES OF GROSS VEHICLE WEIGHTS

6.4.1 Aim

While the allowable loadweights on trucks in Australia were reviewed in the early 70's and the recommended increases accepted by Governments, they are again under review and there is particular interest in provisions to enable a more extensive use of special permits to cover increased loadweights. This study was in part to assess any gain that might accrue from special permits for the ANM log trucks. Four limits for gross vehicle weights (gvw) were assessed in association with a single shift operation for both trucks and loaders:

1. 38 tonne gross vehicle weight
2. 40 tonne gross vehicle weight
3. 42 tonne gross vehicle weight
4. 53 tonne gross vehicle weight.

6.4.2 38 Tonne Gross Vehicle Weight Limit

6.4.2.1 Introduction

A range of 3 to 18 trucks were simulated for the experiment, with either 3 or 4 loaders operating from 6 to 12 scheduled hours, resulting in 112 strategies for each forest block.

Mean truck payloads were the same as was obtained for the Fleetxpress semi-trailer combinations in the ANM operation, namely 23.70 tonnes with a standard deviation of 1.98.

6.4.2.2 Results for four loaders

The detailed results by forest blocks with four loaders for the week are summarized in Table 6.4. The simulated total weekly cost for the operation was $97 200, and 8 240 tonnes were delivered at $11.80 per tonne. Thirty-six trucks were needed to deliver the necessary tonneage which is more than ANM would usually use.

Table 6.5 shows the loader and truck operating hours and their respective utilizations for each forest block. Loader utilizations ranged from 68% in Green Hills-3 to 95% in Myrtleford-1 while truck utilizations ranged from 64% in Myrtleford-1 to 85% in Green Hills-3.

6.4.2.3 Results for three loaders

The detailed results by forest blocks with three loaders for the week are presented in Table 6.6. The simulated total weekly cost for the operation was $99 400, and 8 120 tonnes were delivered at a cost of $12.30 per tonne. Thirty-eight trucks were needed to meet the mill requirements.

Table 6.7 shows the loader and truck operating hours and their respective utilizations for each forest block. Loader utilizations ranged from 81% at Carabost-2 to 95% at Batlow-1, Green Hills-3, Shelley and Myrtleford-1 while truck utilizations ranged from 57% in Myrtleford-1 to 86% in Bondo.

Table 6.4 Results for 38 tonne gross vehicle weight experiment using four loaders

Loader	Monday	Tuesday	Wednesday	Thursday	Friday
	Bondo (350)[1]	Bondo (350)	Bondo (350)	Batlow (350)	Batlow (350)
1	356[2]	356	356	350	350
	$6750[3]	$6750	$6750	$4430	$4430
	15[4]	15	15	8	8
	GH-1 (350)	GH-1 (350)	GH-3 (350)	GH-5 (525)	GH-5 (525)
2	369	369	368	529	529
	$4800	$4800	$4740	$5600	$5600
	8	8	8	10	10
	GH-3 (350)	GH-2 (350)	GH-2 (350)	Car-2 (550)	Car-2 (500)
3	368	379	379	554	516
	$4740	$4780	$4780	$4720	$4453
	8	8	8	8	8
	Myrt-1 (350)	Myrt-1 (350)	Shell (360)	Shell (520)	Shell (520)
4	352	352	365	521	521
	$3330	$3330	$3060	$4700	$4700
	5	5	5	10	10
Tonnes/day	1 450	1 460	1 470	1 950	1 920
Cost/day	$19 600	$19 700	$19 300	$19 400	$19 200
Total trucks	36	36	36	36	36

1 Specified tonneage from forest block
2 Actual tonneage delivered
3 Cost of loader and trucks
4 Number of trucks allocated

Table 6.5 Operating statistics of trucks and loaders for the 38 tonne gross vehicle weight experiment using four loaders

Forest block	Loaders			Trucks		
	Total hours	Operating hours	Utilization (%)	Total hours	Travelling hours	Utilization (%)
Batlow-1	17.0	12.0	71	170	141	83
Green Hills-1	18.4	13.0	71	192	155	81
Green Hills-2	18.8	13.0	69	189	157	83
Green Hills-3	18.6	12.6	68	184	157	85
Green Hills-5	21.4	18.2	85	222	178	80
Carabost-2	23.0	19.4	84	192	150	78
Shelley	29.0	24.0	83	243	179	74
Myrtleford-1	21.2	20.2	95	90	58	64
Bondo	19.5	18.3	94	374	315	84

Table 6.6 Results for 38 tonne gross vehicle weight experiment using three loaders

Loader	Monday	Tuesday	Wednesday	Thursday	Friday
	Bondo (90)[1]	Bondo (280)	Bondo (310)	Bondo (370)	Batlow (700)
1	95[2]	287	311	377	700
	$1970[3]	$5420	$5910	$7190	$9560
	4[4]	12	13	16	18
	GH-2 (700)	GH-1 (700)	GH-3 (700)	GH-5 (525)	GH-5 (525)
2	703	700	700	557	529
	$9200	$9720	$9620	$5900	$5600
	16	18	18	11	10
	Myrt-1 (700)	Car-2 (550)	Car-2 (500)	Shell (710)	Shell (690)
3	701	554	502	710	690
	$8320	$4720	$4230	$6230	$5820
	18	8	7	11	10
Tonnes/day	1 500	1 540	1 510	1 640	1 920
Cost/day	$19 500	$19 900	$19 800	$19 300	$21 000
Total trucks	38	38	38	38	38

1 Specified tonneage from forest block
2 Actual tonneage delivered
3 Cost of loader and trucks
4 Number of trucks allocated

Table 6.7 Operating statistics of trucks and loaders for the 38 tonne gross vehicle weight experiment using three loaders

Forest block	Loaders			Trucks		
	Total hours	Operating hours	Utilization (%)	Total hours	Operating hours	Utilization (%)
Batlow-1	12.8	12.1	95	203	140	69
Green Hills-1	12.5	11.8	94	211	144	68
Green Hills-2	12.6	11.9	94	194	146	75
Green Hills-3	12.4	11.8	95	211	146	72
Green Hills-5	20.9	18.6	89	229	183	80
Carabost-2	22.4	18.2	81	178	139	78
Shelley	25.3	24.0	95	256	178	70
Myrtleford-1	12.9	12.2	95	182	104	57
Bondo	19.4	18.2	94	366	315	86

6.4.3 40 Tonne Gross Vehicle Weight Limit

6.4.3.1 Introduction

A range of 5 to 16 trucks were simulated, with the loaders operating from 6 to 12 hours, a total of 84 strategies for each forest block.

Mean truck payloads were increased by 2 tonnes (8%) to 25.70 tonnes as compared to the 38 tonne experiment. Both load times and travel full times were adjusted to compensate for this increase. After consultation with personnel at ANM, load times were increased by 5% and travel full times by 4%. Travel empty times were not adjusted. Since the unloader in the mill can unload one truck bay at a time (approximately 12 tonnes), the time in the mill for unloading was not increased.

6.4.3.2 Results for four loaders

The simulated total weekly cost for the operation was $90 500 and 8 210 tonnes were delivered at $11.00 per tonne. The operation required 33 trucks per day. The loader utilizations ranged from 56% in Myrtleford-1 to 85% in Green Hills-5 while truck utilizations ranged from 75% in Shelley to 85% in Green Hills-3.

6.4.3.3 Results for three loaders

The simulated total weekly cost for the operation was $90 700, and 8 170 tonnes were delivered at $11.20 per tonne. To meet the mill requirements, the operation required 33 trucks, the same as the 'four loader' operation. Loader utilizations ranged from 67% in Batlow-1 to 95% in Green Hills-1, -2 and Bondo, while truck utilizations ranged from 71% in Shelley to 83% in Batlow-1 and Bondo.

6.4.4 42 Tonne Gross Vehicle Weight Limit

6.4.4.1 Introduction

A range of 5 to 16 trucks, with loaders operating 6 to 12 hours were simulated, resulting in 84 strategies for each forest block.

Mean truck payloads were increased to 27.70 tonnes, an increase of 17% from the 38 tonne gvw. Both load times and travel full times were increased by 10% and 8% respectively from the 38 tonne gvw limit.

6.4.4.2 Results for four loaders

The simulated total weekly cost for the operation was $86 300 and 8 240 tonnes were delivered at $10.50 per tonne. The operation required 31 trucks per day to meet the requirements. Loader utilizations ranged from 56% at Myrtleford-1 to 93% at Bondo, while truck utilizations ranged from 77% at Carabost-2 and Shelley to 85% at Green Hills-3.

6.4.4.3 Results for three loaders

The simulated total weekly cost for the operation was $86 100 and 8 190 tonnes were delivered at $10.50 per tonne. To meet the mill requirements, 31 trucks were used, the same as the 'four loader' experiment. Loader utilizations ranged from 64% in Batlow to 95% in Bondo while truck utilizations ranged from 70% in Shelley to 84% in Batlow-1.

6.4.5 53 Tonne Gross Vehicle Weight Limit

6.4.5.1 Introduction

A range of 3 to 14 trucks and loaders scheduled to work 5 to 12 hours were simulated, that is 96 strategies for each forest block.

Mean truck payloads were increased to 34.5 tonnes with a standard deviation of 1.0. Since this configuration of truck was new in the logging industry, the mean of 34.5 tonnes was somewhat arbitrary. In the ACT, the gross vehicle weight limit for six-axled semi-trailer combinations is 48 tonne and the mean payload of logs is 32 tonnes. These figures were used as a guideline in adopting 34.5 tonnes as the mean payload of a truck with a gross vehicle weight of 53 tonnes.

To compensate for the increased payloads, load times were increased by 35%, travel full times by 25%, fuel consumption by 21% and time spent in the mill by 22%. These figures were adopted after consultation with ANM staff. They are taken as indications of increases that may occur under increased payloads for there is no available data on the performance of such vehicles on public roads in Australia. Ada(1979) found the mean load time for 48 tonne gvw trucks using a similar loading technique to ANM's to be approximately 33 minutes. The increase applied to the ANM basic loading time brought the loading time to approximately 33 minutes also.

6.4.5.2 Results for four loaders

The simulated total weekly operating cost was \$79 700 and 8 320 tonnes were delivered at a cost of \$9.60 per tonne. Twenty-five trucks were necessary to meet the mill requirements. Loader utilizations ranged from 56% in Myrtleford-1 to 96% in Bondo, while truck utilizations ranged from 76% in Carabost-2 to 83% in Green Hills-3.

6.4.5.3 Results for three loaders

The simulated total weekly operating cost was \$79 300 and 8 210 tonnes were delivered at a cost of \$9.70 per tonne. Twenty-six trucks were needed to meet the mill requirements. Loader utilizations ranged from 59% in Green Hills-1 to 95% in Bondo and Myrtleford-1 while truck utilizations ranged from 69% in Myrtleford-1 to 92% in Bondo.

6.4.6 Summary of Gross Vehicle Weight Results

The results of the experiments on the gross vehicle weight limits are summarized for comparison in Tables 6.8 to 6.10.

6.4.7 Review of Gross Vehicle Weight Results

6.4.7.1 The effect of gross vehicle weights on loading and hauling costs

Figure 6.1 shows the simulated total weekly costs for loading and hauling the wood for the selected allowable gross vehicle weight. The studies indicate substantial savings for increased gross vehicle

Table 6.8 Simulated weekly wood deliveries and costs over a five day period for the gross vehicle weight experiment

		Gross Vehicle Weight Limit (tonnes)			
Number of loaders		38	40	42	53
4	Wood deliveries (tonnes)	8 240	8 210	8 240	8 320
	Cost ($)	97 200	90 500	86 300	79 700
	Cost ($/tonne)	11.80	11.00	10.50	9.60
3	Wood deliveries (tonnes)	8 120	8 170	8 190	8 210
	Cost ($)	99 400	90 700	86 100	79 300
	Cost ($/tonne)	12.30	11.20	10.50	9.70

Table 6.9 Simulated utilization of loaders over a five day period for the gross vehicle weight experiment

	Gross vehicle weight limit (tonnes)											
	38			40			42			53		
Forest Block	A[1]	B[2]	C[3]	A	B	C	A	B	C	A	B	C
4 loaders												
Batlow-1	17.0	12.0	71	18.0	12.0	67	17.4	11.5	66	19.1	11.8	62
Green Hills-1	18.4	13.0	71	18.0	11.8	66	18.2	11.5	63	19.3	11.6	60
Green Hills-2	18.8	13.0	69	18.0	11.8	66	18.2	11.3	62	19.4	11.7	60
Green Hills-3	18.6	12.6	68	18.2	11.6	64	18.7	11.4	61	19.4	11.5	59
Green Hills-5	21.4	18.2	85	20.8	17.6	85	20.4	16.8	82	19.7	16.7	85
Carabost-2	23.0	19.4	84	21.6	17.8	82	21.6	17.1	79	23.5	16.7	71
Shelley	29.0	24.0	83	28.4	23.6	83	29.0	22.8	79	34.2	22.3	65
Myrtleford-1	21.2	20.2	95	20.6	11.6	56	20.6	11.6	56	20.9	11.6	56
Bondo	19.5	18.3	94	18.9	17.7	94	18.3	17.1	93	17.6	16.9	96
Total (per week)	187	151	81	183	136	74	182	131	72	193	131	68
Average/ loader/day	9.35			9.15			9.1			9.65		
3 loaders												
Batlow-1	12.8	12.1	95	18.0	12.0	67	18.1	11.5	64	12.2	11.2	92
Green Hills-1	12.5	11.8	94	12.3	11.7	95	12.2	11.5	94	19.4	11.5	59
Green Hills-2	12.6	11.9	94	12.4	11.8	95	12.1	11.2	93	11.9	11.2	94
Green Hills-3	12.4	11.8	95	12.4	11.7	94	12.3	11.5	93	12.0	11.2	93
Green Hills-5	20.9	18.6	89	19.8	17.4	88	19.6	17.0	87	19.7	16.7	85
Carabost-2	22.4	18.2	81	22.4	17.6	79	21.5	17.1	80	23.5	16.7	71
Shelley	25.3	24.0	95	37.2	34.9	94	24.4	22.6	93	24.1	22.7	94
Myrtleford-1	12.9	12.2	95	12.4	11.7	94	12.2	11.3	93	11.7	11.1	95
Bondo	19.4	18.2	94	18.2	17.2	95	18.1	17.2	95	17.5	16.6	95
Total (per week)	151	139	92	165	146	88	151	131	87	152	129	85
Average/ loader/day	10.1			11.0			10.1			10.1		

1 Total loader hours
2 Operating loader hours
3 Loader utilization (%)

Table 6.10 Simulated utilization of trucks over a five day period for the gross vehicle weight experiment

	Gross vehicle weight limit (tonnes)											
	38			40			42			53		
Forest Block	A[1]	B[2]	C[3]	A	B	C	A	B	C	A	B	C
	4 loaders											
Batlow-1	170	141	83	162	134	83	154	126	82	144	117	81
Green Hills-1	192	155	81	174	141	81	163	133	81	150	120	80
Green Hills-2	189	157	83	168	140	83	159	132	83	147	120	82
Green Hills-3	184	157	85	165	140	85	161	137	85	146	121	83
Green Hills-5	222	178	80	211	168	80	200	160	80	184	142	77
Carabost-2	192	150	78	172	134	78	163	125	77	144	109	76
Shelley	243	179	74	226	170	75	216	167	77	186	142	77
Myrtleford-1	90	58	64	120	97	81	118	95	81	108	85	78
Bondo	374	315	84	357	298	84	339	285	84	305	245	80
Total (per week)	1854	1490	80	1755	1423	81	1673	1359	81	1514	1200	79
Average/ loader/day	51.5			53.2			54.0			60.5		
	3 loaders											
Batlow-1	203	140	69	162	134	83	152	127	84	145	111	77
Green Hills-1	211	144	68	189	141	75	179	134	75	152	120	79
Green Hills-2	194	146	75	183	140	76	165	131	80	152	115	76
Green Hills-3	202	146	72	185	144	78	174	136	78	154	118	77
Green Hills-5	229	183	80	213	169	79	203	160	79	184	142	77
Carabost-2	178	139	78	169	133	79	163	125	77	144	109	76
Shelley	256	178	70	377	268	71	230	161	70	200	144	72
Myrtleford-1	182	104	57	134	98	73	123	93	76	118	81	69
Bondo	366	315	86	350	291	83	342	288	83	265	245	92
Total (per week)	2020	1495	74	1962	1527	78	1731	1351	78	1515	1185	78
Average/ loader/day	53.2			59.5			55.8			58.3		

1 Total loader hours
2 Operating loader hours
3 Loader utilization (%)

weights. Except for the 38 tonne gross vehicle weight, there is very little difference in the weekly costs of the operations using either three or four loaders. However, there is a rapid decline in weekly costs from the 38 tonne gross vehicle weight to the 53 tonne gross vehicle weight class.

Figure 6.2 shows the results with the simulated weekly costs expressed as cost per unit tonne. The rate of reduction in the loading and hauling costs decreases as the permitted gross vehicle weights increase up to 53 tonnes gross vehicle weight. The study thus indicates that the 53 tonne gross vehicle weight truck would, with the defined constraints, minimize the cost of loading and hauling. Using the 'four loader', 38 tonne gross vehicle weight operation as a base (Table 6.8), an increase in the mean payloads of two tonnes would enable an annual saving of approximately \$350 000. Increasing the mean payload by four tonnes would provide a saving of \$565 000 and by fifteen tonnes, \$910 000. It must be noted that the simulated costs do not allow for any cost for permits for the use of vehicles carrying loads greater than those now permitted.

The figure also illustrates the result that there is only a small difference in the delivery costs between a three and a four loader operation. The biggest difference in the costs is for the existing gross vehicle weights of 38 tonnes. In this case, the four loader operation shows a saving of approximately \$0.45 per tonne as compared to the three loader operation. The reasons for this much higher unit cost for the 'three loader' operation as compared to the 'four loader' are complex. Under the 'three loader' operation, the forest blocks of Batlow and Green Hills-1, -2 and -3 would only be visited once by one

Figure 6.1 Simulated total weekly cost against the gross vehicle weight allowed

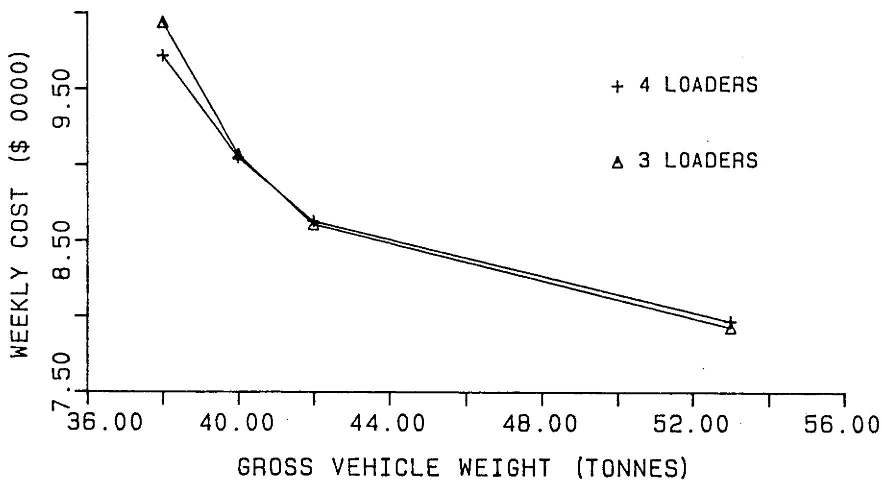
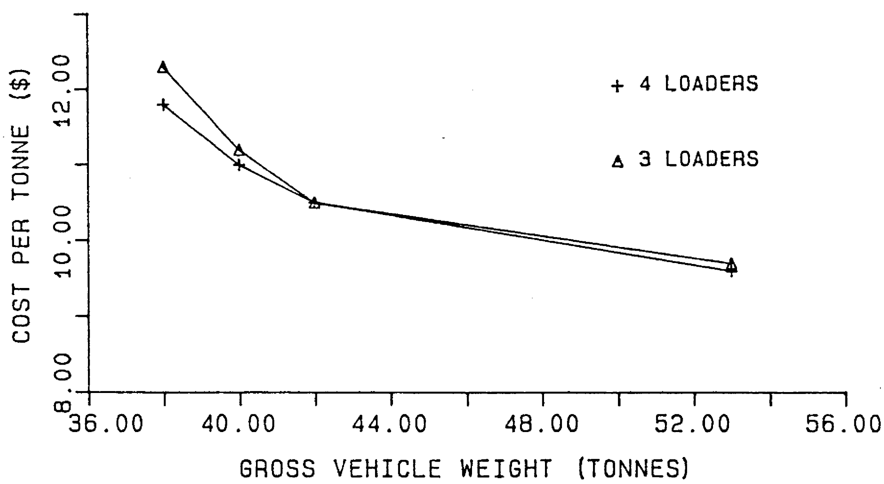


Figure 6.2 Simulated costs per tonne of wood against the gross vehicle weight allowed



loader in 5 days under the specified constraints to loader scheduling. Thus, for these blocks, 700 tonnes must be delivered in one shift. To do this, 18 trucks were required to haul the 700 tonnes from the landing. Queuing was prevalent on the landing when trucks went back for a second load. Truck utilization was relatively low and loader utilization was very high and long hours were required to achieve the tonneage. It thus became a costly operation. However, this does not arise with the 'four loader' operation. With the extra loader, it is possible to visit the above block twice in the week, thus requiring only 350 tonnes per visit (or day). To meet this quota, only 8 trucks were required to service the loader.

6.4.7.2 Three loader versus four loader operations

Table 6.9 shows that for both 'three loader' and 'four loader' operations, total loader hours appears to be stable as gross vehicle weights increased, but total operating hours of the loaders decreased gradually, resulting in a decrease in the loader utilization percentage. In the 'four loader' operation, loader utilization decreased from 81% with 36 trucks of gross vehicle weight 38 tonnes to 68% with 25 trucks of 53 tonne gross vehicle weight. In the 'three loader' operation, loader utilization decreased from 92% with 38 trucks of 38 tonne gross vehicle weight to 85% with 26 trucks of 53 tonnes gross vehicle weight. Average loader hours per day ranged from 9.10 with 4 loaders and 42 tonne gross vehicle weight trucks to 9.65 with 4 loaders and 53 tonne gross vehicle weight trucks and 10.1 with 3 loaders for the 38, 42 and 53 tonne gross vehicle weight trucks to 11.0 with the 40 tonne gross vehicle weight trucks. Such hours would be acceptable in terms of a reasonable length of working day for the operator.

A utilization of three loaders of 92% is very high and probably not feasible on a continuing basis. Furthermore, a 'three loader' operation is more costly than four loaders with a gross vehicle weight of 38 tonnes, the present allowable load limit. The simulation studies therefore suggest that a 'four loader' operation is the most economic with the present allowable load limits. Nevertheless, the result that the haulage task can be completed with three loaders is an important result, for in the event of a major long term breakdown of a loader or the need to replace one of the four loader operators, the mill requirements can still be met with appropriate scheduling of three loaders and the trucks.

6.4.7.3 Truck utilization

Table 6.10 shows that for the 'four loader' operations, truck utilization does not vary greatly with increasing loadweight. It ranges from 79% to 81%. These figures are very reasonable and feasible with well maintained trucks and reliable drivers. Average truck hours per week range from 51 to 60 hours and are feasible and probably of the order that drivers would expect in order to provide reasonable weekly wages.

Truck utilization is not as high with the 'three loader' operation as with the four and ranges from 74% to 78% as loadweights are increased.

The simulations also highlight the difficulties in efficiently scheduling the trucks to the Bondo forest block. The trucks on that 'shuttle service' only deliver one load per day for an average round trip time for the 38 tonne gross vehicle weight truck of 7.5 hours. The 53 tonne gross vehicle weight truck is particularly advantageous on this route because while travel times are increased, one trip per day could be still achieved.

6.4.7.4 Allocation of trucks to loaders

The optimization procedures associated with the simulation model are a feature of the mathematical programming approach and have of course been applied in all the simulation runs of this experiment. For example, Table 6.4 shows the minimum cost of the daily wood deliveries and the associated number of trucks. This cost was derived by inter alia allocating on a daily basis, the 36 trucks among the four loaders to minimize the loading and hauling cost. The number of trucks to be allocated each day was held constant. This number was determined by examining on a daily basis, the actual number of trucks that should be allocated to a loader to minimize the cost. The number for minimum cost varied from day to day with loader location and tonneage required and the maximum number of trucks on any day was adopted as the number of trucks to be allocated each day.

6.5 EXPERIMENT 2 : EVALUATION OF DOUBLE SHIFTS FOR BOTH LOADERS AND TRUCKS

6.5.1 Aim

Harvesting and hauling of wood often requires considerable capital and it is of course important that the capital be used most advantageously. One advantage is to increase the total production of the equipment in one day, thus reducing the 'fixed' equipment costs per unit of wood deliveries. Two shifts per day may accomplish this. In the case study, a double shift operation would be particularly useful in the haul from the Bondo forest block, for two loads per day from one truck are then feasible.

Using the permitted 38 tonne gross vehicle weight trucks, two double shift experiments for trucks and loaders were carried out:

1. Two separate twelve hour shifts in a twenty-four hour day using three loaders.
2. Two overlapping shifts in a twenty-four hour day using three loaders.

The aim of both experiments was to determine the minimum loading and hauling costs using the minimum number of trucks possible, but delivering at least 8 000 tonnes of wood from the nine locations specified in 6.3.1. The same quotas for each location as in the vehicle weight experiment, were used.

6.5.2 Methodology

The simulation and optimization procedures used previously were adopted. However, certain modifications were carried out to the model and data inputs. In all cases, hourly wages for operators of equipment were increased from $8 to $10 as a 'shift penalty rate'. No changes were made to the cycle times for night work. Both decisions were somewhat arbitrary, since there was no reliable data for shift operations. It was anticipated that the 25% loading as the shift penalty rate was high and recommendations for the shift experiments would therefore be conservative. Loading times were not increased, as experience to date with harvesting operations at night does not suggest significant decreased productivity.

For the two separate twelve hour shifts, trucks had to return to the mill before the twelve hour shift expired, in order to be ready for the start of the second shift.

To reduce computational costs, simulations for the two separate twelve hour shifts were not carried out as one shift after another. Since all trucks had to be stationed at the mill before a 12 hour shift expired, simulation runs were only carried out for one shift. The results were then assumed to be the same for the second shift.

The two overlapping shifts were examined to try to increase the working hours of a truck within a twenty-four hour period. The first shift was a maximum of thirteen hours. All trucks had to return to the mill before this time expired. This longer first shift may allow two loads per truck from the Batlow and Green Hills forest blocks which have cycle times ranging from 5.0 to 6.0 hours. Up to three loads per truck may also be possible from the closer forests.

Trucks always returned to the landing as long as the thirteen hour and loader availability constraints permitted. All second shift truck drivers started at the same time, although this time was not constant for all forest blocks. From preliminary investigations, the following times were adopted for the start of the second shift:

Bondo: 9 hours after the commencement of the first shift

Green Hills-1 and Carabost-2: 12 hours after the commencement of the first shift

All other blocks: 11 hours after the commencement of the first shift.

If the nominated truck was at the mill waiting when the second shift drivers came on duty, then work was begun immediately. Otherwise, the second shift driver waited until the truck returned to the mill. In all circumstances, the second shift drivers were paid from when they came on duty, whether a truck was available or not.

When operating the two overlapping shifts, loaders were not shifted during the day's work. Again, loader movement costs and time were not included in the calculations. The scheduled hours of the day's operation were evenly split between the two loader operations. This meant that the two operators would usually work different hours, but this was accepted on the grounds of convenience in scheduling the start time for the operators.

6.5.3 Simulation of Two Separate Twelve Hour Shifts

6.5.3.1 Introduction

A range of 5 to 16 trucks and 4 to 8 scheduled hours for the loaders were simulated, resulting in 60 strategies per forest block.

Mean truck payloads, load times and travel times were the same as the 38 tonne gross vehicle weight experiment. Three loaders were used per day. The adopted loader schedule is shown in Table 6.11.

Table 6.11 Loader schedule and locations for two separate twelve hour shifts

Loader	Monday	Tuesday	Wednesday	Thursday	Friday
1	Bondo 175	Bondo 175	Bondo 175	Batlow 230	Batlow 230
*	Bondo 175	Bondo 175	Bondo 175	Batlow 230	Green H1 230
2	Green H1 230	Green H5 350	Green H5 350	Green H3 230	Green H2 230
*	Green H1 230	Green H5 350	Green H3 230	Green H2 230	Green H2 230
3	M-ford 350	Shelley 350	Shelley 350	Carabost 350	Carabost 350
*	M-ford 350	Shelley 350	Shelley 350	Carabost 350	Green H3 230

* Second shift of relevant loader

The loader schedule provides for the shifting of a loader after a twelve hour shift when the new operator takes over.

6.5.3.2 Results for two twelve hour shifts

The simulated total weekly cost was $100 800 and 8 350 tonnes were delivered at a cost of $12.10 per tonne. An extra 350 tonnes were produced each week above the requirement. This could be trimmed by not returning the last truck for a second or third load. Thirty trucks were needed per day to meet the mill requirements.

Loader utilizations ranged from 87% in Shelley to 96% in Green Hills-5 while truck utilizations ranged from 76% in Green Hills-5 to 87%

in Bondo. The maximum total loader hours in one day was 15 hours, comprising two 7.5 hour shifts. This is quite feasible and allows approximately 4 hours to shift the loader to a new location and for any servicing.

6.5.4 Simulation of Two Overlapping Shifts

6.5.4.1 Introduction

A range of 3 to 14 trucks and loader scheduled hours of 14 to 21 were simulated, resulting in 96 strategies per forest block. Mean truck payloads and loading times remained unchanged.

6.5.4.2 Results for the overlapping shifts

The simulated total weekly cost was $90 400 and 8 220 tonnes were delivered at $11.00 per tonne. To meet the mill requirements, a total of 22 trucks were needed per day.

Loader utilizations ranged from 37% in Batlow-1 to 76% in Green Hills-3 while truck utilizations ranged from 72% in Green Hills-1 to 86% in Batlow-1.

6.5.5 Summary of Double Shift Results

The results of the double shift experiment are summarized for comparison with the 'three loader' operation of the 38 tonne gross vehicle weight experiment in Tables 6.12 and 6.14.

6.5.6 Review of Double Shift Results

6.5.6.1 The effect of double shifts on loading and hauling costs

Table 6.12 shows the weekly cost of the three operations using three loaders, namely single shift, two twelve hour shifts and two overlapping shifts. A yearly saving of approximately $470 000 may occur by employing two overlapping shifts compared to a single shift, the current operation. On a cost per tonne basis, both double shift operations reduced the cost per tonne of delivered wood from $12.30 to $12.10 for the two by twelve hour shifts and to $11.00 for the overlapping shifts.

When compared against a 'four loader' single shift operation with a delivered cost per tonne of $11.80, the two twelve hour separate shifts were not attractive. However, the number of trucks was reduced to thirty instead of thirty-six with four loaders or thirty-eight with three loaders.

The study indicated that the two overlapping shifts would, with the defined constraints, minimize the cost of loading and hauling.

6.5.6.2 Loader utilization

Table 6.13 presents the loader operating statistics for the three operations examined. Total scheduled loader hours increased dramatically in the overlapping shift experiment as compared to the other two, but actual operating hours remained similar. This resulted in a drop in the loader utilization percentage from 92 to 62 which was

Table 6.12 Simulated weekly wood deliveries and costs over a five day period for the double shift experiment using three loaders

	Number of Shifts		
	Single	2 x 12	Overlapping
Wood deliveries (tonnes)	8 120	8 350	8 220
Weekly cost ($)	99 400	100 800	90 400
Cost ($/tonne)	12.30	12.10	11.00

Table 6.13 Simulated utilization of loaders over a five day period for the double shift experiment using three loaders

Forest block	Number of Shifts								
	Single			2 x 12			Overlapping		
	A[1]	B[2]	C[3]	A	B	C	A	B	C
Batlow-1	12.8	12.1	95	13.5	12.1	90	33.1	12.2	37
Green Hills-1	12.5	11.8	94	13.2	12.2	92	16.3	11.9	73
Green Hills-2	12.6	11.9	94	13.5	12.3	91	16.5	12.0	73
Green Hills-3	12.4	11.8	95	13.6	12.2	90	16.0	12.1	76
Green Hills-5	20.9	18.6	89	20.4	19.5	96	30.6	18.7	61
Carabost-2	22.4	18.2	81	21.6	19.0	88	33.2	18.2	55
Shelley	25.3	24.0	95	30.0	26.0	87	36.8	24.4	66
Myrtleford-1	12.9	12.2	95	13.8	12.2	88	18.5	12.4	67
Bondo	19.4	18.2	94	22.0	19.8	90	36.6	18.7	51
Total (per week)	151	139	92	162	145	90	238	141	59
Average/ loader/shift	10.1			5.40			7.93		

1 Total loader hours
2 Operating loader hours
3 Loader utilization (%)

Table 6.14 Simulated utilization of trucks over a five day period for the double shift experiment using three loaders

	Number of shifts								
	Single			2 x 12			Overlapping		
	A[1]	B[2]	C[3]	A	B	C	A	B	C
Batlow-1	203	140	69	172	139	81	167	143	86
Green Hills-1	211	144	68	179	149	83	204	148	72
Green Hills-2	194	146	75	180	147	82	188	145	77
Green Hills-3	202	146	72	181	149	82	200	151	75
Green Hills-5	229	183	80	248	189	76	229	183	80
Carabost-2	178	139	78	191	146	77	175	139	79
Shelley	256	178	70	246	189	77	230	184	80
Myrtleford-1	182	104	57	132	104	79	134	108	80
Bondo	366	315	86	381	333	87	377	321	85
Total (per week)	2020	1495	74	1909	1545	81	1904	1522	80
Average/truck/week	53.2			63.6			86.6		

1 Total truck hours

2 Travelling truck hours

3 Truck utilization (%)

mainly due to the first loader which visited the Batlow and Bondo blocks. For these forests, more trucks would increase the operating time of the loader and decrease idle time (but time the operator is paid). The simulation indicated that with the two overlapping shifts, loader 1 is very poorly utilized. This could be corrected by restructuring the loader schedule, for example, such that loader 1 only worked three days in five.

The high loader utilizations in the two separate twelve hour shift operation are a result of the loaders closing down after the last truck departs in any one of the twelve hour shifts. Of course, in the overlapping shifts, this does not occur since the loader sits and waits on the landing while the first and second shift truck drivers change.

6.5.6.3 Truck utilization

The truck operating statistics for the three operations are presented in Table 6.14. The truck total hours, operating hours and utilization percentages showed little trend. The low truck utilization for the single shift was due to the large number of trucks needed. Both double shift experiments showed similar truck utilizations which were quite high. These utilizations showed that the trucks were operating close to capacity; 87% was the highest utilization percentage.

The hours per week that the trucks were used increases with the double shift operations. For the two twelve hour shift operations, nearly 64 hours per week were worked but this was shared by two drivers. Since each shift was similar, the average weekly hours for each driver was 32. The truck drivers would be paid for at least a 40 hour week and they were therefore underutilized. For the overlapping shift, the trucks were utilized for nearly 87 hours per week. Calculations were not done to split this time between two drivers, but as the intention in such an operation would be for drivers to rotate the early shift, they would each receive in two weeks, payment for 87 hours.

6.6 EXPERIMENT 3 : ASSESSMENT OF THE EFFECT OF REDUCTIONS IN LOADING TIMES

6.6.1 Introduction

The loading time selected for the previous experimental simulations was the mean and standard deviation of all loaders combined in order to reduce the complications and complexities in the experimental design. However, the data collected and reported in Chapter 2 shows there is a difference in both the mean and standard deviations of the loading times of the four ANM loaders. Furthermore, improvement in the skills of the loader operators would reduce loading times and further technological advances may also make available loaders with reduced loading times.

Two simulation experiments were therefore carried out to assess the response of a system delivering 8 000 tonnes from nine locations to decreasing means and standard deviations of load times. To enable comparisons with the 38 tonne gross vehicle weight experiment which used the selected mean and standard deviation of 24.0 and 4.8 respectively, the following loading times were adopted for two simulations:

1. Mean of 20.0 minutes and a standard deviation of 4.0
2. Mean of 16.0 minutes and a standard deviation of 3.0.

The reduction in the standard deviations with reduction in loading time is justified by the assumption that as the loading becomes quicker the variation in the loading times would decrease.

6.6.2 Methodology

Simulated wood deliveries and costs were calculated using similar procedures to those adopted for the experiments reported previously. It was again assumed that the loading times were normally distributed.

6.6.3 Simulated System Performance with a Mean Loading Time of Twenty Minutes

A range of 5 to 16 trucks with scheduled loader hours of 5 to 12 were simulated, resulting in 96 strategies for each forest block.

6.6.3.1 Results for four loaders

The simulated total weekly cost was $94 100 and 8 170 tonnes were delivered at a cost of $11.50 per tonne. Thirty-four trucks per day were needed to meet the mill requirements.

When compared to the loader utilizations under the existing ANM loading times (Table 6.5), loader utilizations decreased markedly. Loader utilizations ranged from 50% in Myrtleford-1 to 96% in Bondo, while truck utilizations ranged from 80% in Carabost-2 and Shelley to 85% in Green Hills-2 and -3.

6.6.3.2 Results for three loaders

The simulated total weekly cost was $93 600 and 8 140 tonnes were delivered at a cost of $11.50 per tonne. Again, 34 trucks were needed per day.

Loader utilizations ranged from 71% in Green Hills-5 to 91% in Batlow-1 and Green Hills-1, while truck utilizations ranged from 72% in Shelley to 87% in Bondo.

6.6.4 Simulated System Performance with a Mean Loading Time of Sixteen Minutes

A range of 5 to 16 trucks with scheduled loader hours of 4 to 12 were simulated, resulting in 108 strategies for each forest block.

6.6.4.1 Results for four loaders

The total simulated weekly cost was $93 400 and 8 180 tonnes were delivered at a cost of $11.40 per tonne. Thirty-four trucks were required to meet the mill requirements.

Loader utilizations ranged from 41% in Myrtleford-1 to 95% in Bondo, while truck utilizations ranged from 81% in Carabost-2 to 87% in Green Hills-3.

6.6.4.2 Results for three loaders

The total simulated weekly cost was $93 000 and 8 220 tonnes were delivered at a cost of $11.30 per tonne. Again, 34 trucks were needed to meet the mill requirements.

Loader utilizations ranged from 60% in Green Hills-5 to 96% in Bondo, while truck utilizations ranged from 80% in Green Hills-1 and Shelley to 86% in Bondo.

6.6.5 Summary of Load Time Results

The results of the experiments to assess the effects of reductions in load times are summarized in Tables 6.15 to 6.17, together with the results of the 38 tonne gross vehicle weight experiment for comparison.

6.6.6 Review of Load Time Results

6.6.6.1 Effect of reducing load times on haulage costs

Figure 6.3 shows the total weekly cost of the operations simulated to assess the effects of changes in loader times. Figure 6.4 shows the effects as measured by the delivered cost per tonne of wood.

As expected, the simulations indicated reductions in cost from a reduction in loading time and the estimated yearly savings for the 'three loader operation' was nearly $300 000 for a reduction in mean load time of 4 minutes and $330 000 for a reduction in load time of 8 minutes. For the 'four loader' operation, a reduction in the mean load time by 4 minutes saved nearly $160 000 per year, while an 8 minute reduction saved nearly $200 000. The cost savings were much more marked for a reduction in loading times from 24 minutes (standard deviation

Table 6.15 Simulated weekly wood deliveries and costs over a five day period for the load time experiment

Number of loaders		Load time (mins) 24	20	16
4	Wood deliveries (tonnes)	8 240	8 170	8 180
	Weekly cost ($)	97 200	94 100	93 400
	Cost ($/tonne)	11.80	11.50	11.40
3	Wood deliveries (tonnes)	8 120	8 140	8 220
	Weekly cost ($)	99 400	93 600	93 000
	Cost ($/tonne)	12.30	11.50	11.30

Table 6.16 Simulated utilization of loaders over a five day period for the load time experiment

Forest block	Mean Load Time (minutes)								
	24			20			16		
	A[1]	B[2]	C[3]	A	B	C	A	B	C
4 Loaders									
Batlow-1	17.0	12.0	71	16.6	10.1	61	15.1	8.3	55
Green Hills-1	18.4	13.0	71	16.8	10.1	60	15.7	8.1	52
Green Hills-2	18.8	13.0	69	16.7	10.5	63	15.1	8.0	53
Green Hills-3	18.6	12.6	68	16.6	9.9	60	16.2	8.1	50
Green Hills-5	21.4	18.2	85	21.7	15.2	70	20.5	12.3	60
Carabost-2	23.0	19.4	84	20.9	15.0	72	19.9	12.2	61
Shelley	29.0	24.0	83	32.3	20.1	62	30.6	16.2	53
Myrtleford-1	21.0	20.2	95	20.6	10.2	50	19.6	8.0	41
Bondo	19.5	18.3	94	15.9	15.3	96	12.9	12.3	95
Total (per week)	187	151	81	178	116	65	166	94	56
Average/ loader/shift	9.35			8.90			8.30		
3 Loaders									
Batlow-1	12.8	12.1	95	11.0	10.0	91	9.7	8.0	82
Green Hills-1	12.5	11.8	94	11.1	10.1	91	9.9	8.0	81
Green Hills-2	12.6	11.9	94	11.1	10.0	90	9.9	8.0	81
Green Hills-3	12.4	11.8	95	11.3	10.1	89	9.9	7.9	80
Green Hills-5	20.9	18.6	89	21.8	15.4	71	20.5	12.4	60
Carabost-2	22.4	18.2	81	20.9	15.1	72	19.9	12.2	61
Shelley	25.3	24.0	95	23.2	20.1	87	20.6	16.2	79
Myrtleford-1	12.9	12.2	95	11.4	10.1	89	11.3	8.6	76
Bondo	19.4	18.2	94	16.7	14.9	89	12.8	12.3	96
Total (per week)	151	139	92	150	116	77	125	94	75
Average/ loader/shift	10.1			10.0			8.33		

1 Total loader hours
2 Operating loader hours
3 Loader utilization (%)

Table 6.17 Simulated utilization of trucks over a five day period for the load time experiment

	Mean Load Time (minutes)								
	24			20			16		
	A[1]	B[2]	C[3]	A	B	C	A	B	C
4 Loaders									
Batlow-1	170	141	83	168	142	84	170	146	85
Green Hills-1	192	155	81	179	147	82	178	147	83
Green Hills-2	189	157	83	178	151	85	171	147	86
Green Hills-3	184	157	85	174	149	85	174	151	87
Green Hills-5	222	178	80	222	182	82	221	184	83
Carabost-2	192	150	78	174	139	80	175	142	81
Shelley	243	179	74	226	181	80	222	182	82
Myrtleford-1	90	58	64	127	105	83	124	104	84
Bondo	374	315	84	369	311	84	374	315	84
Total (per week)	1854	1490	80	1816	1505	83	1808	1517	84
Average/truck/week	51.5			53.4			53.2		
3 Loaders									
Batlow-1	203	140	69	176	143	81	173	143	83
Green Hills-1	211	144	68	186	149	80	183	147	80
Green Hills-2	194	146	75	180	147	82	177	147	83
Green Hills-3	202	146	72	182	149	82	179	149	83
Green Hills-5	229	183	80	221	182	82	220	182	83
Carabost-2	178	139	78	176	140	80	175	142	81
Shelley	256	178	70	250	180	72	228	182	80
Myrtleford-1	182	104	57	131	105	80	138	112	82
Bondo	366	315	86	357	310	87	365	315	86
Total (per week)	2020	1495	74	1858	1504	81	1836	1518	83
Average/truck/week	53.2			53.6			54.0		

1 Total truck hours
2 Travelling truck hours
3 Truck utilization (%)

Figure 6.3 Simulated total weekly cost against the mean time to load a truck

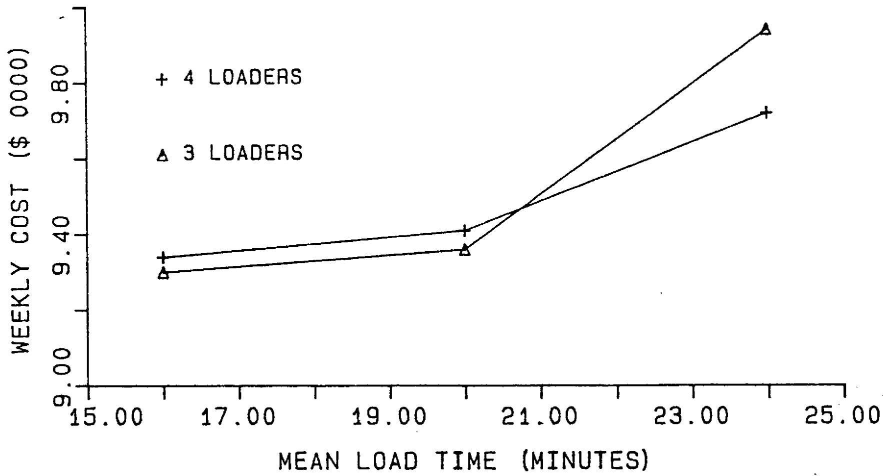
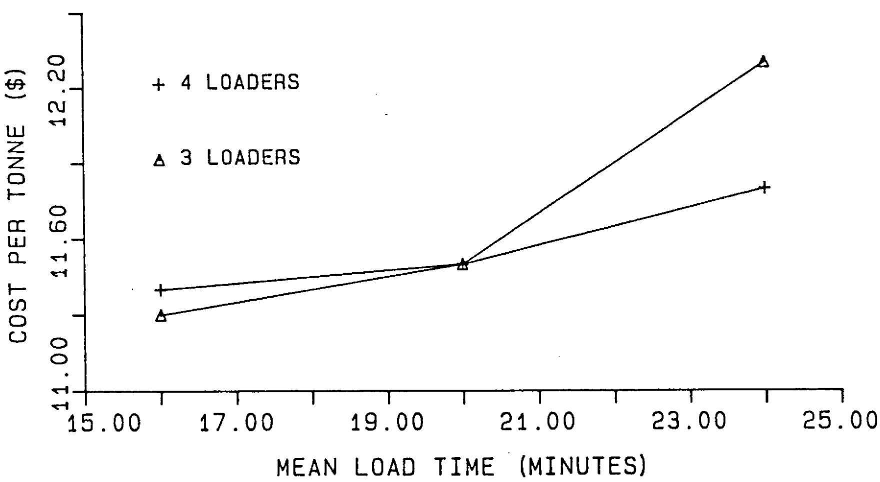


Figure 6.4 Simulated costs per tonne of wood against the mean time to load a truck



4.8) to 20 minutes (standard deviation 4.0) than from the latter to 16 minutes (standard deviation 3.0).

The first 4 minute reduction in loading time enabled a reduction in the number of trucks necessary to meet the mill requirements, by four trucks for the 'three loader' operation and by two for the 'four loader' operation. The second 4 minute reduction in loading times did not reduce the number of trucks required.

6.6.6.2 Four loaders versus three loaders

Figure 6.4 shows that a reduction in mean load times of 4 minutes enabled the 'three loader' operation to become an efficient operation as compared to the relatively high cost operation with a mean load time of 24 minutes. At a mean load time of 20 minutes, there was little difference between the 'three' and 'four loader' operation. A further reduction of 4 minutes in the load time showed the 'three loader' operation as less costly than the 'four loader' operation.

Figure 6.4 suggests an anomaly in the trends of the costs for the 'three loader' operation when the mean load time increased from 20 to 24 minutes. The rapid increase in the costs for the 'three loader' operation was due to the large number of trucks (18) needed for one loader in the Batlow and Green Hills-1, -2 and -3 forest blocks to deliver 700 tonnes in one day. As discussed previously, the loader schedules with the 'four loader' operation provided for only 350 tonnes per day from these blocks and this can be accomplished with only 8 trucks.

The simulations indicated that a reduction of 8 minutes in the mean load time would enable a less costly operation with three loaders. Average loader utilizations would be 75% and this seems a feasible utilization. There would also be considerable advantages with less complicated control of three rather than four loaders. It must be noted of course that such a reduction in loading time would only follow from a changed loader technology. However, a four loader operation may be preferred for operational reasons for, whereas in the 'four loader' operation if a loader breaks down, three loaders can still deliver the required tonneage, it is not established that two loaders could deliver the mill requirements. Further simulations would be required to assess this.

6.6.6.3 Truck utilization

The simulations for the strategies indicated that between 50 and 55 hours per week would need to be worked by truck drivers to meet the mill requirements. These are quite feasible and attainable.

6.7 REVIEW OF EXPERIMENTAL SIMULATION RESULTS

The simulation experiments have demonstrated the magnitude of the substantial reductions in costs associated with increases in gross loadweights, with the introduction of double shifts and with reductions in loading times. Clearly, the model can be successfully applied for the evaluation of options for the management of log hauling fleets. The results of the case studies suggest that managers of large truck fleets should give consideration to permits in the case of loadweights, changes in the operations in the case of the double shift and training or new loaders in the case of the loading times.

Of the three experiments conducted, increasing the allowable gross loadweight of the truck, particularly to 53 tonnes, is the best method of achieving cost reductions. Up to $910 000 per year may be saved in the 'four loader' operation by shifting from 38 tonne gross vehicle weight trucks to 53 tonne gross vehicle weight trucks. Double shifting of trucks and loaders may save approximately $350 000 per year from a single shift 'four loader' operation to a double overlapping shift 'three loader' operation. A reduction in the mean load time from 24 minutes ('four loader' operation) to 20 minutes ('three loader' operation) may save $190 000. If the reduction in load time to 16 minutes could be achieved with a 'three loader' operation, the estimated savings would be $220 000 per year.

The simulations also indicate that for the present, a 'three loader' operation would be inefficient and confirms that the 'four loader' operation is most appropriate.

The specific application of the simulation model to the evaluation of different strategies is clearly demonstrated by the results of the case study experiment and the indicated cost savings. Adaption of the model for wide ranging evaluations is discussed in Chapter 8.

CHAPTER 7

A COMPARATIVE CASE STUDY OF LEASING AND PURCHASING LOG TRUCKS

An Application of the Simulation Model

7.1 INTRODUCTION

Leasing and purchasing are the two main approaches to financing equipment procurement in the forest industries of Australia. In the experiments reported in Chapter 6, equipment costs were based on leasing.

In the ANM operation, one hauling contractor purchases equipment while the other leases. The two equipment procurement procedures may lead to different wood delivery costs; for example, leasing costs per month for a truck may not change with a double shift operation, but the number of trucks required does. The aim of this study was to compare the costs of loading and hauling wood to the mill from two forest blocks when the trucks are leased and when they are purchased.

7.2 METHODOLOGY

The two forest blocks chosen for this study were the Shelley and Batlow-1 blocks of the ANM operation. The respective cycle times for wood deliveries were approximately 220 and 330 minutes. The Shelley block is one of the closest to the mill and Batlow-1, one of the furthest. The two blocks also enabled assessment of the effect of haul distance on the selection of the method of financing equipment procurement.

The simulation model based on the ANM log hauling system was used to generate the costs of loading and hauling wood from the two blocks with a range of truck numbers and scheduled loader hours. The costs associated with leasing of equipment were already generated for the Shelley and Batlow-1 forest blocks in connection with the gross vehicle weight experiment and reported in Chapter 6.

Much of the cost data for leased equipment remains the same if the equipment is purchased, namely the operating costs, wages, workers compensation, insurance, registration and overheads. Thus, as detailed in 2.4, the additional requirement is for the hourly depreciation charges and interest payments which are the costs in lieu of the leasing charges if equipment is purchased.

The hourly depreciation charges were calculated as the purchase price of the equipment ($) minus the resale value ($) divided by the estimated service life of the machine in hours.

The service life for a truck on haulage routes similar to those encountered in the ANM operation was adopted as 7 000 hours (Macarthur pers. comm.). Trucks operate (or travel) for approximately 7 hours per day in the ANM situation and on this basis, the assumed service life is equivalent to an operating life of 1 000 days and for trucks working 240 days per year is equivalent to 4 years, the same period as used in the leasing charges. Reduced average daily work hours for trucks extends the age of the truck at resale. The constant hourly depreciation charge (travelling hours) is $11.79 for a truck purchased for $110 000 and resold after 7 000 hours for $27 500.

Interest charges on equipment purchased were incorporated in the unit costs because income is foregone by purchasing the equipment rather than investing elsewhere. The annual interest charges were calculated as the average invested capital plus the yearly insurance cost multiplied by the interest rate. The interest rate chosen for this analysis was 16%, a figure above a low risk investment rate. Again, assuming 240 working days per year, the interest costs are equivalent to $48.77 per day. However, the interest costs are an annual rather than an hourly charge because the income is foregone whether or not the truck is used. The annual interest charges can of course be pro rated over the actual travelling hours of the truck.

A summary of the cost calculations for the purchasing of trucks are in Appendix 7.1. Taxation concessions or rebates were not included, since the analysis was to compare the costs of purchasing or leasing before tax.

The simulation model was run for the Shelley and Batlow-1 forest blocks, with the cost data for purchasing of equipment incorporated and using 3 to 18 trucks and loaders scheduled to work 6 to 12 hours per day.

7.3 RESULTS

7.3.1 Leasing of Trucks to Service the Shelley Forest Block

The simulated cost per tonne of delivered wood from Shelley under the leasing procedure is shown in Figure 7.1. Cost per tonne of delivered wood decreased consistently as scheduled loader hours increased, obviously due to the decreasing average hourly costs of the fixed leasing costs of the trucks.

Seven trucks were indicated as the optimum number for the Shelley operation when the loader worked for more than eight hours. The truck and loader utilizations were both 78%. However, there was little difference between 5, 7 or 9 trucks for a loader working more than eight hours.

The $4 difference between the cost per tonne for a 13 truck and 7.5 hour loader operation as compared to a 7 truck 11 hour operation is notable. The simulations demonstrate that substantial additional costs could be incurred by using an inappropriate number of trucks and loader hours.

7.3.2 Purchasing of Trucks to Service the Shelley Forest Block

The simulated cost per tonne of delivered wood from Shelley under the purchasing procedure is shown in Figure 7.2. The simulations again show that costs decreased as loader hours increased, although at a much slower rate than with leasing. The slower rate was due in part to the fact that the depreciation charge was costed on a constant per hour

Figure 7.1 Cost per tonne of wood delivered from the Shelley forest block under the leasing system for trucks

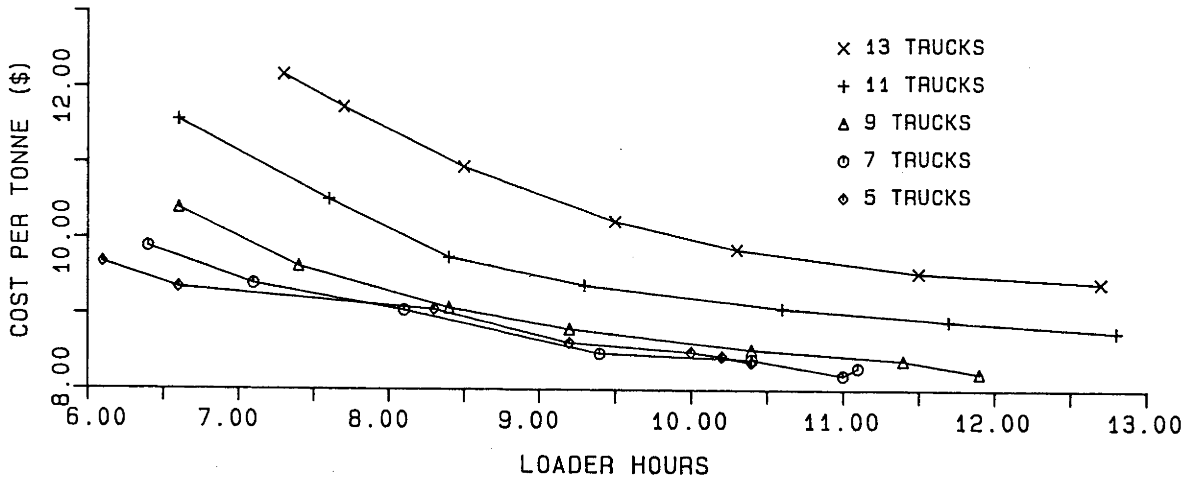
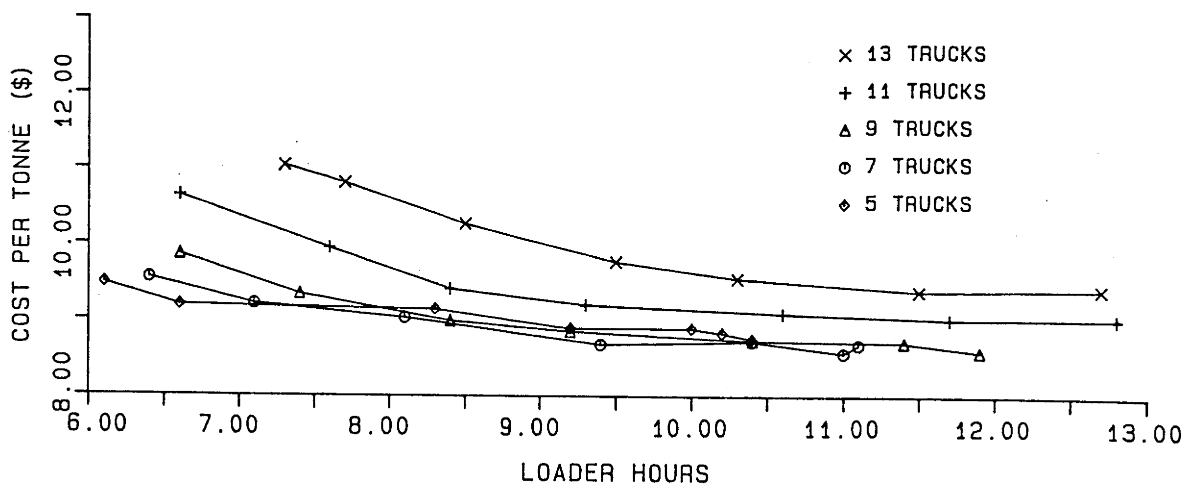


Figure 7.2 Cost per tonne of wood delivered from the Shelley forest block under the purchasing system for trucks



Overlay for purchasing system on back cover of thesis basis and only interest, registration, insurance and overheads decreased per hour of travelling. In the case of leasing, these costs and the leasing charges all decreased per hour as hours increased.

Seven trucks again appeared to be the optimum for the Shelley block, although there was little difference between 5, 7 or 9 trucks working with a loader working over 8 hours.

7.3.3 Leasing of Trucks to Service the Batlow-1 Forest Block

Figure 7.3 shows the simulated cost per tonne of delivered wood from the Batlow-1 forest block under the leasing method. The cost per tonne decreased as the loader hours increased, particularly as the hours increased from 5 to 8. The average cycle time for this block is 5.5 hours and longer hours on the landing by the loader would enable second trips by more trucks and hence reduce leasing costs per trip.

Cost per tonne of wood delivered increased slightly for additional trucks, with 9 to 11 trucks being indicated as the optimum number for the Batlow-1 operation when the loader worked more than 11 hours.

7.3.4 Purchasing of Trucks to Service the Batlow-1 Forest Block

The simulated cost per tonne of delivered wood from Batlow-1 under the purchasing procedure is shown in Figure 7.4. There is a reduction in the cost per tonne of wood delivered as the loader hours increase, but at a much slower rate than with leasing. There is very little difference in cost between the use of 5 to 13 trucks in the operation, but 9 to 11 trucks seems the optimum to minimize the cost per tonne of wood delivered.

Figure 7.3 Cost per tonne of wood delivered from the Batlow-1 forest block under the leasing system for trucks

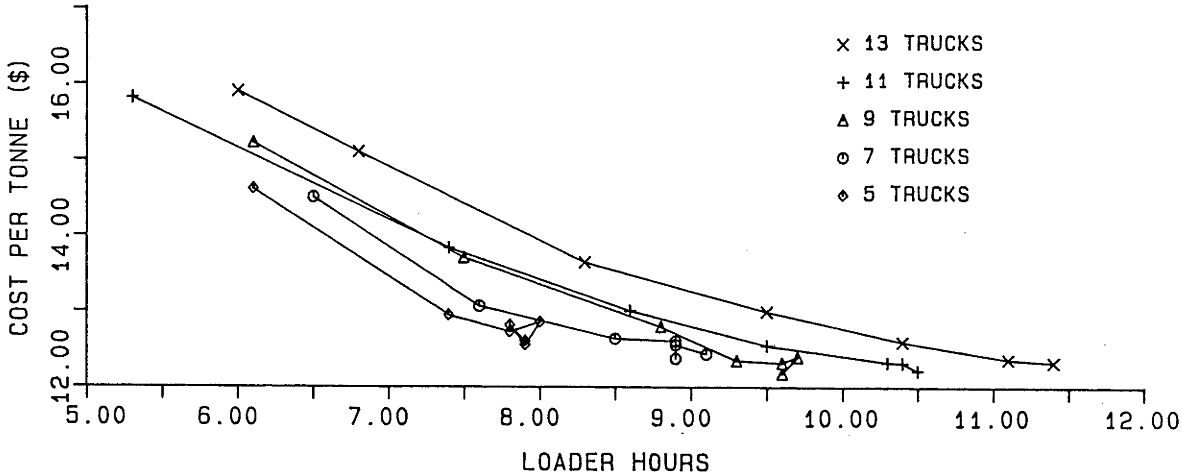
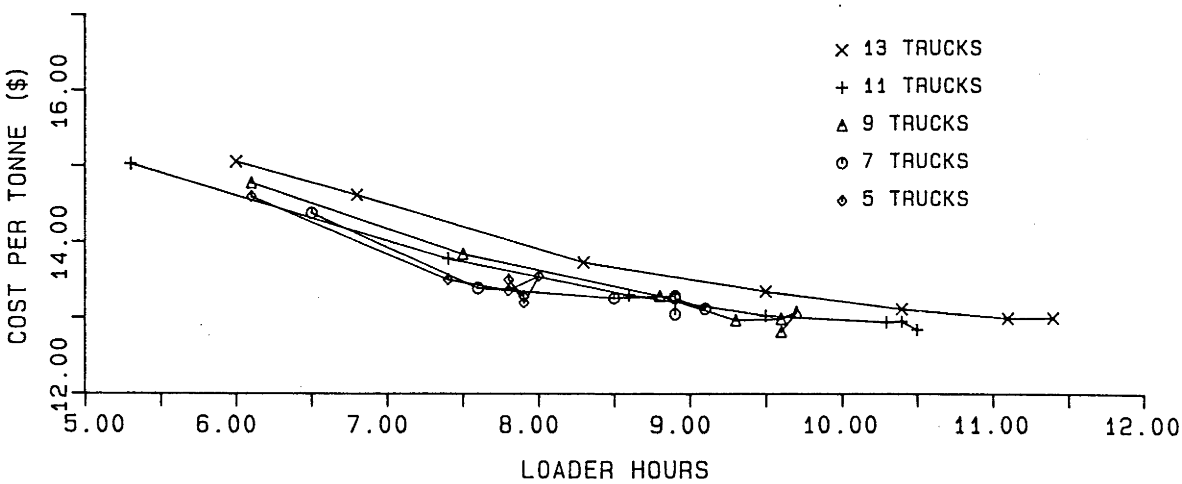


Figure 7.4 Cost per tonne of wood delivered from the Batlow-1 forest block under the purchasing system for trucks



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7.4 REVIEW

The simulations indicate that the wood from the Shelley block can be delivered more cheaply if trucks are purchased rather than leased when the loader works less than 8 hours and up to 9 trucks are scheduled to the loader, when the loader works up to eleven hours and services 11 trucks and when the loader works up to 13 hours and services 13 trucks. These results assume of course that wood is available in unlimited quantities.

The wood from the Batlow-1 block can be delivered more cheaply if trucks are purchased rather than leased if the loader works up to 7 hours and is serviced by up to 9 trucks, when the loader works up to 7.5 hours for all 11 trucks and when the loader works up to 8 hours and is serviced by 13 trucks.

These results are illustrated in Figures 7.1 to 7.4. The simulations for both forest blocks indicate generally that purchasing of trucks is more economic than leasing when the travelling hours per day are relatively low. That this is expected can be shown theoretically by calculations such as those given in Table 7.1 which compares the leasing costs and a number of depreciation charges for various numbers of travelling hours per day by a truck. On a theoretical basis, purchasing trucks would provide the least cost method of wood delivery for some haulage tasks. The parameters involved are the cycle times of the trucks, the number of trucks assigned to the haulage task and quota (tonnes) to be delivered. Purchasing of trucks is less costly than leasing when less than 7 hours travelling are done (using a 7 000 hour service life and 16% interest rate), when less than 6 hours travelling

Table 7.1 Leasing and depreciation costs per day with various hours travelled by trucks

Hours travelled per day	Leasing ($/day)	Dep.[1] ($/day)	Dep.[2] ($/day)	Dep.[3] ($/day)	Dep.[4] ($/day)
1	129	61	73	58	70
2	129	72	85	67	79
3	129	84	96	76	88
4	129	96	108	85	98
5	129	108	120	95	107
6	129	120	132	104	116
7	129	131	143	113	125
8	129	143	155	122	134
9	129	155	167	131	143
10	129	167	179	140	153

1 Depreciation - assume a service life of 7 000 hours, interest rate of 16%

2 Depreciation - assume a service life of 7 000 hours, interest rate of 20%

3 Depreciation - assume a service life of 9 000 hours, interest rate of 16%

4 Depreciation - assume a service life of 9 000 hours, interest rate of 20%

are done (using a 7 000 hour service life and 20% interest rate), when less than 9 hours travelling are done (using a 9 000 hour service life and 16% interest rate) and less than 8 hours (using a 9 000 hour service life and 20% interest rate).

While such generalised information provides guidelines, the use of the simulation model enables more specific assessment based on the stochastic interactions of trucks for it generates the travelling hours for each truck which can then be costed. To illustrate this application of the model further, realistic rather than unlimited tonneage quotas were selected for the two forest blocks and the simulation run under the leasing and the four depreciation charges. The results are shown in Table 7.2. Except for one case, leasing was always less costly than purchasing for the delivery of wood to the mill. The exception was when depreciation charges were based on a 9 000 hour service life and 11 trucks were used to deliver 700 tonnes of wood. For the Batlow-1 block, leasing was also less costly than purchasing except under a 9 000 hour service life and 9 trucks were used to deliver 350 tonnes. In both cases, the average travelling hours per truck per day were between 8 and 9, close to the theoretical breakeven points in Table 7.1.

Table 7.3 shows a range of number of trucks used to deliver a wide range of specified tonneages from the forest blocks. For the Shelley block, purchasing is only less costly when the number of trucks are high enough to reduce to a low figure the average travelling hours per truck per day. In all cases however, leasing provided the minimum cost for delivering a specified tonneage to the mill. For the Batlow-1 block, except for the use of 6 and 7 trucks to deliver 200 tonnes, leasing is less costly than purchasing. This is not unexpected since the round

Table 7.2 Cost per tonne of wood delivered from the Shelley and Batlow-1 forest blocks under specified quotas

Forest block	Quota (Tonnes)	Number of trucks	Av. travel hours	Leasing ($/day)	Dep.[1] ($/day)	Dep.[2] ($/day)	Dep.[3] ($/day)	Dep.[4] ($/day)
	350	5	9.1	8.50	8.89	9.06	8.55	8.72
Shelley	500	7	9.2	8.19	8.57	8.74	8.24	8.41
	700	11	8.3	8.77	9.03	9.22	8.69	8.88
	350	9	8.6	12.80	13.29	13.58	12.76	13.05
Batlow-1	500	11	9.3	12.33	12.95	13.22	12.43	12.69
	600	13	9.6	12.33	13.01	13.27	12.48	12.74

1 Depreciation - assume a service life of 7 000 hours, interest rate 16%

2 Depreciation - assume a service life of 7 000 hours, interest rate 20%

3 Depreciation - assume a service life of 9 000 hours, interest rate 16%

4 Depreciation - assume a service life of 9 000 hours, interest rate 20%

Table 7.3 Comparison of the cost per tonne of delivered wood for various tonneage quotas and numbers of trucks from two forest blocks

Forest block	Quota (tonnes)	Number of trucks	Av. travel hours	Leasing cost ($/tonne)	Purchasing cost ($/tonne)
Shelley	200	3	9.0	8.91	9.27
		4	9.3	9.16	9.28
		5	6.0	9.68	9.48
	300	5	8.3	8.62	8.89
		6	7.1	8.87	8.93
		7	5.6	9.89	9.55
		8	5.3	10.10	9.67
	400	6	8.9	8.39	8.74
		7	7.8	8.48	8.68
		8	6.6	9.09	9.04
		9	5.8	9.63	9.34
	600	9	8.7	8.39	8.71
		10	8.3	8.56	8.82
		11	7.4	8.91	9.02
		12	6.8	9.22	9.22
		13	6.2	9.55	9.39
Batlow-1	200	5	8.9	12.95	13.50
		6	6.8	14.38	14.36
		7	6.5	14.51	14.38
	300	7	9.2	12.64	13.26
		8	8.8	12.66	13.20
		9	7.2	13.71	13.84
	400	9	9.3	12.35	12.97
		10	8.2	12.92	13.31
		11	7.8	13.01	13.30
	600	13	9.6	12.33	13.01
		14	9.0	12.45	13.02
		15	8.7	12.81	13.31
		16	8.2	13.12	13.51
		17	7.6	13.76	13.99

trip time to this block is 5.5 hours. Therefore, it is likely that two trips would be made per truck to meet the tonneage requirements, resulting in high average truck travelling times.

For the two operations described, leasing appears to be a more cost effective method of vehicle acquisition particularly when the tonneages and number of trucks are of the order of those now adopted for the ANM operation. In operations such as the ANM system with relatively large truck fleets and a practice of scheduling to maximize the travelling hours of trucks, the leasing procedure is indicated as the more appropriate method of vehicle acquisition. However, the simulations for the Shelley block indicated as did the theoretical calculations of Table 7.1, that for short haul distances and low tonneages, purchasing may be more cost effective than leasing.

The application of the simulation model to a study to determine the most appropriate financial procedure for truck procurement for log hauling has enabled a realistic assessment of costs for a range of truck numbers, taking into account the stochastic nature of truck travel times and their interaction with stochastic loading times. It is concluded that the model would be useful in assessing the two alternative procedures of leasing and purchasing log trucks in many other situations and adaptions of the model to enable this are discussed in Chapter 8.

CHAPTER 8

REVIEW

8.1 INTRODUCTION

In Australia, road transport of logs is almost universal and long hauls and relatively large log truck fleets hauling to large wood product mills, are now common. However, planning and control of these hauling operations is still based mainly on experience and management innovations can only be tested as practical trials.

While it is readily accepted that operations should be examined as a system within well-defined and appropriate limits, rather than as subsystems or parts, methods to examine operational systems are not straightforward. Stochastic simulation methods have the advantage that the modeller has to examine and understand the total system before modelling can take place.

This study applied stochastic simulation modelling techniques to the analysis of a large log truck fleet. A very considerable data collection and programming effort was required to provide a simulation model generally applicable to log hauling, but its application to the evaluation of a log hauling system demonstrated that considerable improvements with subsequent cost savings may be possible.

The results of the application of the simulation model in association with a mixed-integer optimization model also demonstrated both the practical difficulties in building appropriate and useful models and the possibilities and advantages of the models.

8.2 PRACTICALITIES OF SIMULATION OF LOG HAULING OPERATIONS

The practicalities of constructing a valid working stochastic simulation model can now be seen as a series of problems which can be critically reviewed.

8.2.1 The Conceptual Model

The conceptual model of a system defines the limits of the system, the variables and the inputs and outputs of the system.

In this study, a hauling system was defined by a schematic diagram as interacting sequential cycle times of trucks from the mill to loaders at landings and back to the mill for unloading. A state-change approach was adopted to identify processes which changed the state of the hauling system at the time at which they occurred. The level of detail was limited to types of trucks and individual loaders. Inputs were operational data describing in time intervals the elements of the log-hauling cycle and managerial data describing the operation of the trucks and loaders available and the scheduled hours of operation. The outputs of the model were the number of loads and tonnes delivered to the mill, the actual hours worked by the trucks and loaders and the costs of the operation.

The model was dynamic in that the operational characteristics changed with time and stochastic since deterministic relationships are not known for the production of system responses.

8.2.2 Data Collection

The data required for a validated stochastic simulation model of a log hauling system could become excessive and must be limited by the conceptual model. The task of data collection is eased greatly if the assistance of plant operators is available and extractions can be made from records.

In the case study, the operational data was related to the times of the elements of the log hauling cycle, viz:

1. Time spent by trucks in the mill yard - obtained from records
2. Truck travel times between the landing and the mill - from records
3. Loading times of trucks - from truck drivers and loader operators
4. Truck travel times between the mill and the landing - synthesized from cycle times
5. Frequency and duration of delays - from records
6. Nett loadweights carried by trucks - from records.

The managerial data was:

1. Types and numbers of trucks - from records
2. Number, scheduled hours and location of loaders - from records.

Data collection must also be seen in relation to the fitting of probability density functions, for the required accuracy of fitting significantly affects the number of observations required.

8.2.3 Fitting Probability Density Functions

Theoretical distributions were fitted in this study for: time spent by trucks in the mill yard; truck travel times between the landing and the mill; frequency and duration of delays; and nett loadweights carried by trucks. A computer package was used for fitting distributions but difficulties were experienced in selecting criteria for goodness of fit. The package used the Chi-square statistic, but this statistic is reliable only when all class intervals have more than five observations and the Kolmogorov-Smirnov statistic was used in addition to the Chi-square statistic.

Fitting of distributions requires relatively large data sets which include the range of events. For example, 41 observations of loading time was inadequate and so a normal distribution was assumed. Between 75 and 2440 observations were used for fitting distributions to the travel times from the landings to the mill. The data collected for this study would provide guidelines for sampling elements of log hauling cycles.

8.2.4 Choice of Language

The choice of a programming language for a stochastic simulation model is in the first instance between a general well known programming language, for example FORTRAN and a more specialised language oriented to simulation studies, for example, SIMULA or Simscript. The decision on the language should be related to the nature of the model (discrete or continuous), type of time advance and the sequencing of 'events' within the model.

Of the many simulation languages, Simscript II.5 was chosen for this study because it was the only well documented and available language on the Univac computer suited for such purposes. Ada (1979) used Simscript I.5 in an earlier study. Simscript II.5 is a much more sophisticated language and its application to the present study was very successful. It was not difficult to learn, it was found to be efficient and no significant problems were encountered with its use.

8.2.5 Validation of Log Transport Simulation Models

A major difficulty with simulation is the validation of models since there are no standard universally accepted statistical procedures applicable to all models. The common validation procedure is to verify the ability of the model to predict behaviour of the real world system by comparing the input-output transformations generated by the model to those in the real world. The statistical tests adopted for the comparison in this study were the parametric F-test and t-test and the nonparametric Mann-Whitney and Kolmogorov-Smirnov statistics.

In the case study reported, the model outputs were statistically validated against actual outputs in three periods, two of which were independent of the data used in model construction. In all cases, there was no reason to reject the model as not representing the ANM log hauling system. In addition, a day by day validation was carried out and again the model was accepted, both in results and in the underlying theory of the conceptual model.

8.2.6 Optimization of Log Hauling Operations

A significant advantage of simulation models is that they can be used in conjunction with other Operations Research techniques for experiments to determine optimal scheduling or allocation of trucks and loaders for the haulage task. The criteria for optimality is of course important.

In this study, integer programming techniques (using the Functional Mathematical Programming System) were used to determine the daily allocation of the total number of trucks available to the loaders (four in the case study) in each forest block, to meet specified quotas from each forest block. The criterion for optimal allocation was minimum total delivered cost of wood on each day.

The simulation model was used to generate the different strategies for input to the optimization model. A strategy was defined as the combination of trucks and loaders servicing a forest block. Integer programming techniques were successful and efficient in the optimal allocation of trucks among loaders on a daily basis for the constraints and assumptions specified.

8.2.7 Summary

Simulation has practical disadvantages as a technique for evaluating the operational capabilities of log hauling systems. The collection of data and subsequent processing can be very time consuming and validation and verification may be difficult with too frequent recourse to judgement by the modeller. Access to a main frame computer is necessary and formulation and development of the model is expensive of computer time.

Nonetheless, it is concluded that simulation is a useful tool for analyzing log hauling systems. It may be the only approach providing for experimentation with suggested managerial options which can in turn lead to substantial savings. The major advantages are that replication and development of experiments can be achieved in only a fraction of the real world time once the model is fully developed.

8.3 APPLICATIONS OF THE MODEL

8.3.1 Introduction

The validated simulation model was used to predict the performance of trucks and loaders under specified operating constraints such as hours of operations. Strategies generated with the model for various numbers of trucks and scheduled loader hours for each forest block were used in association with a mixed-integer optimization model to allocate among loaders, a daily number of trucks to deliver specified quotas of wood from forest blocks at minimum cost.

The experiments with the models on changes in gross vehicle weights, shift operation and load times, are seen as a demonstration of the utility and adaptability of the model. They are reviewed here in that context and further applications are then discussed.

8.3.2 Operational Experiments

8.3.2.1 Gross vehicle weight limits

The experiment was to determine the cost savings that might accrue from the use of special permits to allow increased gross vehicle weights for trucks for a single shift operation. Stochastic simulation was useful, since increasing loadweights affected travel-full times, load times, unload times and fuel consumption which in turn, interacted together to determine cycle times.

The model indicated that substantial savings could occur if gross vehicle weights of trucks were increased, but that there was little difference in the costs of a three or four loader operation. An increase of 2 tonnes above the present allowable limits resulted in a saving per year of $350 000, an increase of 4 tonnes a saving of $565 000 and an increase of 15 tonnes, a saving of $910 000.

The number of trucks required per day decreased from 36 to 25 for a 'four loader' operation with a change in loadweight from the current limit to a 53 tonne limit. Loader utilizations decreased from 81% to 68% while truck utilizations remained stable. Average loader hours per day remained at approximately 9.5 hours per day while weekly truck hours increased from 51 to 60 hours.

8.3.2.2 Double shifts for trucks and loaders

Since much of the equipment is leased in the ANM operation, any increase in hours worked by equipment reduces the average hourly fixed costs and if combined with increased deliveries, cost savings can occur. The simulation and optimization models were used to examine possible cost savings by using double shift operations for trucks and three loaders.

The models indicated that $350 000 per year could be saved if an overlapping double shift operation was used instead of the present 'four loader' single shift operation. Although a two separate twelve hour shift operation was cheaper than a 'three loader' single shift operation, it was more costly than the present operation of a single shift and four loaders. A substantial reduction in truck numbers could be effected with the overlapping shifts, only 22 being needed rather than the 36 or 38 for the single shift operations. However, 44 drivers were required. Total loader hours increased dramatically but operating hours remained similar for all operations and loader utilizations decreased from 92 to 62% for the single and overlapping shifts respectively. The poor average loader utilization was due mainly to the low utilization of one loader and the model simulations indicated that for this loader, it might be better to rearrange the loader schedule or even only work this loader 3 days in 5. Truck utilizations remained stable, although average hours per week rose from 53 to 87 for the single and overlapping shifts respectively. However, the 87 hours were shared by two drivers, resulting in better utilization of a driver's time.

8.3.2.3 Load times

The data collection indicated substantial variability in the load times of the four loaders and difference among their mean load times.

Improvement in skills and technology would reduce loading times and their variability.

A reduction in load times from 24 to 20 minutes resulted in a simulated yearly saving of $300 000 and 4 trucks for a 'three loader' operation and $160 000 and 2 trucks for a 'four loader' operation. However, a further reduction of 4 minutes to a 16 minute mean load time only resulted in savings of $30 000 for a 'three loader' operation and $40 000 for a 'four loader' operation. No further reduction in the required number of trucks resulted. The experiment indicated that with present loading times, the 'four loader' operation was preferable to the three, since any breakdowns of a loader would not then jeopardize the delivery of the quota.

Loader utilizations decreased from 92 to 75% for the three and 81 to 56% for the 'four loader' operation respectively. Average loader hours worked per day decreased from 10.1 to 8.3 and 9.4 to 8.3 respectively. Truck utilizations increased slightly and average hours per week remained between 50 and 55 hours.

8.3.2.4 Review

The above experiments demonstrated the utility of the simulation model for the comparison of alternative systems under different operational constraints. In the three experiments, the model indicated that substantial savings could be achieved. The best method for obtaining these savings was by increasing the gross vehicle weights of trucks, then the use of double shifts for trucks and loaders and finally, by reducing the mean load time.

8.3.3 Equipment Procurement Procedures

In the experiments reported, equipment costs were based on leasing charges. However, in Australia, many log hauliers purchase equipment rather than lease it. The two procurement procedures may lead to different wood delivery costs and comparisons were undertaken for the costs of loading and hauling wood to the ANM mill from two forest blocks under the two procedures.

The model indicated that for the Shelley block (220 minute cycle time), purchasing was more cost effective when up to 9 trucks were used and the loader worked up to 8 hours, when 11 trucks were used and the loader worked up to 11 hours and when 13 trucks were used and the loader worked up to 13 hours. On the other hand, for Batlow (330 minute cycle time) the model indicated that leasing was more cost effective when up to 9 trucks were used and the loader worked for over 7 hours, when 11 trucks were used and the loader worked over 7.5 hours and when 13 trucks were used and the loader worked over 8 hours. The simulation model indicated that the purchasing of trucks was more economic than leasing when the travelling hours per day were relatively low.

However, when realistic tonneage quotas were selected for the two forest blocks, the simulations showed that leasing provided the minimum wood delivery cost. The only time when purchasing would be cheaper than the corresponding leasing cost was when excess trucks were used to deliver the wood, forcing the average travelling hours per truck down. Purchasing was never cheaper than leasing when the minimum number of trucks to complete the task were used.

For the two operations described, the model indicated that when realistic tonneages were required, leasing a truck was the more cost effective method of vehicle acquisition. The model indicated that purchasing may be more cost effective when short haul distances and low tonneage quotas apply.

The application of the model to the comparison of equipment procurement procedures also demonstrated the utility and adaptability of the model.

8.4 MODELLING LOG TRUCK BREAKDOWNS

At the commencement of the study, data on the frequency and duration of log truck breakdowns were collected from the truck fleet of New Zealand Forest Products Ltd. It was expected that this data would be required for a stochastic simulation model and it was not available in Australia. However, the data collection in the ANM case study included delays and breakdowns in travel times of less than one days duration. Breakdowns of greater than one days duration were no problem in the case study as the haulage contractors had other contracts and could replace trucks as required.

The data on the frequency and duration of breakdowns was analysed in depth because it is an important factor in the overall evaluation of log truck performance and there is little information on these matters in the literature.

The results showed as expected but now quantitatively, that as trucks became older, durations of breakdowns increased and intervals between breakdowns decreased. The 2-parameter log normal distribution best characterized the intervals between breakdowns for all three classes of trucks classified by distance. The 3-parameter log normal best characterized the durations of breakdowns for the three distance classes.

Both the descriptive statistics and fitting of distributions suggested the presence of time-dependent processes in the intervals between breakdowns. However, time-dependent analyses of individual trucks showed no time-dependence, probably due to a lack of data.

The results obtained could be applicable to a further application of the simulation model. The models fitted to the frequency and durations of breakdowns could be adapted to predict log truck breakdowns in a simulation model. Analyses could then be undertaken to determine the number of trucks available from a 'pool' on a daily basis under different breakdown criteria, for example, distance classes of trucks.

8.5 FURTHER APPLICATIONS OF THE MODEL

8.5.1 Introduction

It is increasingly important that planning and management techniques based on Operations Research methods be applied to the larger and more complex log hauling operations in Australia. The validated stochastic simulation model developed in this study and used in conjunction with a mixed-integer programming model to plan optimal log hauling operations, is seen as a contribution towards improved planning and management of log truck fleets. The project demonstrated the utility and adaptability of the model for the comparison of alternative operational strategies and alternative equipment procurement methods. The model could be used for many other comparisons of alternative strategies for various factors.

8.5.2 New Applications

It is concluded that the simulation model can be readily adapted to other operational studies, for example, individual logging contractors using their own loaders and trucks to deliver to a centralized mill, to assess the effect of reducing or increasing travel times of trucks, to examine the effects of wage or fuel increases and evaluate alternatives for offsetting these increases and with only little adaption, to assess the merits of different truck combinations for different haul distances.

The concepts for the simulation model were oriented towards the ANM log hauling operation which is to a centralized mill. However, again with little adaption, other log hauling operations with different characteristics could be examined, for example, operations with many individual landings or forest blocks. The simulation model could also be used to evaluate and plan log hauling operations to a centralized weighbridge which services multiple mills some distance away, such as the situation in the Australian Capital Territory.

Sustaining planning and control schedules for large log truck fleets is a continuing task requiring updating at perhaps intervals of hours. The simulation model could be adapted to experiment with the scheduling of trucks in real time and assist in determining efficient data bases for scheduling. Scheduling algorithms could be incorporated into the model to despatch trucks to loaders, for example to minimize truck idleness and maximise wood deliveries to the mill. The algorithm could then be evaluated by means of simulation runs. Adopted scheduling algorithms could then be adapted for use on a microcomputer in a centralized mill or weighbridge for the on-line control of trucking operations.

The above suggestions demonstrate the utility and diversity of applications of the simulation model and it is concluded that while the development and validation of the model was time consuming, it is realistic and can be readily applied to wide ranging evaluations of log hauling operations.

8.5.3 Future Research

The development of the simulation and optimization models has indicated areas where future research is desirable. An obvious need is for extended data to be incorporated in the model, particularly if different systems are to be simulated. For example, additional data on operational characteristics of different trucks and loaders are needed for fitting of distributions and application in the model. Additionally, in the reported project, travel times from landings were based on the groupings of times to known landings and when simulating other operations, this data may not be readily available. Therefore, relationships between parameters of the 3-parameter log normal distribution and the haul distance and road type need to be developed for the prediction of stochastic travel times for other operations.

Future research into the frequency and durations of breakdowns requires longer data collection periods for individual trucks so that further time-dependent analyses can be carried out. Data collection should also include reliable information on causes of breakdowns. In more general terms, research of techniques for the stochastic analysis of the performance of logging equipment is seen as a promising direction for research.

The study was concerned with the simulation and optimal planning of log hauling operations. The optimization model was based upon feasible and realistic daily loader schedules. Further research is needed to optimize the loader schedules as well as the log hauling operations by expanding the planning and optimization horizons from one day.

The simulation model assumes wood is available at each forest block or landing. Further research and development could expand the model to encompass the log stockpiles at the landings. With these stockpiles incorporated, the movement of loaders to and from stockpiles could be modelled under constraints of available wood. Further expansion of the model would lead to the simulation of the harvesting operations (the movement of wood from stump to roadside) which generate the log stockpiles. Such a model would then be applicable to the comprehensive planning and optimization of the harvesting and transport process of the wood procurement for a mill. Expansion from the current model would face similar problems as the present study, for example, distribution fitting, choice of language and validation of the model.

It has been demonstrated in this study that the methodologies developed can assist in solving problems in log haulage operations and truck fleet management and in defining improvements. They also provide a basis for the development of a more comprehensive simulation model. It is concluded that stochastic simulation is a useful tool in developing analytical techniques for the planning and management of log transport systems.

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APPENDIX 2.1

Sample form distributed to loader operators.

Sample form distributed to truck drivers.

DATE: LOADER: OPERATOR:

STARTING TIME AT LANDING:

MECHANICAL DELAYS

LOAD NO.	TRUCK REGO NUMBER	TIME STARTED LOADING	DELAY DURING LOADING	COMMENTS	TIME MACHINE STOPPED WORKING	TIME REPAIRS COMPLETED BY	COMMENTS
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

DATE: REGO: DRIVER:

TIME OF LEAVING BASE TO BEGIN WORK:

LOAD NO.	DELAYS WHEN TRAVELLING TO LANDING (MINS)	TIME OF ARRIVAL AT LANDING	START TIME FOR LOADING	DELAYS DURING LOADING (MINS)	TIME OF DEPARTURE FROM LANDING	DELAYS WHEN TRAVELLING TO MILL (MINS)	COMMENTS
1							
2							
3							
4							
5							
6							

NOTE: Only record delays of half an hour or more for the travelling sections.

APPENDIX 2.2

List of distributions fitted to the data in the study.

normal density function:

$$f(x) = \frac{1}{s\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-m}{s}\right)^2} \qquad \begin{array}{l} -\infty<x>\infty \\ -\infty<m>\infty \\ s>0 \end{array}$$

log normal (2-parameter) density function:

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{½\left(\frac{\ln(x)-\mu}{2}\right)^2} \qquad \begin{array}{l} -\infty<x>\infty \\ -\infty<\mu>\infty, \sigma>0 \end{array}$$

log normal (3-parameter) density function:

$$f(x) = \frac{1}{(x-\varepsilon)\sigma\sqrt{2\pi}} e^{½\left(\frac{\ln(x-\varepsilon)-\mu}{2}\right)^2} \qquad \begin{array}{l} -\infty < \varepsilon > \infty \\ x > \varepsilon, \ \sigma > 0 \\ -\infty < \mu > \infty \end{array}$$

Weibull density function:

$$f(x) = cb^c \ x^{(c-1)} \ e^{(-(bx)^c)} \qquad x>0, \ c,b>0$$

gamma density function:

$$f(x) = \frac{b^k x^{(k-1)} e^{-bx}}{\Gamma(k)} \qquad x>0, \ b,k>0$$

beta density function:

$$f(x) = \frac{1}{\beta(p,q)} \frac{b^p x^{(p-1)}}{(1+bx)^{p+q}} \qquad x>0, \ b,q,p>0$$

Source: Ross (1980)

APPENDIX 2.3

Mean and standard deviation of the 2- and 3-parameter log normal distributions.

2-parameter:

$$\text{mean} = e^{\mu + \sigma^2/2}$$

$$\text{variance} = e^{2\mu + \sigma^2}(e^{\sigma^2} - 1)$$

3-parameter:

$$\text{mean} = \varepsilon + e^{\mu + \sigma^2/2}$$

with the same variance as above.

Source: Fishman (1973), Ross (1980) and Russell (1983)

APPENDIX 3.1

Costs for Trucks and Loaders

Trucks:

Purchase price	\$110 000
Resale value	\$27 500
Lease period	48 months
Lease payment	\$2587.20 per month
Insurance (4% of purchase)	\$4400 per year
Registration	\$1856

Tyres

Cost \$10,200 after 120 000 kilometres.

At an average speed of 60 kph, = 2000 hours

= \$5.16 per hour

Fuel

50 litres consumed per 100 km

∴ 50 litres consumed per 1.75 hours =

at \$0.43 per litre = \$12.29 per hour

Oil 10% of fuel costs = \$1.23 per hour

Repairs and Maintenance:

50% of purchase price of prime mover

(\$90 000) = \$6.43 per hour

Loaders:

Purchase price	$110 000
Resale value	$22 000
Lease period	48 months
Lease payment	
Assume 240 working days	$140.16 per day
Insurance (3.5% of purchase)	$3850 per year
Registration	$1150 per year

Tyres

Cost $3000 every 30 000 kilometres (gravel)

Average 50 kms/week, average 50 hours worked per week

= $0.10 per hour

Fuel	15 litres per hour	= $6.45 per hour
Oil	20% of fuel	= $1.29

Repairs and Maintenance

30% of purchase price	= $4.13

APPENDIX 5.1

Verification of a check run

```
THE WEIGHBRIDGE IS CLOSING AT  0.
TRUCK 10 HAS ARRIVED AT LOADER  2 AT  0.2187
TRUCK 10 HAS STARTED LOADING USING LOADER  2 AT  0.2187
TRUCK  1 HAS ARRIVED AT LOADER  1 AT  0.2292
TRUCK  1 HAS STARTED LOADING USING LOADER  1 AT  0.2292
TRUCK 24 HAS ARRIVED AT LOADER  4 AT  0.2292
TRUCK 24 HAS STARTED LOADING USING LOADER  4 AT  0.2292
TRUCK 11 HAS ARRIVED AT LOADER  2 AT  0.2326
TRUCK 10 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  2 AT  0.2348
TRUCK 11 HAS STARTED LOADING USING LOADER  2 AT  0.2348
TRUCK 18 HAS ARRIVED AT LOADER  3 AT  0.2396
TRUCK 18 HAS STARTED LOADING USING LOADER  3 AT  0.2396
TRUCK  2 HAS ARRIVED AT LOADER  1 AT  0.2431
TRUCK 25 HAS ARRIVED AT LOADER  4 AT  0.2431
TRUCK 12 HAS ARRIVED AT LOADER  2 AT  0.2465
TRUCK  1 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  1 AT  0.2467
TRUCK  2 HAS STARTED LOADING USING LOADER  1 AT  0.2467
TRUCK 24 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  4 AT  0.2484
TRUCK 25 HAS STARTED LOADING USING LOADER  4 AT  0.2484
TRUCK 11 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  2 AT  0.2505
TRUCK 12 HAS STARTED LOADING USING LOADER  2 AT  0.2505
TRUCK 19 HAS ARRIVED AT LOADER  3 AT  0.2535
TRUCK  3 HAS ARRIVED AT LOADER  1 AT  0.2569
TRUCK 26 HAS ARRIVED AT LOADER  4 AT  0.2569
TRUCK 18 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  3 AT  0.2579
TRUCK 19 HAS STARTED LOADING USING LOADER  3 AT  0.2579
TRUCK 13 HAS ARRIVED AT LOADER  2 AT  0.2604
TRUCK 20 HAS ARRIVED AT LOADER  3 AT  0.2674
TRUCK 25 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  4 AT  0.2674
TRUCK 26 HAS STARTED LOADING USING LOADER  4 AT  0.2674
TRUCK 12 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  2 AT  0.2708
TRUCK 13 HAS STARTED LOADING USING LOADER  2 AT  0.2708
TRUCK  4 HAS ARRIVED AT LOADER  1 AT  0.2709
TRUCK  2 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  1 AT  0.2715
TRUCK  3 HAS STARTED LOADING USING LOADER  1 AT  0.2715
TRUCK 14 HAS ARRIVED AT LOADER  2 AT  0.2743
TRUCK 19 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  3 AT  0.2784
TRUCK 20 HAS STARTED LOADING USING LOADER  3 AT  0.2784
TRUCK 21 HAS ARRIVED AT LOADER  3 AT  0.2812
TRUCK 26 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  4 AT  0.2837
TRUCK  5 HAS ARRIVED AT LOADER  1 AT  0.2847
TRUCK  3 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  1 AT  0.2868
TRUCK  4 HAS STARTED LOADING USING LOADER  1 AT  0.2868
TRUCK 13 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  2 AT  0.2881
TRUCK 14 HAS STARTED LOADING USING LOADER  2 AT  0.2881
TRUCK 15 HAS ARRIVED AT LOADER  2 AT  0.2882
TRUCK 22 HAS ARRIVED AT LOADER  3 AT  0.2951
TRUCK  6 HAS ARRIVED AT LOADER  1 AT  0.2986
TRUCK  4 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  1 AT  0.2995
TRUCK  5 HAS STARTED LOADING USING LOADER  1 AT  0.2995
TRUCK 20 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  3 AT  0.2995
TRUCK 21 HAS STARTED LOADING USING LOADER  3 AT  0.2995
TRUCK 16 HAS ARRIVED AT LOADER  2 AT  0.3021
TRUCK 14 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  2 AT  0.3046
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TRUCK 15 HAS STARTED LOADING USING LOADER  2 AT   0.3046
TRUCK 23 HAS ARRIVED AT LOADER  3 AT   0.3090
TRUCK  5 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  1 AT   0.3109
TRUCK  6 HAS STARTED LOADING USING LOADER  1 AT   0.3109
TRUCK  7 HAS ARRIVED AT LOADER  1 AT   0.3125
TRUCK 17 HAS ARRIVED AT LOADER  2 AT   0.3160
TRUCK 18 HAS ARRIVED AT WEIGHBRIDGE TO ENTER MILL AT   0.3162
TRUCK 21 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  3 AT   0.3172
TRUCK 22 HAS STARTED LOADING USING LOADER  3 AT   0.3172
TRUCK 15 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  2 AT   0.3183
TRUCK 16 HAS STARTED LOADING USING LOADER  2 AT   0.3183
TRUCK  6 HAS ARRIVED AT LOADER  1 AT   0.3264
TRUCK  6 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  1 AT   0.3274
TRUCK  7 HAS STARTED LOADING USING LOADER  1 AT   0.3274
TRUCK 18 HAS ARRIVED AT WEIGHBRIDGE TO EXIT MILL AT   0.3293
TRUCK 18 IS TO RETURN TO LOADER  3
TRUCK 22 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  3 AT   0.3311
TRUCK 23 HAS STARTED LOADING USING LOADER  3 AT   0.3311
TRUCK 10 HAS ARRIVED AT WEIGHBRIDGE TO ENTER MILL AT   0.3334
TRUCK 16 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  2 AT   0.3339
TRUCK 17 HAS STARTED LOADING USING LOADER  2 AT   0.3339
TRUCK 24 HAS ARRIVED AT WEIGHBRIDGE TO ENTER MILL AT   0.3377
TRUCK  9 HAS ARRIVED AT LOADER  1 AT   0.3403
TRUCK 10 HAS ARRIVED AT WEIGHBRIDGE TO EXIT MILL AT   0.3411
TRUCK 10 IS TO RETURN TO LOADER  2
TRUCK 23 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  3 AT   0.3437
TRUCK 24 HAS ARRIVED AT WEIGHBRIDGE TO EXIT MILL AT   0.3446
TRUCK 24 IS TO RETURN TO LOADER  4
TRUCK  7 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  1 AT   0.3463
TRUCK  8 HAS STARTED LOADING USING LOADER  1 AT   0.3463
TRUCK 19 HAS ARRIVED AT WEIGHBRIDGE TO ENTER MILL AT   0.3488
TRUCK 17 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  2 AT   0.3503
TRUCK 11 HAS ARRIVED AT WEIGHBRIDGE TO ENTER MILL AT   0.3524
TRUCK 25 HAS ARRIVED AT WEIGHBRIDGE TO ENTER MILL AT   0.3562
TRUCK 19 HAS ARRIVED AT WEIGHBRIDGE TO EXIT MILL AT   0.3576
TRUCK 19 IS TO RETURN TO LOADER  3
TRUCK 20 HAS ARRIVED AT WEIGHBRIDGE TO ENTER MILL AT   0.3626
TRUCK 25 HAS ARRIVED AT WEIGHBRIDGE TO EXIT MILL AT   0.3637
TRUCK 25 IS TO RETURN TO LOADER  4
TRUCK 11 HAS ARRIVED AT WEIGHBRIDGE TO EXIT MILL AT   0.3646
TRUCK  8 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  1 AT   0.3646
TRUCK  9 HAS STARTED LOADING USING LOADER  1 AT   0.3646
TRUCK 11 IS TO RETURN TO LOADER  2
TRUCK  2 HAS ARRIVED AT WEIGHBRIDGE TO ENTER MILL AT   0.3700
TRUCK 20 HAS ARRIVED AT WEIGHBRIDGE TO EXIT MILL AT   0.3727
TRUCK 20 IS TO RETURN TO LOADER  3
TRUCK  1 HAS ARRIVED AT WEIGHBRIDGE TO ENTER MILL AT   0.3776
TRUCK  2 HAS ARRIVED AT WEIGHBRIDGE TO EXIT MILL AT   0.3787
TRUCK  2 IS TO RETURN TO LOADER  1
TRUCK  9 IS ABOUT TO DEPART FOR THE MILL FROM LOADER  1 AT   0.3813
TRUCK 12 HAS ARRIVED AT WEIGHBRIDGE TO ENTER MILL AT   0.3814
TRUCK  1 HAS ARRIVED AT WEIGHBRIDGE TO EXIT MILL AT   0.3868
TRUCK  1 IS TO RETURN TO LOADER  1
TRUCK 26 HAS ARRIVED AT WEIGHBRIDGE TO ENTER MILL AT   0.3898
```

APPENDIX 5.2

Listing of the model as used in period validation

```
PREAMBLE

''  PROCESSES LIST

    PROCESSES INCLUDE MORNING, CLOSE.WB
    EVERY LAND.ARRIVAL HAS AN ATRUCK AND AN ALOADER
    DEFINE ATRUCK AND ALOADER AS INTEGER VARIABLES
    EVERY WB.ARRIVAL HAS A BTRUCK, A BLOADER AND A DESTINATION
    DEFINE BTRUCK, BLOADER AND DESTINATION AS INTEGER VARIABLES

''  RESOURCES LIST

    RESOURCES INCLUDE ATTENDENT
    EVERY WB HAS A WAIT.TIME
    EVERY LOADER HAS A P.DAY.L.WORK, A T.L.LOADS,
     A D.L.TIME, A P.L.TIME, A LDR.WORK, A D.L.WORK, A P.L.WORK, A D.L.IDLE,
     A P.L.IDLE, A D.T.TIME, A P.T.TIME, A D.T.WORK, A P.T.WORK, A D.T.IDLE,
     A D.DAY.L.WORK, A P.T.IDLE, A D.L.LOADS, A P.L.LOADS, A UT.LOADER,
     AN ALLOW.HARV, A WAIT.LOADER, A LOADER.INDEX, A NLAND, A NO.WORK.LOADER,
     A NO.LAND.LOADER, A DUE.L.FINISH, A START.LOADER AND A FINISH.LOADER
    DEFINE WAIT.LOADER, START.LOADER, P.L.TIME,
     LDR.WORK, D.L.WORK, P.L.WORK, D.L.IDLE, P.L.IDLE, D.T.TIME,
     P.T.TIME, D.T.WORK, P.T.WORK, D.T.IDLE, P.T.IDLE,
     WAIT.TIME, UT.LOADER, D.L.TIME, DUE.L.FINISH, NO.WORK.LOADER
     AND FINISH.LOADER AS REAL VARIABLES
    DEFINE P.DAY.L.WORK, LOADER.INDEX, NLAND, ALLOW.HARV, T.L.LOADS,
     D.DAY.L.WORK, D.L.LOADS, P.L.LOADS AND
     NO.LAND.LOADER AS INTEGER VARIABLES

''  ENTITIES LIST

    PERMANENT ENTITIES
    EVERY FOREST HAS A NAME AND A STATE
     DEFINE NAME AS A TEXT VARIABLE
     DEFINE STATE AS AN INTEGER VARIABLE
    EVERY TRUCK HAS A DEST.TRUCK, A LDWT, A START.TRUCK, A STATUS.TRUCK,
     A TRAV.TIME, AN ORIGIN, A TYPE, AN ARR.LAND AND A FINISH.TRUCK
    DEFINE DEST.TRUCK AND STATUS.TRUCK AS AN ALPHA VARIABLE
    DEFINE LDWT, TRAV.TIME, START.TRUCK, ARR.LAND AND FINISH.TRUCK AS REAL
          VARIABLES
    DEFINE TYPE AND ORIGIN AS INTEGER VARIABLES

''  VARIABLES LIST

    DEFINE REPORT.PERIOD,MAX.PIG,MAX.S1 AND NO.OF.TRUCKS AS INTEGER VARIABLES
    DEFINE NO.OF.LOADERS, D.LOADS, T.LOADS AND P.LOADS AS INTEGER VARIABLES
    DEFINE HARV.LOADS, P.NTKS, T.NTKS AND DAYS.OF.HAULAGE AS INTEGER VARIABLES
    DEFINE N.HARV, NOLAND, .IN, STREAM, NOMILL AND .OUT AS INTEGER VARIABLES
    DEFINE T.DAYS.HAULAGE AND P.DAYS.HAULAGE AS INTEGER VARIABLES
    DEFINE SHIFT, T.TONS, T.CONS, P.CONS AND OPENING.TIME AS REAL VARIABLES
    DEFINE UT.WB.IN, WORK.TRUCK, PRODUCTION AND UT.WB.OUT AS REAL VARIABLES
    DEFINE MILL.INTAKE, MILL.STOCKPILE AND CAPACITY.MILL AS REAL VARIABLES
    DEFINE P.TRK.TIME,ENDSIM,D.TRK.TIME AND NIGHT.TIME AS REAL VARIABLES
    DEFINE PROD1, EXTERNAL.CHIPS, D.TONS, P.TONS AND PROD2 AS REAL VARIABLES
    DEFINE INTERVAL, OPEN.STOCKPILE,CHIP.DEL AND NOPROD.PERC AS REAL VARIABLES
    DEFINE T.TRK.TIME AS A REAL VARIABLE
    DEFINE REP.DAY AND REP.END AS AN ALPHA VARIABLE

'' ARRAYS LIST
```

```
      DEFINE IDENT.HARV, T.LOADS.AREA AND ALLOW.FOREST AS AN INTEGER,1-DIM ARRAY
      DEFINE OVERNIGHT, LOADS.AREA AND TOTAL.H.LOADS AS AN INTEGER, 1-DIM ARRAY
      DEFINE SEEDS AS AN INTEGER, 1-DIM ARRAY
      DEFINE WB.HOURS AND TONS.AREA AS A REAL,1-DIM ARRAY
      DEFINE NTRUCK.TYPE, PRIORITY AND TRUE.LOADS AS A REAL, 1-DIM ARRAY
      DEFINE TIME.IN, BEGIN.WB.IN, BEGIN.WB.OUT AND TIME.OUT AS REAL,1-DIM ARRAY
      DEFINE POS.LOADER, LDR.INDEX AND POS.HARVESTER AS AN INTEGER, 2-DIM ARRAY
      DEFINE IFULL, ICYCLE AND IEMPTY AS AN INTEGER, 2-DIM ARRAY
      DEFINE MILL.TIME, TRAV.EMP, BEGIN.LOADER AND LOADWT AS A REAL, 2-DIM ARRAY
      DEFINE FULL, SCHED.HOURS, LOAD.TIME, CYCLE AND EMPTY AS A REAL,2-DIM ARRAY
      DEFINE TRAV.FULL AND NTRUCK.LOADER AS A REAL, 3-DIM ARRAY
      DEFINE ALLOW.LOADER AS AN ALPHA, 2-DIM ARRAY

''  STATISTICS

      TALLY MEAN.WAIT AS THE MEAN AND MAX.WAIT AS THE MAXIMUM OF WAIT.TIME
      TALLY MEAN.PROD AS THE MEAN AND STD.PROD AS THE STD.DEV OF PRODUCTION
      TALLY MEAN.L.WAIT AS THE MEAN AND MAX.L.WAIT AS THE MAXIMUM OF
         WAIT.LOADER
      ACCUMULATE AV.QUEUE.LENGTH AS THE MEAN AND MAX.QUEUE.LENGTH AS THE
         MAXIMUM OF N.Q.WB
      ACCUMULATE AV.G.LOADER AS THE MEAN AND MAX.G.LOADER AS THE
         MAXIMUM OF N.Q.LOADER
   END


   MAIN
      DEFINE I AND K AS AN INTEGER VARIABLE
      LET .IN = 1
      LET .OUT = 2
      RESERVE SEEDS AS 10
      LET SEEDS(1) = 2116429302
      LET SEEDS(2) = 683743814
      LET SEEDS(3) = 964393174
      LET SEEDS(4) = 1217426631
      LET SEEDS(5) = 618433579
      LET SEEDS(6) = 1157240309
      LET SEEDS(7) = 15726055
      LET SEEDS(8) = 48108509
      LET SEEDS(9) = 1797920909
      LET SEEDS(10) = 477424540
      CALL INPUT
      CREATE EVERY WB(2)
      LET U.WB(.IN) = 1
      LET U.WB(.OUT) = 1
      CREATE EVERY ATTENDENT(1)
      LET U.ATTENDENT(1) = 1
      ACTIVATE A CLOSE.WB NOW
      START SIMULATION
   END

   SUBROUTINE SCHEDULER GIVEN ITRUCK AND ILOADER
      DEFINE FOR, ILOADER, BLK AND ITRUCK AS INTEGER VARIABLES
      DEFINE DES.DUE AS AN ALPHA VARIABLE
      LET FOR = POS.LOADER(ILOADER,1)
      LET BLK = POS.LOADER(ILOADER,2)
      LET MEAN = TRAV.FULL(FOR,BLK,1) + TRAV.EMP(FOR,BLK)
      IF (TIME.V+((MEAN-(SHIFT*MEAN))/1440.)) GT DUE.L.FINISH(ILOADER)
```

```
          LET DES.DUE = "LAND"
          CALL HOME.TRUCK GIVING ITRUCK, ILOADER AND DES.DUE
        ELSE
          LET MEAN = TRAV.FULL(FOR,BLK,1) - TRAV.FULL(FOR,BLK,3)
          LET TRAV = LOG.NORMAL.F(MEAN,TRAV.FULL(FOR,BLK,2),STREAM)
          LET TRAV = TRAV + TRAV.FULL(FOR,BLK,3)
          LET EMP = TRAV.EMP(FOR,BLK) * TRAV
          IF (TIME.V+(EMP/1440.)) GT (DUE.L.FINISH(ILOADER) + 0.0104)
            LET DES.DUE = "LAND"
            CALL HOME.TRUCK GIVING ITRUCK, ILOADER AND DES.DUE
          ELSE
            LET TIME = (EMP + 25. + TRAV.FULL(FOR,BLK,1)) / 60.
            IF (((TIME.V - START.TRUCK(ITRUCK)) * 24.) + TIME) IS GT WORK.TRUCK
              LET DES.DUE = "LAND"
              CALL HOME.TRUCK GIVING ITRUCK, ILOADER AND DES.DUE
            ELSE
              ACTIVATE A LAND.ARRIVAL GIVING ITRUCK AND ILOADER IN EMP MINUTES
              ADD EMP TO EMPTY(FOR,BLK)
              ADD 1 TO IEMPTY(FOR,BLK)
              ADD EMP TO TRAV.TIME(ITRUCK)
            ALWAYS
          ALWAYS
        ALWAYS
        RETURN
    END


    SUBROUTINE INPUT
        DEFINE I AND J AS AN INTEGER VARIABLE
        READ STREAM
        LET SEED.V(STREAM) = SEEDS(STREAM)
        SKIP 2 CARDS
        READ I, REPORT.PERIOD, REP.DAY, REP.END, DAYS.OF.HAULAGE
        LET ENDSIM = REAL.F(I)
        SKIP 2 CARDS
        READ N.LOADER, N.HARV, N.FOREST, NO.OF.TRUCKS
        RESERVE LOADS.AREA, T.LOADS.AREA, WB.HOURS AND TONS.AREA AS 2
        RESERVE NTRUCK.TYPE AS 3
        RESERVE ALLOW.FOREST AS N.FOREST
        RESERVE IDENT.HARV, TOTAL.H.LOADS, TRUE.LOADS AND PRIORITY AS N.HARV
        RESERVE TIME.IN,BEGIN.WB.IN,BEGIN.WB.OUT AND TIME.OUT AS NO.OF.TRUCKS
        RESERVE OVERNIGHT AS NO.OF.TRUCKS
        RESERVE SCHED.HOURS AS N.LOADER BY 2
        RESERVE POS.LOADER AND LOAD.TIME AS N.LOADER BY 3
        RESERVE LDR.INDEX AS N.LOADER+1 BY N.LOADER
        RESERVE LOADWT AND MILL.TIME AS 3 BY 3
        RESERVE POS.HARVESTER AS N.HARV BY 2
        RESERVE ALLOW.LOADER AS N.LOADER BY N.HARV
        RESERVE BEGIN.LOADER,CYCLE,ICYCLE,TRAV.EMP,FULL,EMPTY,IFULL,IEMPTY
                                          AS N.FOREST BY 5
        RESERVE NTRUCK.LOADER AS 2 BY N.LOADER BY N.FOREST
        RESERVE TRAV.FULL AS N.FOREST BY 5 BY 3
        CREATE EVERY LOADER(N.LOADER)
        CREATE EVERY FOREST(N.FOREST)
        SKIP 2 CARDS
        READ NTRUCK.TYPE(1) , NTRUCK.TYPE(2) , NTRUCK.TYPE(3) , MAX.PIG , MAX.S1
        SKIP 2 CARDS
        FOR I = 1 TO 3, DO
        READ MILL.TIME(I,1) , MILL.TIME(I,2) , MILL.TIME(I,3)
        LOOP
```

```
SKIP 2 CARDS
FOR I = 1 TO N.FOREST, DO
READ NAME(I) AS T *
READ STATE(I)
READ BEGIN.LOADER(I,1),BEGIN.LOADER(I,2),BEGIN.LOADER(I,3),
BEGIN.LOADER(I,4) AND BEGIN.LOADER(I,5)
FOR J = 1 TO 5, DO
READ TRAV.FULL(I,J,1) , TRAV.FULL(I,J,2) , TRAV.FULL(I,J,3)
LOOP
READ TRAV.EMP(I,1), TRAV.EMP(I,2), TRAV.EMP(I,3), TRAV.EMP(I,4),
TRAV.EMP(I,5)
LOOP
SKIP 2 CARDS
FOR I = 1 TO 3, DO
READ LOADWT(I,1) , LOADWT(I,2) , LOADWT(I,3)
LOOP
SKIP 2 CARDS
FOR I = 1 TO N.LOADER, DO
READ LOAD.TIME(I,1) , LOAD.TIME(I,2) , LOAD.TIME(I,3)
LOOP
SKIP 2 CARDS
READ I
LET INTERVAL = I / 1440.0
SKIP 2 CARDS
READ SHIFT
SKIP 2 CARDS
READ WB.HOURS(1) , WB.HOURS(2)
SKIP 2 CARDS
READ NIGHT.TIME
LET NIGHT.TIME = NIGHT.TIME / 24.
SKIP 2 CARDS
FOR I = 1 TO N.LOADER, DO
READ NO.LAND.LOADER(I), NO.WORK.LOADER(I), SCHED.HOURS(I,1),
SCHED.HOURS(I,2)
LET U.LOADER(I) = NO.LAND.LOADER(I)
LOOP
SKIP 2 CARDS
FOR I = 1 TO N.LOADER+1, DO
READ LDR.INDEX(I,1), LDR.INDEX(I,2), LDR.INDEX(I,3), LDR.INDEX(I,4)
LOOP
SKIP 2 CARDS
FOR I = 1 TO N.LOADER, DO
READ ALLOW.LOADER(I,1), ALLOW.LOADER(I,2), ALLOW.LOADER(I,3),
ALLOW.LOADER(I,4),ALLOW.LOADER(I,5),ALLOW.LOADER(I,6),ALLOW.LOADER(I,7),
ALLOW.LOADER(I,8),ALLOW.LOADER(I,9),ALLOW.LOADER(I,10),ALLOW.LOADER(I,11),
ALLOW.LOADER(I,12),ALLOW.LOADER(I,13)
LOOP
SKIP 2 CARDS
FOR I = 1 TO N.FOREST, DO
READ NTRUCK.LOADER(1,1,I) , NTRUCK.LOADER(1,2,I) , NTRUCK.LOADER(1,3,I) ,
NTRUCK.LOADER(1,4,I)
READ NTRUCK.LOADER(2,1,I) , NTRUCK.LOADER(2,2,I) , NTRUCK.LOADER(2,3,I) ,
NTRUCK.LOADER(2,4,I)
LOOP
SKIP 2 CARDS
FOR I = 1 TO N.HARV, DO
READ POS.HARVESTER(I,1),POS.HARVESTER(I,2),IDENT.HARV(I),
TRUE.LOADS(I)
LOOP
SKIP 2 CARDS
```

```
        READ WORK.TRUCK
        RETURN
    END

    SUBROUTINE LDR.NIGHT
        DEFINE I AND JJ AS AN INTEGER VARIABLE
        FOR JJ = 1 TO NO.OF.LOADERS, DO
        LET I = LOADER.INDEX(JJ)
        LET HOURS = (FINISH.LOADER(I) - START.LOADER(I)) * 24.0
        ADD HOURS TO P.L.TIME(I)
        ADD HOURS TO D.L.TIME(I)
        LET WORK = LDR.WORK(I) / 60.0
        IF WORK IS GT (HOURS + 0.1)
           PRINT 1 LINE WITH HOURS, WORK AND I AS FOLLOWS
             FOR ***.* HOURS, WORK TIME OF ***.* FOR LOADER *
        ALWAYS
        LET IDLE = ABS.F(HOURS - WORK)
        ADD WORK TO D.L.WORK(I)
        ADD WORK TO P.L.WORK(I)
        ADD IDLE TO D.L.IDLE(I)
        ADD IDLE TO P.L.IDLE(I)
        ADD 1 TO P.DAY.L.WORK(I)
        ADD 1 TO D.DAY.L.WORK(I)
        LOOP
        IF REP.DAY EQ "Y"
           CALL REPORT.DAY
        ALWAYS
        RETURN
    END

    SUBROUTINE DAY.CLEAR
        DEFINE I AND J AS INTEGER VARIABLES
        LET D.LOADS = 0
        LET D.TONS = 0.
        LET D.TRK.TIME = 0.
        FOR I = 1 TO N.LOADER, DO
        LET D.L.TIME(I) = 0.
        LET D.L.WORK(I) = 0.
        LET D.L.IDLE(I) = 0.
        LET D.T.TIME(I) = 0.
        LET D.T.WORK(I) = 0.
        LET D.T.IDLE(I) = 0.
        LET LDR.WORK(I) = 0.
        LET D.L.LOADS(I) = 0
        LET D.DAY.L.WORK(I) = 0
        LOOP
        RETURN
    END

    SUBROUTINE PERIOD.CLEAR
        DEFINE I AND J AS INTEGER VARIABLES
        LET P.TONS = 0.
        LET P.DAYS.HAULAGE = 0.
        LET LOADS.AREA(1) = 0
        LET LOADS.AREA(2) = 0
        LET P.NTKS = 0
        LET TONS.AREA(1) = 0.
```

```
        LET TONS.AREA(2) = 0.
        LET P.LOADS = 0
        LET P.TONS = 0.
        LET P.TRK.TIME = 0.
        FOR I = 1 TO N.LOADER, DO
        LET P.L.TIME(I) = 0.
        LET P.L.WORK(I) = 0.
        LET P.L.IDLE(I) = 0.
        LET P.T.TIME(I) = 0.
        LET P.T.WORK(I) = 0.
        LET P.T.IDLE(I) = 0.
        LET P.L.LOADS(I) = 0
        LET P.DAY.L.WORK(I) = 0
        LOOP
        RETURN
    END


    PROCESS MORNING
        DEFINE I, JJ, FOR, BLK, ILOADER, IST, IFIN AND K AS INTEGER VARIABLES
        ACTIVATE A CLOSE.WB AT NIGHT.TIME
        IF WEEKDAY.F(TIME.V) IS GE 2 AND WEEKDAY.F(TIME.V) LE (DAYS.OF.HAULAGE+1)
          CALL LDR.NIGHT
        ALWAYS
        IF TIME.V GE (ENDSIM-0.5)
          IF REP.END EQ "Y"
            CALL END.REPORT
          ELSE
            LET LOADS1 = T.LOADS.AREA(1) / T.LOADS * 100.0
            LET LOADS2 = T.LOADS.AREA(2) / T.LOADS * 100.0
            PRINT 4 LINES WITH LOADS1 AND LOADS2 AS FOLLOWS

                           NSW                             VIC
                          **.*%                           **.*%

          ALWAYS
          STOP
        ELSE
        CALL DAY.CLEAR
        IF WEEKDAY.F(TIME.V) IS EQ 7
          LET I = (TIME.V+1) / 7.0
          IF MOD.F(I,REPORT.PERIOD) EQ 0,
            CALL REPORT
          ALWAYS
        ALWAYS
        IF WEEKDAY.F(TIME.V) IS LT (DAYS.OF.HAULAGE+1)
          ADD 1 TO T.DAYS.HAULAGE
          ADD 1 TO P.DAYS.HAULAGE
          CALL LOADER.MORN
          CALL TRUCK.MORN
          LET IST = 1
          LET IFIN = NLAND(LOADER.INDEX(1))
          FOR JJ = 1 TO NO.OF.LOADERS, DO
          LET ILOADER = LOADER.INDEX(JJ)
          LET FOR = POS.LOADER(ILOADER,1)
          LET BLK = POS.LOADER(ILOADER,2)
          LET TIME = TRUNC.F(TIME.V) + (BEGIN.LOADER(FOR,BLK) / 24.0)
          LET START.LOADER(ILOADER) = TIME
          LET FINISH = NORMAL.F(SCHED.HOURS(ILOADER,1),SCHED.HOURS(ILOADER,2),
                                                                  STREAM)
```

```
            LET DUE.L.FINISH(ILOADER) = TIME + (FINISH / 24.0)
            FOR I = IST TO IFIN, DO
            IF STATUS.TRUCK(I) EQ ¤FIN¤
              IF DEST.TRUCK(I) EQ ¤LAND¤
                ACTIVATE A LAND.ARRIVAL GIVING I AND ILOADER AT TIME
                LET START.TRUCK(I) = TIME
                ADD INTERVAL TO TIME
              ELSE
                LET TIME1 = TRUNC.F(TIME.V) + 0.3125
                ACTIVATE A WE.ARRIVAL GIVING I, ILOADER AND .IN AT TIME1
                LET START.TRUCK(I) = TIME1
              ALWAYS
              LET DEST.TRUCK(I) = ¤LAND¤
            ALWAYS
            LET STATUS.TRUCK(I) = ¤NOTFIN¤
            LOOP
            LET IST = NLAND(LOADER.INDEX(JJ)) + IST
            LET IFIN = NLAND(LOADER.INDEX(JJ+1)) + IFIN
            LOOP
          ALWAYS
        END


        SUBROUTINE LOADER.MORN
          DEFINE JJ, LDR, L, I, J, K AS INTEGER VARIABLES
          FOR I = 1 TO N.FOREST, DO
          LET ALLOW.FOREST(I) = 0
          LOOP
          LET NO.OF.LOADERS = N.LOADER
          LET LDR = 2
          LET I = 1
          LET R = RANDOM.F(STREAM)
          FOR JJ = 1 TO N.LOADER, DO
          IF R LT NO.WORK.LOADER(JJ)
            LET I = JJ + 1
            LET NO.OF.LOADERS = N.LOADER - 1
            LET LDR = 1
            LEAVE
          ELSE
          LOOP
          FOR J = 1 TO N.LOADER, DO
          LET LOADER.INDEX(J) = LDR.INDEX(I,J)
          LET ALLOW.HARV(J) = 0
          LOOP
          FOR K = 1 TO N.HARV, DO
          LET PRIORITY(K) = TRUE.LOADS(IDENT.HARV(K)) -
              (TOTAL.H.LOADS(IDENT.HARV(K)) / HARV.LOADS)
          LOOP
          CALL SORT
          FOR JJ = 1 TO NO.OF.LOADERS, DO
          LET J = LOADER.INDEX(JJ)
          FOR I = 1 TO N.HARV, DO
          LET K = I
          IF ALLOW.LOADER(J,IDENT.HARV(I)) EQ ¤N¤
            CYCLE
          ELSE
          FOR L = 1 TO N.LOADER, DO
          IF ALLOW.HARV(L) EQ IDENT.HARV(I)
            GO TO NEXT
          ELSE
```

```
          LOOP
          IF ALLOW.FOREST(POS.HARVESTER(IDENT.HARV(I),1)) GT 2
            CYCLE
          ELSE
          IF NTRUCK.LOADER(LDR,J,POS.HARVESTER(IDENT.HARV(K),1))
          IS GT 0.
            GO TO LEAVE
          ELSE
 'NEXT'        LOOP
          PRINT 1 LINE WITH JJ AS FOLLOWS
     FAULT  -  LOADER ** CANT GO ANYWHERE
          STOP
 'LEAVE'     LET POS.LOADER(J,1) = POS.HARVESTER(IDENT.HARV(K),1)
          LET POS.LOADER(J,2) = POS.HARVESTER(IDENT.HARV(K),2)
          LET POS.LOADER(J,3) = IDENT.HARV(K)
          ADD 1 TO ALLOW.FOREST(POS.LOADER(J,1))
          LET ALLOW.HARV(JJ) = IDENT.HARV(K)
          LOOP
          RETURN
      END


      SUBROUTINE SORT
          DEFINE K, IP1, I, J AND S1 AS INTEGER VARIABLES
          FOR I = 1 TO N.HARV-1, DO
          LET K = I
          LET S = PRIORITY(I)
          LET S1 = IDENT.HARV(I)
          LET IP1 = I + 1
          FOR J = IP1 TO N.HARV, DO
          IF PRIORITY(J) LE S
            CYCLE
          ELSE
          LET K = J
          LET S = PRIORITY(J)
          LET S1 = IDENT.HARV(J)
          LOOP
          IF K EQ I
            CYCLE
          ELSE
          LET PRIORITY(K) = PRIORITY(I)
          LET IDENT.HARV(K) = IDENT.HARV(I)
          LET PRIORITY(I) = S
          LET IDENT.HARV(I) = S1
          LOOP
          RETURN
      END


       SUBROUTINE TRUCK.WORK
          DEFINE PIG, LDR, ILOADER, JJ, I, J, K, S1 AND S2 AS INTEGER VARIABLES
          IF (NOMILL + NOLAND) NE N.TRUCK
            PRINT 1 LINE WITH N.TRUCK AND (NOMILL+NOLAND) AS FOLLOWS
        FOR ** TRUCKS,    ONLY ** HAVE RETURNED HOME !!!
          ALWAYS
          LET LDR = 2
          IF NO.OF.LOADERS NE N.LOADER
            LET LDR = 1
          ALWAYS
          DESTROY EACH TRUCK(N.TRUCK)
```

```
        LET N.TRUCK = 0
        FOR JJ = 1 TO NO.OF.LOADERS, DO
        LET I = LOADER.INDEX(JJ)
        LET AB = NTRUCK.LOADER(LDR,I,POS.LOADER(I,1))
        LET R = RANDOM.F(STREAM)
        LET NLAND(I) = TRUNC.F(AB + R)
        ADD NLAND(I) TO N.TRUCK
        LOOP
        IF N.TRUCK GT NO.OF.TRUCKS
          PRINT 1 LINE AS FOLLOWS
              HAVE GENERATED TO MANY TRUCKS FOR MORNING
          STOP
        ELSE
        CREATE EVERY TRUCK(N.TRUCK)
        ADD N.TRUCK TO P.NTKS
        FOR I = 1 TO N.TRUCK, DO
        LET TRAV.TIME(I) = 0.
        LET STATUS.TRUCK(I) = ¤FIN¤
        LET DEST.TRUCK(I) = ¤LAND¤
'AGAIN'  LET PP = RANDOM.F(STREAM)
        LET J = 1
        FOR K = 1 TO 2, DO
        IF PP IS GT NTRUCK.TYPE(K)
          LET J = K + 1
        ALWAYS
        LOOP
        IF J IS EQ 1
          IF PIG IS GE MAX.PIG
            GO TO AGAIN
          ELSE
            LET TYPE(I) = 1
            ADD 1 TO PIG
        ELSE
          IF J IS EQ 2
            IF S1 IS GE MAX.S1
              GO TO AGAIN
            ELSE
              LET TYPE(I) = 2
              ADD 1 TO S1
          ELSE
            LET TYPE(I) = 3
            ADD 1 TO S2
          ALWAYS
        ALWAYS
        LOOP
        IF NOMILL NE 0
          PRINT 1 LINE WITH NOMILL AND N.TRUCK AS FOLLOWS
         ** TRUCKS ARE DUE TO START AT THE MILL OUT OF A TOTAL OF ** TRUCKS
          FOR I = 1 TO NOMILL, DO
'LOOP'     LET K = RANDI.F(1,N.TRUCK,STREAM)
          FOR J = 1 TO I, DO
          IF OVERNIGHT(J) EQ K
            GO TO LOOP
          ELSE
          LOOP
          LET OVERNIGHT(I) = K
          LET DEST.TRUCK(K) = ¤MILL¤
          LET ORIGIN(K) = RANDI.F(1,2,STREAM)
          IF TYPE(K) EQ 1
            LET LDWT(K) = NORMAL.F(LOADWT(1,1),LOADWT(1,2),STREAM)
```

```
            ELSE
              LET MEAN = LOADWT(TYPE(K),1) - LOADWT(TYPE(K),3)
              LET WT = LOG.NORMAL.F(MEAN,LOADWT(TYPE(K),2),STREAM)
              LET LDWT(K) = WT + LOADWT(TYPE(K),3)
            ALWAYS
            LOOP
          ALWAYS
          LET PIG = 0
          LET S1 = 0
          LET S2 = 0
          IF NOMILL NE 0
            FOR I = 1 TO NOMILL, DO
            LET OVERNIGHT(I) = 0
            LOOP
          ALWAYS
          LET NOMILL = 0
          LET NOLAND = 0
          RETURN
     END


      PROCESS LAND.ARRIVAL
          DEFINE ITRUCK, HARV, FOR, BLK AND ILOADER AS INTEGER VARIABLES
          DEFINE DES.DUE AS AN ALPHA VARIABLE
          LET ITRUCK = ATRUCK
          LET ILOADER = ALOADER
          LET ARR.LAND(ITRUCK) = TIME.V
          REQUEST 1 LOADER(ILOADER)
          LET FOR = POS.LOADER(ILOADER,1)
          LET BLK = POS.LOADER(ILOADER,2)
          LET TRAV = TRAV.FULL(FOR,BLK,1)
          LET LDTM = LOAD.TIME(ILOADER,1)
          IF (TIME.V + ((TRAV + LDTM) / 1440.)) LE NIGHT.TIME
            LET WAIT.LOADER(ILOADER) = (TIME.V - ARR.LAND(ITRUCK)) * 1440.
    'AGAIN' LET TIME.TO.LOAD = NORMAL.F(LOAD.TIME(ILOADER,1),
                                       LOAD.TIME(ILOADER,2), STREAM)
            IF TIME.TO.LOAD IS LT LOAD.TIME(ILOADER,3)
              GO TO AGAIN
            ELSE
            ADD TIME.TO.LOAD TO LDR.WORK(ILOADER)
            ADD WAIT.LOADER(ILOADER) TO CYCLE(FOR,BLK)
            ADD TIME.TO.LOAD TO CYCLE(FOR,BLK)
            ADD 1 TO ICYCLE(FOR,BLK)
            WORK TIME.TO.LOAD MINUTES
            RELINQUISH 1 LOADER(ILOADER)
            IF TYPE(ITRUCK) EQ 1
              LET LDWT(ITRUCK) = NORMAL.F(LOADWT(1,1),LOADWT(1,2),STREAM)
            ELSE
              LET MEAN = LOADWT(TYPE(ITRUCK),1) - LOADWT(TYPE(ITRUCK),3)
              LET WT = LOG.NORMAL.F(MEAN,LOADWT(TYPE(ITRUCK),2),STREAM)
              LET LDWT(ITRUCK) = WT + LOADWT(TYPE(ITRUCK),3)
            ALWAYS
            LET FOR = POS.LOADER(ILOADER,1)
            LET BLK = POS.LOADER(ILOADER,2)
            LET HARV = POS.LOADER(ILOADER,3)
            LET MEAN = TRAV.FULL(FOR,BLK,1) - TRAV.FULL(FOR,BLK,3)
            LET TRAV = LOG.NORMAL.F(MEAN,TRAV.FULL(FOR,BLK,2),STREAM)
            LET TRAV = TRAV + TRAV.FULL(FOR,BLK,3)
            LET ORIGIN(ITRUCK) = STATE(FOR)
            ADD 1 TO TOTAL.H.LOADS(HARV)
```

```
          IF (FRAC.F(TIME.V) + (TRAV / 1440.)) IS GT 0.9700
             LET DES.DUE = "MILL"
             CALL HOME.TRUCK GIVING ITRUCK, ILOADER AND DES.DUE
          ELSE
             ACTIVATE A WB.ARRIVAL GIVING ITRUCK,ILOADER AND .IN IN TRAV MINUTES
             ADD TRAV TO FULL(FOR,BLK)
             ADD 1 TO IFULL(FOR,BLK)
             ADD TRAV TO TRAV.TIME(ITRUCK)
          ALWAYS
          LET FINISH.LOADER(ILOADER) = TIME.V
       ELSE
          RELINQUISH 1 LOADER(ILOADER)
          LET DES.DUE = "LAND"
          CALL HOME.TRUCK GIVEN ITRUCK, ILOADER AND DES.DUE
       ALWAYS
    END


    PROCESS CLOSE.WB
       LET RESULT = NORMAL.F(WB.HOURS(1),WB.HOURS(2),STREAM)
       IF RESULT GT 7.5
          LET RESULT = 7.5
       ALWAYS
       IF TIME.V LT 0.5
          ACTIVATE A MORNING IN 5 HOURS
          REQUEST 1 WB(.IN)
          WAIT RESULT HOURS
          RELINQUISH 1 WB(.IN)
       ELSE
          ADD 1.0 TO NIGHT.TIME
          LET TIME = TRUNC.F(TIME.V) + 1.2083
          ACTIVATE A MORNING AT TIME
          IF WEEKDAY.F(TIME.V) IS LE (DAYS.OF.HAULAGE+1)
             LET DIFF = (24.0 - (FRAC.F(TIME.V) * 24.0))
             LET RESULT = RESULT + DIFF
             REQUEST 1 WB(.IN)
             WAIT RESULT HOURS
             RELINQUISH 1 WB(.IN)
          ALWAYS
       ALWAYS
    END


    PROCESS WB.ARRIVAL
       DEFINE ILOADER, FOR, BLK, DEST AND ITRUCK AS INTEGER VARIABLES
       DEFINE DES.DUE AS AN ALPHA VARIABLE
       LET DEST = DESTINATION
       LET ITRUCK = BTRUCK
       LET ILOADER = BLOADER
       IF DEST EQ .IN
          IF TIME.V GT NIGHT.TIME OR FRAC.F(TIME.V) LT 0.1250
             LET DES.DUE = "MILL"
             CALL HOME.TRUCK GIVEN ITRUCK, ILOADER AND DES.DUE
          ELSE
           IF WEEKDAY.F(TIME.V) GE (DAYS.OF.HAULAGE+1),
              LET DES.DUE = "MILL"
              CALL HOME.TRUCK GIVEN ITRUCK, ILOADER AND DES.DUE
           ELSE
              LET TIME.IN(ITRUCK) = TIME.V
              REQUEST 1 WB(DEST)
```

```
            LET WAIT.TIME(DEST) = (TIME.V-TIME.IN(ITRUCK))*1440.
            LET BEGIN.WB.IN(ITRUCK) = TIME.V
            REQUEST 1 ATTENDENT(1)
            WORK 0.25 MINUTES
            RELINQUISH 1 ATTENDENT(1)
            RELINQUISH 1 WB(DEST)
            LET UT.WB.IN = UT.WB.IN + (TIME.V - BEGIN.WB.IN(ITRUCK)) * 1440.
            LET MEAN = MILL.TIME(TYPE(ITRUCK),1) - MILL.TIME(TYPE(ITRUCK),3)
            LET TIME = LOG.NORMAL.F(MEAN,MILL.TIME(TYPE(ITRUCK),2),STREAM)
            LET TIME = TIME + MILL.TIME(TYPE(ITRUCK),3)
            CALL WB.STATS GIVING ILOADER AND ITRUCK
            ACTIVATE A WB.ARRIVAL GIVING ITRUCK, ILOADER AND .OUT IN TIME MINUTES
          ALWAYS
         ALWAYS
       ELSE
         LET TIME.OUT(ITRUCK) = TIME.V
         REQUEST 1 WB(DEST)
         LET WAIT.TIME(DEST) = (TIME.V-TIME.OUT(ITRUCK))*1440.
         LET BEGIN.WB.OUT(ITRUCK) = TIME.V
         REQUEST 1 ATTENDENT(1)
         WORK 0.25 MINUTES
         RELINQUISH 1 ATTENDENT(1)
         RELINQUISH 1 WB(DEST)
         LET UT.WB.OUT = UT.WB.OUT + (TIME.V - BEGIN.WB.OUT(ITRUCK)) * 1440.
         CALL SCHEDULER GIVING ITRUCK AND ILOADER
       ALWAYS
   END


   SUBROUTINE WB.STATS GIVEN ILOADER AND ITRUCK
       DEFINE ITRUCK AND ILOADER AS INTEGER VARIABLES
       ADD 1 TO D.LOADS
       ADD 1 TO P.LOADS
       ADD 1 TO T.LOADS
       ADD LDWT(ITRUCK) TO D.TONS
       ADD LDWT(ITRUCK) TO P.TONS
       ADD LDWT(ITRUCK) TO T.TONS
       ADD 1 TO HARV.LOADS
       ADD 1 TO LOADS.AREA(ORIGIN(ITRUCK))
       ADD 1 TO T.LOADS.AREA(ORIGIN(ITRUCK))
       ADD LDWT(ITRUCK) TO TONS.AREA(ORIGIN(ITRUCK))
       ADD LDWT(ITRUCK) TO T.TONS.AREA(ORIGIN(ITRUCK))
       ADD LDWT(ITRUCK) TO MILL.STOCKPILE
       ADD 1 TO D.L.LOADS(ILOADER)
       ADD 1 TO P.L.LOADS(ILOADER)
       ADD 1 TO T.L.LOADS(ILOADER)
       RETURN
   END


   SUBROUTINE HOME.TRUCK GIVEN ITRUCK, ILOADER AND DESTIN
       DEFINE ITRUCK AND ILOADER AS AN INTEGER VARIABLE
       DEFINE DESTIN AS AN ALPHA VARIABLE
       LET FINISH.TRUCK(ITRUCK) = TIME.V
       LET STATUS.TRUCK(ITRUCK) = "FIN"
       LET DEST.TRUCK(ITRUCK) = DESTIN
       LET TIME = (FINISH.TRUCK(ITRUCK) - START.TRUCK(ITRUCK)) * 24.0
       IF TIME GT 1.0
         ADD TIME TO D.T.TIME(ILOADER)
         ADD TIME TO P.T.TIME(ILOADER)
```

```
        LET WORK = TRAV.TIME(ITRUCK) / 60.0
        IF WORK IS GT (TIME + 0.1)
          PRINT 1 LINE WITH TIME, WORK AND ITRUCK AS FOLLOWS
             FOR TOTAL TIME ***.*, A WORK TIME OF ***.* FOR TRUCK **
        ALWAYS
        LET IDLE = TIME - WORK
        ADD WORK TO D.T.WORK(ILOADER)
        ADD WORK TO P.T.WORK(ILOADER)
        ADD IDLE TO D.T.IDLE(ILOADER)
        ADD IDLE TO P.T.IDLE(ILOADER)
        ADD TIME TO D.TRK.TIME
        ADD TIME TO P.TRK.TIME
        ADD TIME TO T.TRK.TIME
        ADD 1 TO P.NTKS
        ADD 1 TO T.NTKS
     ALWAYS
     IF DESTIN EQ "MILL"
        ADD 1 TO NOMILL
        IF NOMILL GT NO.OF.TRUCKS,
          PRINT 1 LINE AS FOLLOWS
         FAULT        NOT ENOUGH ROOM IN ARRAY OVERNIGHT
          STOP
        ELSE
     ELSE
        ADD 1 TO NOLAND
     ALWAYS
     RETURN
  END


   SUBROUTINE REPORT
      DEFINE I, JWEEK AND J AS INTEGER VARIABLES
      LET JWEEK = (TIME.V + 1.) / 7.
      LET LOADS1 = LOADS.AREA(1) / P.LOADS * 100.0
      LET LOADS2 = LOADS.AREA(2) / P.LOADS * 100.0
      LET TONS1 = TONS.AREA(1) / P.TONS * 100.0
      LET TONS2 = TONS.AREA(2) / P.TONS * 100.0
      LET AV.LOADS = P.LOADS / P.DAYS.HAULAGE
      LET AV.TONS = P.TONS / P.DAYS.HAULAGE
      START NEW PAGE
      PRINT 1 LINE WITH JWEEK AS FOLLOWS
            REPORT AFTER ** WEEKS OF SIMULATION
      SKIP 1 LINE
      PRINT 3 LINES WITH AV.LOADS,P.LOADS,LOADS1,LOADS2,AV.TONS,P.TONS,
      TONS1 AND TONS2 AS FOLLOWS
                                DAY AVG        GRAND TOTAL      NSW        VIC
     NO OF LOADS                ***.*            ******        **.*%      **.*%
     PULP DELIVERED            *****.*          *******        **.*%      **.*%
      SKIP 1 LINE
      LET TIME = P.TRK.TIME / P.NTKS
      LET AV = P.NTKS / P.DAYS.HAULAGE
      PRINT 1 LINE WITH AV AND TIME AS FOLLOWS
     AN AVERAGE OF **.* TRUCKS WORKED AN AVERAGE OF **.* HOURS PER DAY
      LET UT.WB.IN = (UT.WB.IN / 960.0 / P.DAYS.HAULAGE) * 100.
      LET UT.WB.OUT = (UT.WB.OUT / 960.0 / P.DAYS.HAULAGE) * 100.
      FOR J = 1 TO N.LOADER, DO
      LET I = LDR.INDEX(1,J)
      LET UT.LOADER(I) = (P.L.WORK(I) / P.L.TIME(I)) * 100.
      LOOP
      PRINT 5 LINES WITH UT.WB.IN, AV.QUEUE.LENGTH(1), MAX.QUEUE.LENGTH(1),
```

```
          MEAN.WAIT(1), MAX.WAIT(1), UT.WB.OUT, AV.QUEUE.LENGTH(2),
          MAX.QUEUE.LENGTH(2), MEAN.WAIT(2), MAX.WAIT(2) AS FOLLOWS

                     AV. HOURS   UTILISATION     QUEUE LENGTH          WAIT TIME
                      WORKED                   MEAN    MAXIMUM     MEAN    MAXIMUM
      WB IN                        ***.*%      **.*       **        **.*     ***
      WB OUT                       ***.*%      **.*       **        **.*     ***
          FOR J = 1 TO N.LOADER, DO
          LET I = LDR.INDEX(1,J)
          PRINT 1 LINE WITH I+70,P.L.TIME(I)/P.DAY.L.WORK(I),UT.LOADER(I),
          AV.Q.LOADER(I),MAX.Q.LOADER(I),MEAN.L.WAIT(I),MAX.L.WAIT(I) AS FOLLOWS
     LOADER **       **.*          ***.*%      **.*       **        **.*     ***
          LOOP
          SKIP 1 LINE
          LET UT.WB.IN = 0.
          LET UT.WB.OUT = 0.
          PRINT 1 LINE AS FOLLOWS
     CYCLE TIMES     FOREST        BLOCK1     BLOCK2     BLOCK3     BLOCK4     BLOCK5
          LET MP = MEAN.MILL.PIG + MEAN.WAIT(1) + MEAN.WAIT(2)
          FOR I = 1 TO N.FOREST, DO
          PRINT 1 LINE WITH NAME(I),
     ((FULL(I,1)/IFULL(I,1))+(EMPTY(I,1)/IEMPTY(I,1))+(CYCLE(I,1)/ICYCLE(I,1))+MP),
     ((FULL(I,2)/IFULL(I,2))+(EMPTY(I,2)/IEMPTY(I,2))+(CYCLE(I,2)/ICYCLE(I,2))+MP),
     ((FULL(I,3)/IFULL(I,3))+(EMPTY(I,3)/IEMPTY(I,3))+(CYCLE(I,3)/ICYCLE(I,3))+MP),
     ((FULL(I,4)/IFULL(I,4))+(EMPTY(I,4)/IEMPTY(I,4))+(CYCLE(I,4)/ICYCLE(I,4))+MP),
          AND
     ((FULL(I,5)/IFULL(I,5))+(EMPTY(I,5)/IEMPTY(I,5))+(CYCLE(I,5)/ICYCLE(I,5))+MP)
          AS FOLLOWS
                     ***********      ****.*     ****.*     ****.*     ****.*     ****.*
          LOOP
          SKIP 1 LINE
          PRINT 1 LINE AS FOLLOWS
            HARVESTER          ACTUAL          ESTIMATED
          FOR I = 1 TO N.HARV, DO
          LET AB1 = HARV.LOADS * TRUE.LOADS(I)
          PRINT 1 LINE WITH I, TOTAL.H.LOADS(I) AND AB1 AS FOLLOWS
                **             *****           *****
          LOOP
          CALL PERIOD.CLEAR
          RETURN
     END


     SUBROUTINE END.REPORT
          DEFINE I, JWEEK AND J AS INTEGER VARIABLES
          LET JWEEK = (TIME.V + 1.) / 7.
          LET LOADS1 = LOADS.AREA(1) / T.LOADS * 100.0
          LET LOADS2 = LOADS.AREA(2) / T.LOADS * 100.0
          LET TONS1 = TONS.AREA(1) / T.TONS * 100.0
          LET TONS2 = TONS.AREA(2) / T.TONS * 100.0
          LET AV.LOADS = T.LOADS / T.DAYS.HAULAGE
          LET AV.TONS = T.TONS / T.DAYS.HAULAGE
          START NEW PAGE
          PRINT 1 LINE WITH JWEEK AS FOLLOWS
                 FINAL REPORT AFTER ** WEEKS OF SIMULATION
          SKIP 1 LINE
          PRINT 3 LINES WITH AV.LOADS,T.LOADS,LOADS1,LOADS2,AV.TONS,T.TONS,
          TONS1 AND TONS2 AS FOLLOWS
                               DAY AVG        GRAND TOTAL       NSW          VIC
        NO OF LOADS             ***.*           ******         **.*%        **.*%
```

```
   PULP DELIVERED        *****.*          *******        **.*%        **.*%
     SKIP 1 LINE
     LET TIME = T.TRK.TIME / T.NTKS
     LET AV = T.NTKS / T.DAYS.HAULAGE
     PRINT 1 LINE WITH AV AND TIME AS FOLLOWS
   AN AVERAGE OF **.* TRUCKS WORKED AN AVERAGE OF **.* HOURS PER DAY
     LET UT.WB.IN = (UT.WB.IN / 960.0 / T.DAYS.HAULAGE) * 100.
     LET UT.WB.OUT = (UT.WB.OUT / 960.0 / T.DAYS.HAULAGE) * 100.
     FOR J = 1 TO N.LOADER, DO
     LET I = LDR.INDEX(1,J)
     LET UT.LOADER(I) = (P.L.WORK(I) / P.L.TIME(I)) * 100.
     LOOP
     PRINT 5 LINES WITH UT.WB.IN, AV.QUEUE.LENGTH(1), MAX.QUEUE.LENGTH(1),
     MEAN.WAIT(1), MAX.WAIT(1), UT.WB.OUT, AV.QUEUE.LENGTH(2),
     MAX.QUEUE.LENGTH(2), MEAN.WAIT(2), MAX.WAIT(2) AS FOLLOWS

                AV. HOURS   UTILISATION     QUEUE LENGTH         WAIT TIME
                 WORKED                    MEAN    MAXIMUM    MEAN    MAXIMUM
 WB IN                        ***.*%       **.*      **       **.*      ***
 WB OUT                       ***.*%       **.*      **       **.*      ***
     FOR J = 1 TO N.LOADER, DO
     LET I = LDR.INDEX(1,J)
     PRINT 1 LINE WITH I+70,P.L.TIME(I)/P.DAY.L.WORK(I),UT.LOADER(I),
     AV.Q.LOADER(I),MAX.Q.LOADER(I),MEAN.L.WAIT(I),MAX.L.WAIT(I) AS FOLLOWS
 LOADER **      **.*          ***.*%       **.*      **       **.*      ***
     LOOP
     SKIP 1 LINE
     LET UT.WB.IN = 0.
     LET UT.WB.OUT = 0.
     PRINT 1 LINE AS FOLLOWS
 CYCLE TIMES     FOREST          BLOCK1     BLOCK2     BLOCK3     BLOCK4     BLOCK5
     LET MP = MEAN.MILL.PIG + MEAN.WAIT(1) + MEAN.WAIT(2)
     FOR I = 1 TO N.FOREST, DO
     PRINT 1 LINE WITH NAME(I),
((FULL(I,1)/IFULL(I,1))+(EMPTY(I,1)/IEMPTY(I,1))+(CYCLE(I,1)/ICYCLE(I,1))+MP),
((FULL(I,2)/IFULL(I,2))+(EMPTY(I,2)/IEMPTY(I,2))+(CYCLE(I,2)/ICYCLE(I,2))+MP),
((FULL(I,3)/IFULL(I,3))+(EMPTY(I,3)/IEMPTY(I,3))+(CYCLE(I,3)/ICYCLE(I,3))+MP),
((FULL(I,4)/IFULL(I,4))+(EMPTY(I,4)/IEMPTY(I,4))+(CYCLE(I,4)/ICYCLE(I,4))+MP),
     AND
((FULL(I,5)/IFULL(I,5))+(EMPTY(I,5)/IEMPTY(I,5))+(CYCLE(I,5)/ICYCLE(I,5))+MP)
     AS FOLLOWS
                ***********      ****.*     ****.*     ****.*     ****.*     ****.*
     LOOP
     SKIP 1 LINE
     PRINT 1 LINE AS FOLLOWS
       HARVESTER          ACTUAL          ESTIMATED
     FOR I = 1 TO N.HARV, DO
     LET AB1 = HARV.LOADS * TRUE.LOADS(I)
     PRINT 1 LINE WITH I, TOTAL.H.LOADS(I) AND AB1 AS FOLLOWS
          **             *****            *****
     LOOP
     RETURN
 END


 SUBROUTINE REPORT.DAY
     DEFINE I AND J AS INTEGER VARIABLES
     LET TIME = D.TRK.TIME / N.TRUCK
     USE UNIT 10 FOR OUTPUT
     PRINT 1 LINE WITH D.LOADS, D.TONS, N.TRUCK AND TIME AS FOLLOWS
```

```
          2     ***         *****.*          ***          ****.*
          USE UNIT 11 FOR OUTPUT
          FOR I = 1 TO NO.OF.LOADERS, DO
          LET J = LOADER.INDEX(I)
          PRINT 1 LINE WITH J+70 AND D.L.TIME(J) AS FOLLOWS
          **    2      ***.*
          LOOP
          USE UNIT 6 FOR OUTPUT
          RETURN
      END
```

APPENDIX 5.3

Example of a data deck as used in period validation

```
NPA652*TEST(6).DATA(60)
        NO. OF DAYS, REPORT PERIOD, DAY AND PERIOD REPORT(Y OR N), HAULAGE DAYS PER WEEK
        28 20 Y N 5
        NO. OF LOADERS(MAX), NO. OF HARVESTERS, NO. OF FORESTS, NO. OF TRUCKS(MAX)
        4 13 7 20
        THE PERCENTAGES OF TRUCK TYPES WITH MAXIMUM NUMBERS OF TYPE 1 AND 2
        .15 .66 1.0 5 14
        THE MEAN,STD DEV,MIN AND MAX OF THE TIME TRUCKS SPEND IN THE MILL(REAL, MINS)
        14.66 3.24 3.66
        13.12 2.67 7.09
        12.69 2.64 7.21
        TRAVEL TIMES FULL FOR FOREST AND BLOCK, MEAN, STD AND SHIFT
        □BATLOW□
        1
        5.5 5.25 0. 0. 0.
        149.42 27.13 118.2
        170.98 29.98 117.2
        0. 0. 0.
        0. 0. 0.
        0. 0. 0.
        0.92 0.86 0. 0. 0.
        □GREEN HILLS□
        1
        5.5 5.25 5.25 5.25 5.25
        164.22 24.68 125.97
        160.56 22.33 125.95
        160.23 25.33 121.76
        144.62 23.95 115.56
        131.02 16.8 97.22
        0.82 0.85 0.89 0.86 0.83
        □CARABOST□
        1
        5.5 5.75 5.5 0. 0.
        99.26 12.11 70.18
        93.79 12.16 64.05
        107.45 14.45 81.53
        0. 0. 0.
        0. 0. 0.
        0.88 0.9 0.84 0. 0.
        □SHELLEY□
        2
        5.75 0. 0. 0. 0.
        97.47 11.43 71.26
        0. 0. 0.
        0. 0. 0.
        0. 0. 0.
        0. 0. 0.
        0.86 0. 0. 0. 0.
        □MYRTLEFORD□
        2
        5.5 6.0 0. 0. 0.
        109.42 19.86 80.96
        126.66 42.53 82.51
        0. 0. 0.
        0. 0. 0.
        0. 0. 0.
        0.93 0.75 0. 0. 0.
        □BEECHWORTH□
        2
        6. 0. 0. 0. 0.
```

```
97.59 39.78 72.85
0. 0. 0.
0. 0. 0.
0. 0. 0.
0. 0. 0.
0.83 0. 0. 0. 0.
¤BRIGHT¤
2
6. 0. 0. 0. 0.
107.45 14.45 81.53
0. 0. 0.
0. 0. 0.
0. 0. 0.
0. 0. 0.
0.84 0. 0. 0. 0.
THE MEAN,STD. DEV.,MIN AND MAX OF THE LOADWEIGHT OF A TRUCK (REAL)
24.0 1.83 0.0
23.70 1.98 12.91
23.63 1.77 10.08
PARAMETERS FOR THE TIME TO LOAD A TRUCK
23.9 5.06 15.
22.17 4.48 15.
25.38 4.22 15.
27.78 3.63 15.
READ INTERVAL TIME BETWEEN TRUCKS ON LANDING
20
SHIFT FOR SCHEDULER
0.15
HOUR OF THE DAY THAT THE WEIGHBRIDGE WILL OPEN UP
7.449 0.085
NIGHT TIME
23.5
NO. LOADERS ON EACH LANDING, PERC OF NO WORK, MEAN HRS AND STD DEV HRS
1 0. 9.39 0.54
1 0. 9.73 1.13
1 0.15 10.35 0.86
1 0.40 8.79 1.09
LOADER PRIORITY
1 2 3 4
2 3 4 0
1 3 4 0
1 2 4 0
1 2 3 0
WHAT HARVESTERS LOADERS ARE ALLOWED TO VISIT
Y Y N Y Y N N N N N Y N N
Y N N Y N N N Y Y Y N N N
N N N N N N N N N N Y N Y
Y Y N Y Y N N N N N N N N
NUMBER OF TRUCKS FOR LOADERS FROM FORESTS AND BLOCKS
10. 8.3 0. 0.
0. 0. 0. 3.9
10.0 0. 0. 7.
3.9 0. 0. 3.3
0. 7. 0. 0.
0. 6. 0. 0.
0. 0. 6. 0.
7. 0. 5.5 0.
0. 0. 0. 0.
0. 0. 0. 0.
0. 0. 0. 0.
```

```
0. 0. 0. 0.
0. 0. 8. 0.
0. 0. 7.5 0.
POSITION OF HARVESTERS AND THEIR LOADER PRIORITY
1 1 1 0.095
1 2 2 0.029
2 1 3 0.0
2 2 4 0.295
2 3 5 0.040
2 4 6 0.0
2 5 7 0.0
3 1 8 0.098
3 2 9 0.001
3 3 10 0.104
4 1 11 0.164
6 1 12 0.0
7 1 13 0.154
NUMBER OF HOURS TRUCKS SHOULD WORK (REAL)
14.

@RESUME,M
```

APPENDIX 5.4

Comparison of the actual and simulated performance for the daily validation

NOVEMBER 1

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
46.	16.	62.	1469.9	9.1	8.9	16	10.2	20	10.5	16	9.0	10
45.	19.	64.	1510.6	9.5	8.4	16	10.5	21	10.9	19	7.6	8
44.	18.	62.	1503.7	9.6	9.6	16	10.8	20	10.4	18	7.8	8
45.	18.	63.	1485.1	9.5	9.0	16	10.8	21	10.7	18	7.7	8
45.	18.	63.	1481.2	9.4	8.3	16	10.8	21	10.2	18	8.2	8
45.	18.	63.	1465.6	9.5	8.4	16	10.8	21	10.2	18	7.7	8
45.	18.	63.	1496.2	9.6	8.7	16	10.7	21	10.6	18	7.2	8
45.	18.	63.	1500.0	9.5	8.8	16	10.6	21	9.9	18	8.9	8
45.	15.	63.	1530.4	9.4	9.2	16	10.4	21	10.5	18	7.7	8
44.	19.	63.	1488.9	9.4	8.6	16	10.5	20	10.8	19	7.3	8
45.	18.	63.	1488.9	9.7	9.3	16	11.1	21	10.6	18	8.0	8

NOVEMBER 2

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
41.	11.	52.	1241.6	8.7	8.5	16	8.8	15	8.5	11	9.0	10
42.	11.	53.	1251.8	8.8	8.6	16	9.3	16	8.9	11	8.3	10
40.	10.	50.	1214.2	8.6	8.3	15	8.8	15	8.9	10	8.6	10
43.	10.	53.	1264.2	8.7	8.7	16	9.4	17	8.4	10	9.5	10
42.	11.	53.	1242.3	8.9	8.8	16	9.4	16	9.4	11	8.3	10
43.	11.	54.	1270.6	8.9	8.9	16	9.5	17	8.8	11	8.1	10
42.	11.	53.	1273.1	8.7	8.7	16	9.4	16	8.8	11	7.6	10
43.	11.	54.	1275.1	8.9	8.6	16	9.4	17	9.1	11	8.7	10
42.	12.	54.	1300.3	9.1	8.6	16	9.5	16	9.2	12	8.3	10
42.	12.	54.	1295.0	8.9	8.8	16	8.9	16	8.9	12	8.1	10
40.	11.	51.	1209.0	8.6	8.7	16	8.4	14	9.1	11	7.8	10

NOVEMBER 3

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
49.	12.	61.	1410.5	9.3	8.6	16	9.3	18	9.2	12	11.3	15
47.	12.	59.	1377.6	9.2	8.5	15	9.8	17	9.6	12	10.3	15
48.	12.	60.	1447.6	9.8	9.0	16	9.8	17	9.4	12	11.6	15
50.	12.	62.	1478.8	9.6	9.2	16	9.9	18	9.3	12	11.3	16
48.	12.	60.	1395.8	9.5	8.3	16	9.7	17	8.9	12	11.0	15
49.	12.	61.	1433.7	9.7	8.9	15	9.6	17	9.0	12	12.0	17
48.	12.	60.	1422.2	9.5	8.4	15	9.5	17	9.5	12	11.1	16
49.	12.	61.	1434.7	9.9	9.2	15	10.4	18	9.4	12	11.9	15
50.	12.	62.	1482.4	10.2	9.5	16	10.4	18	9.6	12	10.9	16
49.	12.	61.	1411.1	9.8	9.4	16	9.7	17	9.3	12	11.6	16
50.	12.	62.	1463.4	10.0	9.4	16	9.9	18	9.8	12	11.9	16

NOVEMBER 4

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
47.	13.	60.	1387.9	9.8	9.8	17	9.7	19	12.5	13	10.5	11
46.	15.	61.	1452.4	10.0	8.8	16	9.8	18	12.1	15	10.7	12
46.	13.	59.	1415.4	10.3	9.5	16	10.4	18	12.7	13	10.2	12
45.	16.	61.	1460.9	10.0	9.0	16	9.3	17	13.0	16	9.7	12
46.	15.	61.	1426.4	10.3	9.0	16	10.1	18	13.0	15	10.3	12
46.	16.	62.	1445.0	10.4	10.3	17	10.2	17	13.3	16	9.7	12
46.	15.	61.	1426.7	10.2	9.0	16	10.0	18	13.0	15	10.1	12
45.	16.	61.	1474.8	10.0	8.9	16	9.4	17	13.0	16	9.7	12
46.	15.	61.	1443.9	10.4	10.2	15	10.8	16	13.0	15	10.0	12
46.	16.	62.	1458.3	10.4	9.7	16	10.1	18	13.3	16	10.2	12
46.	16.	62.	1494.0	10.4	10.4	17	9.9	17	12.9	16	10.0	12

NOVEMBER 8

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
47.	18.	65.	1439.7	9.9	9.2	16	9.8	18	9.0	18	13.6	13
47.	16.	63.	1487.8	9.6	9.1	16	10.2	17	9.2	16	12.2	14
46.	16.	62.	1495.9	9.9	9.7	16	9.9	17	9.7	16	12.0	13
50.	16.	66.	1587.2	10.2	9.3	16	9.9	18	9.4	16	13.5	16
48.	17.	65.	1549.6	9.8	8.5	16	10.3	18	9.6	17	12.7	14
49.	17.	66.	1558.4	10.2	9.4	16	10.2	18	9.6	17	13.4	15
47.	17.	64.	1514.2	10.0	9.5	16	9.9	17	9.9	17	13.0	14
49.	16.	65.	1537.4	9.9	8.6	16	10.3	18	9.6	16	13.1	15
49.	16.	65.	1545.5	10.1	9.2	16	10.3	18	9.8	16	12.8	15
50.	17.	67.	1570.8	10.3	9.1	16	10.4	18	9.8	17	13.5	16
48.	16.	64.	1525.4	10.0	9.0	16	10.3	18	9.8	16	12.6	14

NOVEMBER 9

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
48.	18.	66.	1494.7	9.7	8.5	16	12.8	13	9.7	18	11.2	19
51.	17.	68.	1557.4	10.5	9.1	16	13.2	16	9.9	17	11.9	19
50.	18.	68.	1660.0	10.7	9.6	15	13.1	16	10.5	18	11.8	19
49.	18.	67.	1577.0	10.4	9.2	15	13.2	16	10.5	18	10.9	18
51.	18.	69.	1638.4	10.7	9.3	16	13.2	16	10.4	18	11.2	19
49.	18.	67.	1574.5	10.5	8.9	15	12.8	16	10.9	18	11.3	18
50.	18.	68.	1598.4	10.7	9.5	15	13.5	16	10.1	18	11.5	19
50.	17.	67.	1595.3	10.3	9.0	16	12.9	16	10.0	17	10.5	18
48.	18.	66.	1570.3	10.2	8.9	14	13.2	16	10.2	18	11.0	18
50.	18.	68.	1593.7	10.6	9.8	15	12.5	16	10.7	18	11.6	19
49.	17.	66.	1562.5	10.2	8.5	15	12.6	15	10.0	17	11.7	19

NOVEMBER 10

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
47.	18.	65.	1499.2	9.4	8.8	16	10.0	18	10.4	18	11.9	13
50.	19.	69.	1635.8	10.1	9.1	16	9.9	18	10.7	19	12.5	16
49.	17.	66.	1597.4	10.0	9.2	16	10.4	18	10.4	17	10.7	15
49.	18.	67.	1571.8	9.9	9.2	16	10.2	18	10.4	18	10.6	15
48.	18.	66.	1571.2	9.6	8.1	14	9.7	17	9.9	18	12.3	17
50.	19.	69.	1652.0	10.0	8.5	16	9.8	18	11.1	19	12.4	16
49.	18.	67.	1572.7	9.9	8.9	16	10.5	17	10.3	18	11.8	16
49.	18.	67.	1568.7	9.9	9.3	16	9.7	17	10.7	18	10.7	16
51.	18.	69.	1638.2	10.2	9.2	16	9.9	18	10.5	18	12.6	17
50.	18.	68.	1599.5	10.1	9.7	16	9.8	18	10.5	18	12.5	16
50.	18.	68.	1621.5	10.0	8.6	16	10.4	18	10.3	18	12.4	16

NOVEMBER 11

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
46.	20.	66.	1537.9	9.9	10.5	13	11.4	20	11.3	20	7.7	13
46.	21.	67.	1588.8	10.2	10.4	13	11.5	19	11.7	21	8.4	14
43.	19.	62.	1500.7	9.6	8.3	12	11.3	13	10.6	19	8.1	13
44.	21.	65.	1541.6	9.9	11.2	14	10.6	18	11.7	21	8.0	12
46.	21.	67.	1580.3	10.2	10.8	13	11.9	19	11.7	21	8.4	14
46.	20.	66.	1571.4	10.0	11.1	13	11.2	19	11.1	20	8.5	14
46.	21.	67.	1605.4	10.2	10.8	14	10.8	18	11.6	21	8.5	14
46.	20.	66.	1570.2	10.2	10.5	13	11.3	19	11.2	20	9.0	14
43.	20.	63.	1492.3	9.8	8.2	12	10.6	18	12.0	20	8.0	13
46.	21.	67.	1585.4	10.2	10.6	13	11.9	19	11.8	21	8.8	14
44.	22.	66.	1593.1	10.1	10.5	13	10.5	18	12.0	22	8.4	13

NOVEMBER 12

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
45.	19.	64.	1488.8	9.5	9.8	18	10.1	19	10.4	19	7.8	8
44.	18.	62.	1454.7	9.3	9.3	18	10.5	18	10.3	18	7.6	8
43.	19.	62.	1496.1	9.6	9.7	18	10.5	17	10.7	19	7.4	8
43.	19.	62.	1450.4	9.6	10.3	18	10.4	17	11.0	19	6.8	8
44.	20.	64.	1499.0	9.8	9.3	18	10.3	18	10.8	20	7.1	8
44.	19.	63.	1470.5	9.5	9.0	18	10.3	18	10.7	19	7.3	8
44.	19.	63.	1498.8	9.7	9.8	18	10.4	18	11.0	19	7.1	8
45.	20.	65.	1551.5	9.9	10.2	19	10.6	18	11.2	20	7.2	8
44.	21.	65.	1569.2	9.8	9.1	18	10.8	18	11.3	21	7.7	8
44.	21.	65.	1560.5	9.9	10.1	18	10.4	18	11.7	21	7.6	8
44.	20.	64.	1514.2	9.8	10.2	18	10.4	18	11.5	20	8.5	8

NOVEMBER 15

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
44.	18.	62.	1473.3	9.4	9.0	17	10.0	19	10.2	18	10.0	8
44.	18.	62.	1463.9	9.6	9.3	18	10.3	18	10.3	18	8.5	8
41.	18.	59.	1402.7	9.5	9.5	16	10.3	17	10.2	18	8.0	8
44.	18.	62.	1476.6	9.7	9.2	18	10.5	18	10.5	18	8.0	8
43.	18.	61.	1438.9	9.3	8.9	17	10.2	18	10.7	18	7.6	8
43.	18.	61.	1449.9	9.4	9.0	17	10.8	18	10.3	18	7.6	8
44.	18.	62.	1471.7	9.7	9.3	18	10.4	18	10.4	18	8.2	8
44.	18.	62.	1470.0	9.7	9.5	18	10.9	18	10.6	18	7.8	8
44.	18.	62.	1480.3	9.7	9.6	18	10.5	18	10.3	18	8.2	8
44.	18.	62.	1472.4	9.6	9.2	18	10.5	18	10.5	18	8.0	8
43.	18.	61.	1447.8	9.5	9.4	18	10.2	17	10.5	18	7.8	8

NOVEMBER 16

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
45.	19.	64.	1462.5	10.1	10.7	17	9.2	19	11.5	19	9.1	9
42.	20.	62.	1480.0	9.6	9.5	18	9.2	16	11.9	20	7.6	8
44.	19.	63.	1529.1	10.3	11.2	19	9.6	17	11.8	19	8.0	8
44.	20.	64.	1519.0	9.8	9.8	18	9.9	18	12.0	20	8.0	8
43.	19.	62.	1497.4	9.6	10.6	19	9.6	16	11.5	19	7.5	8
44.	20.	64.	1525.4	9.9	10.7	19	9.7	17	12.0	20	7.9	8
44.	19.	63.	1493.7	10.0	9.5	18	9.7	18	11.5	19	8.3	8
43.	20.	63.	1478.2	10.1	10.3	18	9.5	17	11.8	20	8.3	8
43.	20.	63.	1499.0	10.0	10.1	18	9.8	17	12.1	20	7.9	8
43.	20.	63.	1498.2	9.9	9.7	18	9.6	17	12.2	20	8.1	8
44.	19.	63.	1517.7	10.0	11.4	20	10.0	16	12.1	19	7.7	8

NOVEMEER 17

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
45.	17.	62.	1473.9	9.8	9.4	17	10.7	19	9.2	17	8.5	9
44.	20.	64.	1520.3	9.5	9.2	17	11.3	19	9.9	20	7.9	8
44.	18.	62.	1506.7	9.7	10.1	18	10.6	18	9.4	18	8.1	8
44.	19.	63.	1493.3	9.6	9.9	18	10.9	19	10.0	19	8.5	7
44.	19.	63.	1481.2	9.4	10.1	18	9.9	18	9.5	19	8.0	8
44.	18.	62.	1452.6	9.3	9.4	18	9.8	18	9.6	18	8.0	8
44.	19.	63.	1510.6	9.5	9.5	18	10.4	18	9.5	19	7.8	3
44.	19.	63.	1512.7	9.5	9.4	18	10.8	18	9.8	19	8.5	8
44.	19.	63.	1502.0	9.6	9.6	18	10.4	18	9.7	19	7.9	8
46.	19.	65.	1529.5	9.7	9.6	18	11.3	20	9.8	19	7.7	8
44.	19.	63.	1473.3	9.5	9.5	18	10.8	18	9.7	19	7.8	8

NOVEMBER 18

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
47.	15.	62.	1463.2	9.5	9.7	18	10.7	18	10.2	15	8.5	11
46.	15.	61.	1437.4	9.7	9.2	16	10.0	18	10.4	15	8.8	12
46.	15.	61.	1477.9	10.1	9.5	16	10.6	18	10.4	15	8.5	12
49.	15.	63.	1474.5	10.0	10.0	16	11.3	20	10.0	15	8.3	12
46.	15.	61.	1446.8	9.6	9.6	16	11.0	19	10.3	15	8.6	11
46.	14.	60.	1421.7	9.5	9.7	16	9.8	18	9.6	14	8.5	12
46.	15.	61.	1447.2	9.8	9.0	16	11.1	18	10.2	15	8.0	12
46.	15.	61.	1462.8	9.7	9.4	16	10.3	18	10.1	15	8.5	12
46.	15.	61.	1466.7	9.8	9.6	16	10.0	18	9.8	15	8.6	12
46.	15.	61.	1460.8	9.6	9.3	16	10.1	18	9.6	15	8.3	12
47.	15.	62.	1477.5	9.9	9.1	16	11.2	19	10.0	15	8.8	12

NOVEMBER 19

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
46.	18.	64.	1551.7	9.6	10.2	18	10.3	18	9.8	18	8.0	10
45.	18.	64.	1512.7	9.7	9.4	18	10.1	18	10.5	18	8.0	10
46.	17.	63.	1507.6	9.8	10.0	18	10.5	18	10.5	17	8.4	10
46.	18.	64.	1515.7	9.8	10.3	19	10.3	16	10.8	18	7.6	9
47.	18.	65.	1536.1	9.9	10.6	19	10.1	18	10.1	18	7.7	10
46.	18.	64.	1490.2	9.8	10.1	18	10.2	18	10.5	18	8.2	10
46.	17.	63.	1498.1	9.6	9.7	18	10.1	18	10.1	17	8.0	10
46.	18.	64.	1534.2	9.8	9.5	18	10.5	18	10.3	18	8.5	10
46.	18.	64.	1516.7	10.0	10.1	18	10.4	18	10.2	18	8.6	10
46.	18.	64.	1532.9	9.5	9.6	18	10.1	18	10.2	18	8.1	10
46.	17.	63.	1492.7	9.9	10.1	18	10.6	18	10.0	17	8.7	10

NOVEMBER 22

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
42.	24.	66.	1584.9	10.1	11.0	21	12.0	21	12.2	24	.0	0
46.	27.	73.	1713.6	10.9	11.4	23	11.7	23	12.9	27	.0	0
43.	25.	68.	1642.3	10.7	10.5	22	11.4	21	12.8	25	.0	0
45.	27.	72.	1701.2	10.8	11.7	23	12.0	22	12.6	27	.0	0
44.	26.	70.	1656.8	10.4	10.1	22	11.3	22	12.4	26	.0	0
46.	26.	72.	1680.7	11.0	11.4	23	12.3	23	12.7	26	.0	0
46.	27.	73.	1739.1	11.1	11.8	24	12.1	22	13.0	27	.0	0
46.	27.	73.	1705.0	11.2	11.1	23	12.2	23	13.4	27	.0	0
46.	28.	74.	1777.4	11.3	11.7	24	11.7	22	12.9	28	.0	0
44.	27.	71.	1692.9	10.5	9.9	22	12.1	22	12.6	27	.0	0
45.	25.	70.	1657.4	10.6	10.9	23	11.6	22	12.3	25	.0	0

NOVEMBER 23

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
43.	23.	66.	1557.7	9.9	10.3	23	10.5	20	11.8	23	.0	0
43.	23.	66.	1558.6	10.2	10.6	22	10.9	21	11.8	23	.0	0
41.	24.	65.	1573.2	10.5	10.8	22	10.4	19	13.1	24	.0	0
43.	24.	67.	1577.9	10.5	10.4	22	10.9	21	12.5	24	.0	0
43.	23.	66.	1553.7	10.2	10.5	22	10.9	21	11.8	23	.0	0
43.	22.	65.	1520.5	9.9	9.7	22	11.1	21	11.6	22	.0	0
43.	23.	66.	1551.5	10.3	10.7	22	11.3	21	11.9	23	.0	0
43.	25.	68.	1616.4	10.5	10.7	23	10.5	20	12.8	25	.0	0
43.	24.	67.	1592.9	10.6	11.0	23	10.6	20	12.4	24	.0	0
42.	25.	67.	1583.4	10.4	9.8	21	11.2	21	12.4	25	.0	0
42.	24.	66.	1589.9	10.1	10.1	22	10.7	20	12.4	24	.0	0

NOVEMBER 24

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
47.	20.	67.	1633.4	9.7	9.2	19	9.5	18	11.8	20	8.7	10
46.	19.	65.	1526.1	9.8	9.1	18	10.5	18	12.0	19	8.2	10
44.	20.	64.	1550.3	10.1	10.0	18	10.0	16	11.9	20	8.4	10
44.	20.	64.	1531.3	9.6	9.1	18	9.5	17	12.2	20	7.7	9
46.	19.	65.	1554.3	9.6	9.3	18	10.3	18	11.2	19	8.2	10
46.	19.	65.	1530.3	9.6	9.4	18	9.9	18	11.7	19	8.0	10
45.	21.	66.	1571.3	9.9	9.4	18	9.6	17	12.4	21	8.5	10
45.	19.	64.	1542.6	9.6	9.7	18	9.7	17	11.8	19	8.8	10
45.	20.	65.	1522.7	9.8	10.0	18	9.8	17	12.1	20	7.9	10
45.	20.	65.	1537.9	9.7	9.9	18	9.9	17	11.3	20	8.1	10
45.	21.	66.	1583.2	10.0	9.9	18	9.8	17	12.3	21	8.2	10

NOVEMBER 25

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
35.	22.	57.	1344.8	9.2	7.8	13	7.0	12	10.4	22	9.3	10
35.	23.	58.	1369.7	8.4	7.6	12	7.0	13	11.1	23	8.1	10
36.	23.	59.	1437.0	9.0	9.0	14	6.8	12	10.6	23	8.0	10
35.	23.	58.	1344.8	8.6	8.2	13	6.3	12	10.9	23	8.0	10
36.	23.	59.	1405.2	8.9	9.2	14	5.9	12	11.3	23	8.2	10
36.	24.	60.	1407.2	8.8	8.1	14	6.2	12	11.2	24	8.2	10
36.	24.	60.	1446.6	8.9	8.8	14	6.4	12	10.8	24	8.4	10
35.	24.	59.	1399.5	8.6	8.5	13	6.4	12	11.1	24	8.3	10
34.	23.	57.	1346.6	8.5	7.9	12	6.1	12	10.9	23	8.4	10
37.	23.	60.	1430.9	8.6	8.3	14	7.5	13	10.7	23	8.5	10
35.	23.	58.	1394.7	8.5	7.6	13	6.6	12	10.6	23	9.4	10

NOVEMBER 26

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
48.	17.	65.	1617.9	10.1	9.8	18	9.5	18	9.7	17	9.5	12
45.	18.	63.	1475.7	9.5	9.9	18	9.9	17	10.5	18	8.2	10
45.	18.	63.	1512.5	10.2	9.9	18	10.1	17	10.2	18	8.7	10
46.	18.	64.	1527.3	9.7	10.0	18	10.2	18	10.2	18	8.2	10
46.	18.	64.	1529.4	9.5	9.8	18	9.8	18	9.7	18	8.1	10
46.	18.	64.	1484.6	9.8	9.6	18	10.2	18	10.6	18	8.3	10
45.	17.	62.	1452.3	9.3	8.7	17	10.0	18	9.7	17	8.2	10
45.	18.	63.	1494.4	9.5	9.9	18	10.0	17	10.3	18	8.2	10
44.	18.	62.	1466.2	9.3	10.1	17	9.8	17	9.9	18	8.1	10
44.	18.	62.	1471.9	9.1	9.1	18	9.4	16	10.3	18	7.6	10
45.	17.	62.	1470.6	9.5	9.7	18	10.1	17	10.2	17	8.0	10

NOVEMBER 29

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
49.	18.	67.	1611.2	10.0	10.2	19	10.0	19	11.2	18	8.6	11
46.	19.	65.	1514.5	9.9	10.6	18	10.0	18	11.6	19	8.3	10
46.	19.	65.	1582.2	10.2	9.5	18	10.4	18	11.7	19	8.8	10
46.	19.	65.	1538.4	10.1	9.9	18	10.4	18	11.2	19	8.2	10
46.	19.	65.	1545.9	9.7	9.4	18	10.3	18	11.4	19	7.9	10
46.	18.	64.	1482.9	9.7	9.5	18	10.1	18	10.4	13	8.1	10
46.	19.	65.	1538.7	9.9	9.4	18	10.4	18	11.5	19	8.7	10
46.	20.	66.	1552.7	10.0	10.0	18	10.1	18	11.7	20	8.0	10
46.	19.	65.	1545.4	10.1	9.9	18	10.1	18	11.6	19	8.9	10
46.	20.	66.	1571.1	9.8	9.6	18	9.9	18	12.0	20	8.3	10
46.	19.	65.	1532.3	9.9	9.4	18	10.4	18	11.6	19	8.0	10

NOVEMBER 30

NSW	VIC	LOADS	TONS	HOURS	LOADER 71		LOADER 72		LOADER 73		LOADER 74	
					HOURS	LOADS	HOURS	LOADS	HOURS	LOADS	HOURS	LOADS
54.	7.	61.	1501.2	9.2	9.7	21	10.2	13	13.4	7	9.9	15
57.	6.	63.	1480.1	9.6	10.0	21	10.8	22	10.4	6	9.0	14
55.	6.	61.	1451.8	9.7	10.1	22	11.2	19	9.9	6	9.6	14
57.	7.	64.	1524.1	9.9	10.2	22	10.4	21	11.6	7	10.2	14
57.	8.	65.	1539.9	9.7	10.3	22	10.5	21	12.1	8	8.8	14
56.	6.	62.	1467.5	9.4	9.8	21	10.5	21	10.0	6	8.8	14
57.	6.	63.	1480.5	9.8	10.4	22	10.5	21	11.6	6	9.1	14
56.	6.	62.	1443.3	9.5	9.8	21	10.5	21	10.2	6	9.3	14
57.	6.	63.	1487.1	9.7	10.3	22	10.6	21	9.9	6	9.4	14
56.	6.	62.	1462.4	9.4	9.6	21	10.7	21	10.8	6	9.0	14
57.	6.	63.	1499.2	9.5	9.9	22	10.8	21	8.8	6	9.7	14

FEBRUARY 1

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
52.	0.	52.	1202.6	9.0	11.0	20	9.0	20	.0	0	9.3	12
53.	0.	53.	1240.4	9.5	10.6	20	9.7	21	.0	0	10.0	12
52.	0.	52.	1242.1	9.8	11.0	20	9.7	20	.0	0	9.3	12
54.	0.	54.	1274.1	9.6	11.2	20	9.7	22	.0	0	8.8	12
53.	0.	53.	1239.3	9.3	11.1	21	9.2	20	.0	0	8.0	12
52.	0.	52.	1228.3	9.2	10.7	20	9.2	20	.0	0	8.7	12
53.	0.	53.	1253.6	9.4	11.2	20	9.8	21	.0	0	8.5	12
53.	0.	53.	1247.7	9.3	10.7	20	9.6	21	.0	0	8.7	12
52.	0.	52.	1241.5	9.3	11.0	20	9.4	20	.0	0	8.4	12
54.	0.	54.	1282.2	9.5	11.3	21	9.7	21	.0	0	8.5	12
51.	0.	51.	1217.8	9.3	10.3	20	8.8	19	.0	0	8.9	12

FEBRUARY 2

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
52.	0.	52.	1194.3	9.9	10.2	17	11.0	22	.0	0	9.2	13
55.	0.	55.	1304.6	9.9	9.7	18	11.5	21	.0	0	10.1	16
55.	0.	55.	1328.4	10.4	9.9	13	11.4	21	.0	0	11.0	16
56.	0.	56.	1346.6	9.9	9.6	18	11.3	22	.0	0	9.9	16
55.	0.	55.	1282.2	9.9	10.3	18	11.0	21	.0	0	9.5	16
55.	0.	55.	1293.8	9.9	9.6	18	11.2	21	.0	0	9.9	16
54.	0.	54.	1270.9	9.7	9.6	18	11.0	21	.0	0	9.0	15
55.	0.	55.	1306.3	9.8	9.5	18	11.0	21	.0	0	9.6	16
55.	0.	55.	1319.8	9.8	9.3	18	11.2	21	.0	0	10.1	16
56.	0.	56.	1340.2	9.8	9.9	13	11.5	22	.0	0	9.7	16
55.	0.	55.	1308.9	9.8	8.9	13	11.4	21	.0	0	9.8	16

FEBRUARY 3

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
43.	18.	61.	1400.3	10.0	10.2	16	11.7	19	10.2	18	8.8	8
44.	18.	62.	1457.0	10.3	10.8	17	12.0	19	10.3	18	7.6	8
43.	17.	60.	1453.0	10.2	9.4	16	12.0	19	10.2	17	8.1	8
43.	19.	62.	1452.7	10.1	9.0	16	12.0	19	10.8	19	7.9	8
43.	18.	61.	1425.3	10.0	9.2	16	12.0	19	10.7	18	7.8	8
43.	18.	61.	1436.1	10.0	8.8	16	12.0	19	10.5	18	8.9	8
43.	18.	61.	1440.8	10.1	9.4	16	11.6	19	10.8	18	8.4	8
43.	18.	61.	1465.9	9.9	9.1	16	11.7	19	10.6	18	7.6	8
43.	18.	61.	1462.2	10.1	9.2	16	12.2	19	10.4	18	7.6	8
44.	18.	62.	1464.0	10.2	10.4	17	12.1	19	10.3	18	7.5	8
42.	18.	60.	1390.0	10.0	9.1	16	10.6	18	10.7	18	7.5	8

FEBRUARY 4

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
40.	18.	58.	1366.7	9.6	10.3	14	9.7	18	10.3	18	8.9	8
40.	18.	58.	1364.2	9.9	10.5	15	9.9	17	10.7	18	7.7	8
39.	18.	57.	1369.1	10.3	9.7	14	10.2	17	10.6	18	9.4	8
38.	18.	56.	1313.5	9.4	8.8	14	9.9	16	10.3	18	7.5	8
39.	18.	57.	1329.3	9.5	8.2	14	10.2	17	10.3	18	7.5	8
39.	19.	58.	1372.7	9.6	10.2	14	10.1	17	10.7	19	8.1	8
40.	18.	58.	1361.6	9.9	8.9	14	11.1	16	10.4	18	8.3	8
39.	18.	57.	1375.2	9.5	8.4	14	10.2	17	10.5	18	7.5	8
39.	18.	57.	1354.5	9.8	9.3	14	10.0	17	10.5	18	7.7	8
40.	19.	59.	1386.5	10.1	8.1	14	10.8	18	10.8	19	9.1	8
38.	18.	56.	1320.7	9.5	9.3	14	9.5	16	10.3	18	7.7	8

FEBRUARY 7

NS.	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
44.	17.	61.	1481.9	9.5	10.3	19	9.1	18	9.7	17	9.5	7
41.	18.	59.	1396.8	9.5	9.1	18	10.0	17	10.2	18	6.9	6
39.	17.	56.	1353.7	9.3	10.2	18	9.2	15	9.6	17	7.4	6
42.	18.	60.	1442.0	9.7	9.8	18	10.0	18	10.3	18	6.8	6
41.	18.	59.	1389.8	9.4	9.2	18	9.6	17	10.3	18	7.9	6
42.	18.	60.	1399.0	10.0	10.0	18	10.3	18	9.8	18	7.3	6
41.	18.	59.	1382.1	9.5	10.0	18	9.6	17	9.9	18	7.6	6
40.	18.	58.	1373.1	9.5	9.6	18	9.9	16	10.3	18	6.9	6
41.	17.	58.	1373.7	9.6	9.8	18	9.9	17	10.0	17	6.8	6
41.	17.	58.	1395.1	9.1	9.4	18	9.3	17	10.2	17	6.9	6
41.	17.	58.	1379.1	9.4	10.2	18	9.8	17	9.9	17	7.3	6

FEBRUARY 8

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
52.	0.	52.	1241.2	8.4	10.0	23	8.6	15	.0	0	9.1	14
53.	0.	53.	1240.2	9.0	10.5	22	8.7	17	.0	0	9.2	14
53.	0.	53.	1273.7	9.5	10.8	22	9.5	17	.0	0	9.7	14
53.	0.	53.	1244.5	9.1	10.1	22	8.6	17	.0	0	9.3	14
54.	0.	54.	1256.1	9.3	10.9	22	9.1	18	.0	0	9.0	14
52.	0.	52.	1226.6	8.7	10.0	22	8.6	17	.0	0	8.5	13
52.	0.	52.	1201.8	8.9	10.2	21	9.1	17	.0	0	9.1	14
54.	0.	54.	1269.7	9.4	10.6	22	9.0	18	.0	0	9.4	14
54.	0.	54.	1294.8	9.5	11.2	22	9.7	18	.0	0	9.5	14
54.	0.	54.	1287.7	9.2	10.2	22	9.6	18	.0	0	9.2	14
53.	0.	53.	1236.6	9.2	11.0	22	8.6	17	.0	0	9.4	14

FEBRUARY 9

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
45.	19.	64.	1474.3	9.5	10.3	20	9.2	18	10.7	19	8.8	7
42.	21.	63.	1480.3	9.8	10.5	20	9.9	16	11.2	21	7.1	6
43.	20.	63.	1523.9	10.0	10.7	21	9.6	16	11.1	20	7.6	6
41.	20.	61.	1443.5	9.5	9.9	20	9.8	15	10.9	20	7.2	6
43.	21.	64.	1509.8	9.9	10.9	21	9.6	16	11.1	21	6.9	6
43.	21.	64.	1534.7	9.7	9.8	20	9.7	17	11.7	21	7.7	6
42.	20.	62.	1459.1	9.7	10.7	20	9.8	16	10.8	20	7.5	6
40.	21.	61.	1441.3	9.3	9.5	20	9.5	14	11.7	21	6.3	6
43.	20.	63.	1484.7	9.9	9.9	20	9.7	17	11.0	20	7.2	6
41.	21.	62.	1452.6	9.6	9.8	20	9.5	15	11.4	21	7.0	6
43.	21.	64.	1522.9	9.8	10.5	20	9.8	17	11.6	21	7.4	6

FEBRUARY 10

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
35.	21.	56.	1320.7	9.5	9.3	20	9.4	15	10.7	21	.0	0
34.	23.	57.	1337.2	9.6	10.3	20	8.4	14	11.7	23	.0	0
31.	21.	52.	1250.8	9.1	8.7	17	8.8	14	11.3	21	.0	0
34.	23.	57.	1329.2	9.4	9.9	20	8.3	14	11.5	23	.0	0
33.	23.	56.	1325.2	9.1	9.5	19	8.8	14	10.9	23	.0	0
34.	23.	57.	1348.1	9.6	9.9	20	8.3	14	11.4	23	.0	0
33.	22.	55.	1295.0	9.2	9.8	19	9.0	14	10.9	22	.0	0
33.	24.	57.	1336.9	9.5	9.8	19	9.1	14	11.8	24	.0	0
34.	23.	57.	1396.5	9.6	9.9	20	8.0	14	11.4	23	.0	0
34.	22.	56.	1310.1	9.6	11.2	20	8.0	14	10.9	22	.0	0
34.	23.	57.	1359.9	9.9	10.1	20	8.1	14	11.9	23	.0	0

FEBRUARY 11

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
37.	20.	57.	1343.1	9.2	10.0	19	9.0	18	11.0	20	.0	0
36.	24.	60.	1419.3	9.6	9.9	18	9.3	18	11.4	24	.0	0
36.	23.	59.	1406.3	10.2	11.0	18	10.0	18	11.2	23	.0	0
36.	24.	60.	1418.9	9.6	9.5	18	8.8	18	11.6	24	.0	0
36.	24.	60.	1431.1	9.8	9.9	18	9.5	18	11.5	24	.0	0
36.	25.	61.	1437.1	9.8	9.8	18	9.4	18	11.8	25	.0	0
36.	24.	60.	1412.8	9.7	9.5	18	9.3	18	11.9	24	.0	0
36.	22.	58.	1340.7	9.5	9.5	18	9.5	18	11.0	22	.0	0
37.	23.	60.	1447.8	9.7	10.4	19	9.0	18	11.5	23	.0	0
36.	23.	59.	1384.0	9.7	9.7	18	9.5	18	11.4	23	.0	0
36.	23.	59.	1419.7	9.6	9.9	18	8.9	18	11.7	23	.0	0

FEBRUARY 14

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
23.	41.	64.	1549.8	10.2	10.0	21	8.7	15	11.8	20	10.0	8
22.	43.	65.	1538.3	10.0	10.6	21	8.7	16	12.2	22	7.1	6
22.	40.	62.	1483.8	10.1	10.2	19	9.2	16	12.1	21	7.3	6
22.	43.	65.	1514.2	10.1	10.5	21	9.7	16	12.4	22	7.7	6
23.	43.	66.	1566.4	10.4	10.7	21	9.1	16	12.1	22	10.3	7
23.	42.	65.	1523.3	10.1	10.5	21	8.8	16	11.8	21	10.7	7
20.	43.	63.	1483.2	9.6	10.3	21	7.8	14	12.4	22	7.7	6
22.	42.	64.	1519.3	9.9	10.0	20	8.9	16	12.1	22	8.2	6
22.	43.	65.	1559.3	10.1	10.6	21	8.6	16	12.4	22	6.8	6
22.	42.	64.	1502.1	10.0	10.7	21	8.9	15	11.1	21	10.3	7
23.	41.	64.	1517.3	10.1	10.5	20	8.7	16	11.7	21	10.6	7

FEBRUARY 15

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
24.	40.	64.	1521.3	9.7	10.3	21	9.2	16	11.7	19	8.2	8
22.	42.	64.	1524.1	9.8	10.9	21	8.9	16	11.2	21	7.5	6
22.	41.	63.	1494.6	10.2	10.8	20	9.6	16	12.4	21	7.6	6
22.	43.	65.	1524.7	9.9	10.7	22	8.9	16	11.5	21	8.8	6
22.	43.	65.	1522.8	10.0	10.7	21	9.3	16	12.2	22	6.8	6
22.	42.	64.	1486.8	10.0	10.7	21	9.5	16	11.0	21	6.7	6
22.	43.	65.	1531.1	10.0	10.6	21	8.7	16	11.9	22	6.9	6
22.	44.	66.	1586.6	10.2	10.7	21	9.2	16	12.4	23	6.9	6
22.	43.	65.	1550.2	10.2	11.0	20	9.6	16	12.5	23	7.5	6
22.	45.	67.	1591.6	10.2	11.1	22	8.6	16	12.4	23	8.0	6
22.	43.	65.	1529.7	10.3	11.0	21	9.4	16	12.0	22	7.5	6

FEBRUARY 16

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
26.	39.	65.	1566.0	9.5	8.8	19	8.0	16	10.5	20	8.8	10
23.	40.	63.	1472.4	9.0	9.4	19	8.5	15	11.0	21	7.5	8
22.	40.	62.	1490.2	9.2	9.8	18	8.7	14	11.0	22	8.1	8
23.	41.	64.	1518.1	9.0	9.1	19	8.7	15	11.1	22	8.4	8
24.	42.	66.	1559.9	9.5	9.1	19	9.7	16	11.6	23	7.7	8
23.	41.	64.	1494.1	9.2	9.1	18	8.6	15	11.5	23	7.7	8
23.	40.	63.	1499.0	8.9	9.1	18	8.6	15	11.1	22	7.6	8
24.	39.	63.	1507.1	9.0	8.7	17	8.4	16	10.9	22	7.7	8
22.	40.	62.	1477.5	8.8	9.0	18	8.1	14	10.6	22	7.9	8
23.	40.	63.	1475.0	9.1	9.4	18	8.7	15	10.8	22	7.2	8
24.	40.	64.	1514.6	9.3	9.7	17	8.9	16	11.3	23	7.2	8

FEBRUARY 17

NS.	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
30.	40.	70.	1682.1	9.5	9.4	20	9.8	18	11.0	20	9.5	12
30.	41.	71.	1668.0	9.9	10.4	20	10.1	18	11.6	21	8.1	12
30.	38.	68.	1629.2	9.8	10.0	18	9.9	18	11.6	20	9.2	12
30.	41.	71.	1691.8	9.9	10.3	20	9.9	18	11.4	21	9.3	12
30.	40.	70.	1688.4	9.7	10.1	19	9.6	18	11.6	21	8.5	12
30.	40.	70.	1645.9	9.6	9.4	19	10.6	18	11.4	21	8.1	12
29.	41.	70.	1674.5	10.0	10.1	20	9.9	17	11.8	21	9.2	12
30.	41.	71.	1677.8	10.1	10.4	20	10.6	18	11.6	21	8.4	12
30.	41.	71.	1700.3	10.0	10.3	20	10.3	18	11.5	21	8.5	12
29.	41.	70.	1669.8	9.6	10.6	20	9.2	17	11.4	21	8.4	12
30.	41.	71.	1686.5	10.0	10.5	20	10.2	18	11.2	21	9.3	12

FEBRUARY 18

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
44.	19.	63.	1466.4	9.3	9.7	20	9.5	20	9.7	19	5.3	4
41.	19.	60.	1391.1	9.2	10.2	20	10.0	17	10.5	19	5.4	4
39.	18.	57.	1392.9	8.8	10.3	19	9.5	17	10.7	18	1.4	3
42.	18.	60.	1434.3	9.1	10.3	20	10.1	18	10.5	18	5.9	4
42.	17.	59.	1390.6	8.8	10.0	20	9.8	17	9.3	17	6.1	5
42.	19.	61.	1440.7	9.0	9.9	20	9.7	18	10.5	19	5.1	4
39.	19.	58.	1353.4	8.7	9.5	19	9.8	17	10.7	19	1.4	3
40.	18.	58.	1364.6	8.7	10.0	20	9.8	17	9.9	18	1.5	3
41.	18.	59.	1394.7	9.1	10.7	20	9.9	17	10.1	18	5.6	4
41.	19.	60.	1420.5	8.9	9.6	19	10.0	18	10.5	19	5.9	4
41.	18.	59.	1393.1	8.9	9.9	20	10.3	18	10.2	18	1.4	3

FEBRUARY 21

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
44.	14.	53.	1341.5	9.8	9.8	18	12.0	18	8.9	14	8.5	8
42.	14.	56.	1303.6	9.6	9.5	18	10.8	18	9.5	14	6.9	6
43.	12.	55.	1318.6	9.9	10.3	18	11.9	19	8.7	12	7.9	6
45.	15.	60.	1437.5	10.2	9.9	18	12.7	21	10.0	15	6.5	6
43.	14.	57.	1345.2	9.8	9.4	18	11.4	19	9.4	14	7.0	6
46.	14.	60.	1448.2	10.0	9.9	18	12.8	22	9.3	14	9.0	6
42.	13.	55.	1283.9	9.4	9.4	18	10.3	18	8.6	13	8.0	6
43.	13.	56.	1315.5	9.9	10.7	18	11.0	19	8.9	13	7.2	6
42.	13.	55.	1313.6	9.7	9.4	18	10.6	18	9.1	13	7.6	6
44.	15.	59.	1417.2	10.1	9.4	18	12.5	20	9.4	15	7.3	6
43.	12.	55.	1293.7	9.7	9.9	18	11.7	19	8.6	12	7.2	6

FEBRUARY 22

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
41.	24.	65.	1529.2	9.5	9.5	16	11.0	19	10.0	24	8.3	6
41.	23.	64.	1514.9	9.3	9.7	17	10.7	18	10.2	23	7.4	6
42.	23.	65.	1557.6	10.2	10.3	18	11.1	18	11.2	23	8.3	6
43.	21.	64.	1512.7	9.3	9.4	18	10.9	19	9.9	21	8.3	6
42.	25.	67.	1572.9	10.1	10.0	18	10.5	18	11.4	25	7.3	6
42.	23.	65.	1529.2	9.5	9.1	18	10.7	18	10.7	23	6.9	6
43.	24.	67.	1587.1	10.0	10.3	18	11.6	19	10.6	24	7.9	6
42.	23.	65.	1542.9	9.4	9.7	18	9.7	18	10.7	23	7.4	6
42.	23.	65.	1543.6	9.7	9.4	18	10.7	18	10.7	23	7.7	6
42.	22.	64.	1498.2	9.4	9.4	18	10.2	18	10.1	22	7.5	6
42.	24.	66.	1602.8	9.6	9.8	18	10.6	18	10.8	24	7.3	6

FEBRUARY 23

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
41.	18.	59.	1420.9	9.8	9.6	17	10.8	18	10.5	18	9.6	6
43.	18.	61.	1428.6	10.1	10.0	18	11.2	19	10.1	18	7.4	6
42.	18.	60.	1461.1	10.2	9.7	18	11.1	18	10.5	18	7.7	6
42.	18.	60.	1428.4	9.9	9.5	18	10.5	18	10.2	18	7.5	6
42.	18.	60.	1434.0	9.7	10.1	18	10.5	18	10.0	18	7.4	6
42.	18.	60.	1395.6	9.9	9.3	18	10.4	18	11.7	18	7.6	6
42.	19.	61.	1443.9	10.0	10.1	18	10.7	18	10.8	19	7.2	6
42.	18.	60.	1401.4	10.0	9.5	18	10.7	18	10.6	18	7.8	6
42.	18.	60.	1402.5	10.2	9.9	18	10.7	18	10.8	18	6.9	6
42.	18.	60.	1411.4	10.0	10.1	18	10.8	18	9.8	18	6.8	6
42.	18.	60.	1424.5	9.9	9.9	18	10.3	18	10.5	18	7.3	6

FEBRUARY 24

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
43.	19.	62.	1400.4	9.9	10.5	24	11.0	19	11.0	19	.0	0
42.	20.	62.	1466.5	10.1	11.2	24	10.1	18	11.7	20	.0	0
42.	18.	60.	1460.9	10.0	11.1	24	10.1	18	11.0	18	.0	0
42.	18.	60.	1409.9	9.9	10.4	24	10.3	18	10.2	18	.0	0
42.	20.	62.	1485.3	9.7	10.4	24	10.0	18	11.3	20	.0	0
43.	19.	62.	1450.7	10.2	10.4	24	11.3	19	11.1	19	.0	0
43.	19.	62.	1474.3	10.0	10.6	24	11.4	19	11.1	19	.0	0
43.	19.	62.	1498.3	10.2	11.3	24	10.9	19	11.3	19	.0	0
43.	19.	62.	1476.6	10.2	11.2	24	11.4	19	11.6	19	.0	0
43.	19.	62.	1474.0	10.0	11.1	24	11.4	19	10.7	19	.0	0
43.	20.	63.	1494.2	10.3	11.2	24	11.4	19	11.6	20	.0	0

FEBRUARY 25

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
35.	16.	51.	1249.7	8.9	9.0	19	8.7	16	8.8	16	.0	0
34.	16.	50.	1171.3	8.6	9.4	13	8.8	16	9.4	16	.0	0
34.	15.	49.	1195.8	8.7	9.3	18	8.8	16	9.3	15	.0	0
36.	15.	51.	1205.1	8.7	9.5	20	8.3	16	8.8	15	.0	0
36.	16.	52.	1237.4	9.0	9.6	20	9.3	16	9.4	16	.0	0
36.	16.	52.	1246.6	9.0	10.0	20	8.9	16	9.2	16	.0	0
36.	16.	52.	1225.9	9.1	10.1	20	8.7	16	9.2	16	.0	0
34.	16.	50.	1181.9	8.5	9.5	18	8.5	16	9.3	16	.0	0
35.	16.	51.	1235.3	8.7	9.8	19	8.7	16	9.1	16	.0	0
36.	16.	52.	1233.7	9.1	10.3	20	8.7	16	9.3	16	.0	0
35.	17.	52.	1244.0	9.1	9.7	19	8.9	16	9.7	17	.0	0

FEBRUARY 28

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
32.	17.	49.	1209.8	8.9	9.5	16	7.9	16	9.5	17	.0	0
34.	18.	52.	1237.3	8.9	9.7	18	8.5	16	10.2	18	.0	0
34.	16.	50.	1202.4	8.9	10.0	18	8.4	16	10.6	16	.0	0
35.	16.	51.	1207.7	8.8	9.1	18	8.8	17	10.0	16	.0	0
35.	18.	53.	1261.2	8.9	9.4	18	8.7	17	10.3	18	.0	0
34.	17.	51.	1200.8	8.6	9.4	18	8.0	16	9.7	17	.0	0
35.	17.	52.	1236.9	8.8	9.3	18	8.3	17	10.0	17	.0	0
35.	18.	53.	1264.2	9.0	10.0	18	8.9	17	10.1	18	.0	0
34.	18.	52.	1260.9	8.8	9.7	18	8.1	16	10.2	18	.0	0
34.	18.	52.	1233.3	8.8	9.1	17	8.5	17	9.9	18	.0	0
34.	17.	51.	1212.1	8.8	9.5	18	8.4	16	10.2	17	.0	0

JUNE 1

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
52.	23.	75.	1756.4	9.3	10.5	23	11.3	29	9.4	23	.0	0
50.	22.	72.	1682.4	9.5	11.2	23	11.4	27	9.7	22	.0	0
50.	21.	71.	1708.8	9.8	11.1	22	12.4	28	9.6	21	.0	0
52.	22.	74.	1766.2	9.9	11.0	23	12.4	29	10.2	22	.0	0
52.	22.	74.	1746.5	10.0	11.3	23	12.1	29	9.9	22	.0	0
50.	23.	73.	1750.2	9.7	10.7	22	11.8	28	10.0	23	.0	0
48.	24.	72.	1665.9	10.0	10.7	22	11.9	26	10.5	24	.0	0
49.	23.	72.	1683.1	9.6	10.8	22	11.8	27	10.2	23	.0	0
49.	23.	72.	1712.1	9.8	10.5	22	12.2	27	10.1	23	.0	0
49.	23.	72.	1683.1	9.7	10.6	22	11.9	27	10.3	23	.0	0
51.	24.	75.	1798.6	10.0	10.7	23	12.3	28	10.3	24	.0	0

JUNE 2

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
59.	14.	73.	1727.0	10.0	11.1	21	10.8	24	10.0	14	8.4	14
56.	12.	68.	1587.7	9.6	9.8	20	11.4	22	10.1	12	9.0	14
54.	12.	66.	1603.5	9.9	11.8	21	11.4	21	10.6	12	8.9	12
58.	14.	72.	1725.7	10.3	11.9	22	12.0	23	11.4	14	8.3	13
56.	12.	68.	1621.1	9.5	11.5	22	10.8	21	10.1	12	9.2	13
57.	13.	70.	1660.9	9.9	11.4	21	11.4	22	10.4	13	9.0	14
56.	13.	69.	1631.4	9.9	10.3	20	11.2	22	9.3	13	9.1	14
56.	13.	69.	1652.2	9.8	11.0	21	11.3	22	9.5	13	9.0	13
55.	13.	68.	1646.9	9.8	10.2	20	11.1	21	9.6	13	9.0	14
56.	13.	69.	1657.0	9.7	10.8	21	11.4	22	9.8	13	8.5	13
57.	13.	70.	1659.4	10.1	11.2	21	11.2	22	10.6	13	9.1	14

JUNE 3

NS.	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
62.	0.	62.	1467.6	9.6	11.7	20	10.0	23	.0	0	10.3	19
59.	0.	59.	1400.2	9.3	11.4	21	10.1	20	.0	0	9.9	18
61.	0.	61.	1483.3	9.8	11.2	21	10.5	22	.0	0	10.3	18
61.	0.	61.	1433.8	9.5	10.1	20	11.0	23	.0	0	10.1	18
62.	0.	62.	1456.2	9.7	12.3	22	9.6	21	.0	0	10.7	19
63.	0.	63.	1480.6	9.8	12.4	22	10.3	23	.0	0	9.9	18
62.	0.	62.	1483.3	9.7	11.2	21	10.7	23	.0	0	10.6	18
61.	0.	61.	1432.4	9.6	12.0	21	9.8	21	.0	0	10.7	19
62.	0.	62.	1483.9	9.9	11.6	22	10.1	22	.0	0	10.6	18
61.	0.	61.	1458.3	9.4	10.0	20	10.5	23	.0	0	9.8	18
62.	0.	62.	1460.8	10.0	11.7	21	11.0	23	.0	0	10.1	18

JUNE 6

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
44.	15.	59.	1384.1	9.4	10.3	21	.0	0	10.6	15	10.9	23
43.	14.	57.	1358.0	9.9	10.0	20	.0	0	10.8	14	11.4	23
42.	14.	56.	1356.1	10.2	10.1	20	.0	0	11.0	14	11.5	22
44.	15.	59.	1392.8	10.2	10.8	21	.0	0	10.8	15	11.4	23
44.	15.	59.	1363.1	10.6	10.0	20	.0	0	10.6	15	12.6	24
44.	15.	59.	1397.1	10.0	10.1	20	.0	0	10.6	15	11.9	24
43.	15.	58.	1384.4	10.1	10.0	20	.0	0	11.5	15	11.4	23
43.	15.	58.	1374.5	10.1	10.9	21	.0	0	11.0	15	11.3	22
44.	14.	58.	1383.5	10.4	10.9	20	.0	0	10.6	14	12.2	24
43.	15.	58.	1378.5	10.2	9.8	20	.0	0	11.1	15	12.0	23
43.	15.	58.	1386.4	10.1	10.2	20	.0	0	10.4	15	11.6	23

JUNE 7

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
42.	15.	57.	1336.9	8.8	9.4	20	.0	0	11.0	15	9.7	22
41.	15.	56.	1342.5	9.5	9.6	20	.0	0	11.4	15	10.6	21
38.	14.	52.	1247.6	9.3	10.6	20	.0	0	11.3	14	8.8	18
40.	14.	54.	1271.8	9.1	9.9	20	.0	0	10.9	14	9.7	20
41.	15.	56.	1326.9	9.5	9.8	20	.0	0	10.8	15	10.7	21
40.	15.	55.	1285.0	9.5	9.6	19	.0	0	11.2	15	10.6	21
42.	15.	57.	1328.4	10.1	10.5	20	.0	0	11.7	15	10.9	22
41.	15.	56.	1319.9	9.7	9.8	19	.0	0	10.9	15	11.4	22
41.	15.	56.	1355.9	9.7	9.9	20	.0	0	11.0	15	10.5	21
42.	15.	57.	1340.6	10.1	10.3	20	.0	0	11.6	15	10.8	22
39.	15.	54.	1271.0	9.1	10.4	20	.0	0	10.9	15	10.3	19

JUNE 8

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
46.	4.	50.	1165.4	9.3	10.2	23	.0	0	8.0	4	10.3	23
46.	4.	50.	1193.7	9.6	10.3	22	.0	0	5.2	4	12.1	24
43.	5.	48.	1127.2	9.7	10.8	21	.0	0	8.7	5	11.4	22
45.	5.	50.	1167.4	9.4	10.6	23	.0	0	8.1	5	11.0	22
47.	5.	52.	1237.7	9.6	10.8	23	.0	0	8.5	5	11.5	24
45.	5.	50.	1158.8	9.5	9.9	21	.0	0	8.5	5	11.6	24
46.	4.	50.	1196.7	9.6	10.6	22	.0	0	5.2	4	11.6	24
46.	4.	50.	1195.9	9.5	10.6	22	.0	0	5.0	4	11.8	24
44.	4.	48.	1139.2	9.1	10.6	22	.0	0	5.5	4	10.8	22
45.	4.	49.	1173.5	9.3	10.3	22	.0	0	5.1	4	11.2	23
43.	4.	47.	1125.2	8.8	10.5	22	.0	0	5.9	4	10.2	21

JUNE 9

NSW	VIC	LOADS	TONS	HOURS	LOADER 71		LOADER 72		LOADER 73		LOADER 74	
					HOURS	LOADS	HOURS	LOADS	HOURS	LOADS	HOURS	LOADS
52.	3.	55.	1302.8	9.6	9.7	19	10.1	21	8.5	3	9.3	12
53.	3.	56.	1325.0	9.8	10.2	20	10.6	21	8.8	3	9.7	12
51.	2.	53.	1274.3	9.8	10.4	20	10.1	19	5.5	2	9.2	12
51.	3.	54.	1271.4	9.4	9.8	20	10.1	19	8.0	3	8.7	12
53.	3.	56.	1320.3	9.6	10.1	20	10.8	21	7.6	3	8.4	12
52.	3.	55.	1303.8	9.6	10.0	20	10.6	20	8.0	3	8.6	12
52.	3.	55.	1311.1	9.4	9.9	20	10.8	20	8.0	3	8.2	12
51.	3.	54.	1298.6	9.1	9.8	19	10.2	20	8.0	3	9.1	12
51.	3.	54.	1304.3	9.5	9.9	19	10.6	20	7.9	3	8.6	12
52.	3.	55.	1285.3	9.7	10.2	20	10.5	20	8.6	3	8.3	12
52.	3.	55.	1313.4	9.5	10.1	20	10.2	20	7.9	3	8.7	12

JUNE 10

NSW	VIC	LOADS	TONS	HOURS	LOADER 71		LOADER 72		LOADER 73		LOADER 74	
					HOURS	LOADS	HOURS	LOADS	HOURS	LOADS	HOURS	LOADS
52.	6.	58.	1340.5	10.0	10.0	20	12.5	24	10.0	6	7.0	8
52.	6.	58.	1385.8	10.2	10.2	20	12.2	24	9.3	6	7.3	8
52.	6.	58.	1418.2	10.8	10.5	20	13.1	24	10.2	6	7.3	8
52.	6.	58.	1379.9	10.2	9.9	20	11.9	24	9.6	6	7.1	8
53.	6.	59.	1392.3	10.2	9.9	20	12.4	25	9.0	6	8.0	8
51.	6.	57.	1337.7	10.0	10.6	20	12.8	24	8.5	6	7.5	7
52.	6.	58.	1382.2	10.1	10.1	20	12.2	24	9.0	6	7.2	8
51.	6.	57.	1339.9	10.0	10.3	20	12.4	24	8.7	6	7.5	7
51.	6.	57.	1351.8	10.1	10.3	20	11.9	24	9.4	6	6.9	7
52.	6.	58.	1365.9	10.2	10.1	20	12.5	24	9.2	6	7.4	8
52.	6.	58.	1396.9	10.2	9.8	20	12.5	24	9.5	6	7.1	8

JUNE 13

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
56.	0.	56.	1325.5	9.2	10.7	20	9.9	19	.0	0	10.0	17
56.	0.	56.	1323.4	9.9	12.2	23	10.1	17	.0	0	9.3	16
52.	0.	52.	1242.3	9.8	10.3	20	10.5	16	.0	0	10.3	16
54.	0.	54.	1259.1	9.4	10.6	21	9.8	17	.0	0	9.1	16
56.	0.	56.	1331.7	9.7	11.6	21	10.4	18	.0	0	10.1	17
56.	0.	56.	1319.8	9.6	12.4	22	10.4	18	.0	0	9.4	16
54.	0.	54.	1288.8	9.4	11.1	21	9.9	17	.0	0	9.2	16
54.	0.	54.	1279.1	9.6	10.8	21	9.9	17	.0	0	10.2	16
55.	0.	55.	1314.7	9.7	11.1	21	10.2	18	.0	0	10.1	16
55.	0.	55.	1284.1	9.9	11.6	21	10.2	18	.0	0	10.2	16
54.	0.	54.	1293.2	9.5	10.1	20	10.6	18	.0	0	10.4	16

JUNE 14

NSW	VIC	LOADS	TONS	HOURS	LOADER 71 HOURS	LOADER 71 LOADS	LOADER 72 HOURS	LOADER 72 LOADS	LOADER 73 HOURS	LOADER 73 LOADS	LOADER 74 HOURS	LOADER 74 LOADS
58.	10.	68.	1599.9	10.2	11.3	23	11.1	19	10.1	10	9.8	16
58.	12.	70.	1671.2	10.4	11.4	23	12.2	21	10.2	12	9.1	14
57.	11.	63.	1625.8	10.7	12.5	22	11.3	21	10.5	11	9.7	14
58.	11.	69.	1611.5	10.1	11.5	23	11.2	21	10.5	11	8.9	14
57.	12.	69.	1641.4	10.1	11.2	23	11.2	20	10.2	12	9.5	14
58.	12.	70.	1662.8	10.1	10.6	23	11.2	21	10.3	12	8.8	14
57.	12.	69.	1624.2	10.3	11.4	23	11.6	20	10.5	12	8.6	14
57.	11.	68.	1606.9	10.0	10.8	23	11.1	20	10.3	11	9.4	14
57.	12.	69.	1658.2	10.1	11.0	23	11.5	20	10.6	12	9.1	14
57.	11.	68.	1600.1	10.1	10.7	23	11.8	20	10.0	11	9.0	14
56.	12.	68.	1621.3	10.2	11.8	23	11.5	19	10.7	12	9.0	14

APPENDIX 6.1

Listing of the model as used in experiments

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NRA652*LOADSIM(6).PROG(27)
          PREAMBLE

''   PROCESSES LIST

       PROCESSES INCLUDE MORNING, CLOSE.WB, OPEN.LOADER, START.UP
       EVERY LAND.ARRIVAL HAS AN ATRUCK AND AN ALOADER
       DEFINE ATRUCK AND ALOADER AS INTEGER VARIABLES
       EVERY WB.ARRIVAL HAS A BTRUCK, A BLOADER AND A DESTINATION
       DEFINE BTRUCK, BLOADER AND DESTINATION AS INTEGER VARIABLES
       EVERY OPEN.LOADER HAS A CLOADER AND AN ATIME
       DEFINE CLOADER AS AN INTEGER VARIABLE
       DEFINE ATIME AS A REAL VARIABLE
       EVERY START.UP HAS A CTRUCK AND A DLOADER
       DEFINE CTRUCK AND DLOADER AS INTEGER VARIABLES

''   RESOURCES LIST

       RESOURCES INCLUDE ATTENDENT
       EVERY WB HAS A WAIT.TIME
       EVERY LOADER HAS A P.DAY.L.WORK, A T.L.LOADS, A PAY.L.WORK, A PAY.T.WORK,
        A D.L.TIME, A P.L.TIME, A LDR.WORK, A D.L.WORK, A P.L.WORK, A D.L.IDLE,
        A P.L.IDLE, A D.T.TIME, A P.T.TIME, A D.T.WORK, A P.T.WORK, A D.T.IDLE,
        A D.DAY.L.WORK, A P.T.IDLE, A D.L.LOADS, A P.L.LOADS, A UT.LOADER,
        A D.L.TONS, A P.L.TONS, A T.L.TONS, A PERIOD.WORK, A STOP.PERIOD,
        AN ALLOW.HARV, A WAIT.LOADER, A LOADER.INDEX, A NLAND, A NO.WORK.LOADER,
        A NO.LAND.LOADER, A DUE.L.FINISH, A START.LOADER AND A FINISH.LOADER
       DEFINE WAIT.LOADER, START.LOADER, P.L.TIME, PAY.L.WORK, PAY.T.WORK,
        LDR.WORK, D.L.WORK, P.L.WORK, D.L.IDLE, P.L.IDLE, D.T.TIME, D.L.TONS,
        P.T.TIME, D.T.WORK, P.T.WORK, D.T.IDLE, P.T.IDLE, P.L.TONS, T.L.TONS,
        WAIT.TIME, UT.LOADER, D.L.TIME, DUE.L.FINISH, NO.WORK.LOADER,
        PERIOD.WORK, STOP.PERIOD AND FINISH.LOADER AS REAL VARIABLES
       DEFINE P.DAY.L.WORK, LOADER.INDEX, NLAND, ALLOW.HARV, T.L.LOADS,
        D.DAY.L.WORK, D.L.LOADS, P.L.LOADS AND
        NO.LAND.LOADER AS INTEGER VARIABLES

''   ENTITIES LIST

       PERMANENT ENTITIES
       EVERY FOREST HAS A NAME AND A STATE
        DEFINE NAME AS A TEXT VARIABLE
        DEFINE STATE AS AN INTEGER VARIABLE
       EVERY TRUCK HAS A DEST.TRUCK, A LDWT, A START.TRUCK, A STATUS.TRUCK,
        A TRAV.TIME, AN ORIGIN, A TYPE, AN ARR.LAND AND A FINISH.TRUCK
       DEFINE DEST.TRUCK AND STATUS.TRUCK AS AN ALPHA VARIABLE
       DEFINE LDWT, TRAV.TIME, START.TRUCK, ARR.LAND AND FINISH.TRUCK AS REAL
             VARIABLES
       DEFINE TYPE AND ORIGIN AS INTEGER VARIABLES

''   VARIABLES LIST

       DEFINE REPORT.PERIOD,MAX.PIG,MAX.S1 AND NO.OF.TRUCKS AS INTEGER VARIABLES
       DEFINE NO.OF.LOADERS, D.LOADS, T.LOADS AND P.LOADS AS INTEGER VARIABLES
       DEFINE HARV.LOADS, P.NTKS, T.NTKS AND DAYS.OF.HAULAGE AS INTEGER VARIABLES
       DEFINE N.HARV, NOLAND, .IN, STREAM, NOMILL AND .OUT AS INTEGER VARIABLES
       DEFINE T.DAYS.HAULAGE AND P.DAYS.HAULAGE AS INTEGER VARIABLES
       DEFINE SHIFT, T.TONS, T.CONS, P.CONS AND OPENING.TIME AS REAL VARIABLES
       DEFINE UT.WB.IN, WORK.TRUCK, PRODUCTION AND UT.WB.OUT AS REAL VARIABLES
       DEFINE MILL.INTAKE, MILL.STOCKPILE AND CAPACITY.MILL AS REAL VARIABLES
       DEFINE P.TRK.TIME, ENDSIM, D.TRK.TIME AND NIGHT.TIME AS REAL VARIABLES
```

```
       DEFINE PROD1, EXTERNAL.CHIPS, D.TONS, P.TONS AND PROD2 AS REAL VARIABLES
       DEFINE INTERVAL, OPEN.STOCKPILE,CHIP.DEL AND NOPROD.PERC AS REAL VARIABLES
       DEFINE T.TRK.TIME, LFIXED, TFIXED, TWAGES AND LWAGES AS REAL VARIABLES
       DEFINE LVARCOST, WORK.HRS, LOAD.SHIFT, FULL.SHIFT, LDWT.LIMIT AND TVARCOST
           AS REAL VARIABLES

'' ARRAYS LIST

       DEFINE IDENT.HARV, T.LOADS.AREA AND ALLOW.FOREST AS AN INTEGER,1-DIM ARRAY
       DEFINE OVERNIGHT, LOADS.AREA AND TOTAL.H.LOADS AS AN INTEGER, 1-DIM ARRAY
       DEFINE SEEDS AS AN INTEGER, 1-DIM ARRAY
       DEFINE WB.HOURS AND TONS.AREA AS A REAL,1-DIM ARRAY
       DEFINE NTRUCK.TYPE, PRIORITY AND TRUE.LOADS AS A REAL, 1-DIM ARRAY
       DEFINE TIME.IN, BEGIN.WB.IN, BEGIN.WB.OUT AND TIME.OUT AS REAL,1-DIM ARRAY
       DEFINE POS.LOADER, LDR.INDEX AND POS.HARVESTER AS AN INTEGER, 2-DIM ARRAY
       DEFINE IFULL, WK.TK, ICYCLE AND IEMPTY AS AN INTEGER, 2-DIM ARRAY
       DEFINE MILL.TIME, TRAV.EMP, BEGIN.LOADER AND LOADWT AS A REAL, 2-DIM ARRAY
       DEFINE FULL, SCHED.HOURS, CYCLE AND EMPTY AS A REAL, 2-DIM ARRAY
       DEFINE BEGIN.T.LOADER AND LOAD.TIME AS A REAL, 2-DIM ARRAY
       DEFINE TRAV.FULL AND NTRUCK.LOADER AS A REAL, 3-DIM ARRAY
   END


   MAIN
       DEFINE I AND K AS AN INTEGER VARIABLE
       LET .IN = 1
       LET .OUT = 2
       RESERVE SEEDS AS 10
       LET SEEDS(1) = 2116429302
       LET SEEDS(2) = 683743814
       LET SEEDS(3) = 964393174
       LET SEEDS(4) = 1217426631
       LET SEEDS(5) = 618433579
       LET SEEDS(6) = 1157240309
       LET SEEDS(7) = 15726055
       LET SEEDS(8) = 43108509
       LET SEEDS(9) = 1797920909
       LET SEEDS(10) = 477424540
       CALL INPUT
       CREATE EVERY WB(2)
       LET U.WB(.IN) = 1
       LET U.WB(.OUT) = 1
       CREATE EVERY ATTENDENT(1)
       LET U.ATTENDENT(1) = 1
       ACTIVATE A CLOSE.WB NOW
       START SIMULATION
   END


   SUBROUTINE SCHEDULER GIVEN ITRUCK AND ILOADER
       DEFINE FOR, ILOADER, BLK AND ITRUCK AS INTEGER VARIABLES
       DEFINE DES.DUE AS AN ALPHA VARIABLE
       LET FOR = POS.LOADER(ILOADER,1)
       LET BLK = POS.LOADER(ILOADER,2)
       LET MEAN = TRAV.FULL(FOR,BLK,1) * TRAV.EMP(FOR,BLK)
       IF (TIME.V+((MEAN-(SHIFT*MEAN))/1440.)) GT (DUE.L.FINISH(ILOADER) -
            (LOAD.TIME(ILOADER,1) * LOAD.SHIFT * N.G.LOADER(ILOADER) / 1440.0))
         LET DES.DUE = "LAND"
         CALL HOME.TRUCK GIVING 1, ITRUCK, ILOADER AND DES.DUE
       ELSE
```

```
          LET MEAN = TRAV.FULL(FOR,BLK,1) - TRAV.FULL(FOR,BLK,3)
          LET TRAV = LOG.NORMAL.F(MEAN,TRAV.FULL(FOR,BLK,2),STREAM)
          LET TRAV = TRAV + TRAV.FULL(FOR,BLK,3)
          LET EMP = TRAV.EMP(FOR,BLK) * TRAV
          IF (TIME.V+(EMP/1440.)) GT (DUE.L.FINISH(ILOADER) + 0.0104 -
            (LOAD.TIME(ILOADER,1) * LOAD.SHIFT * N.G.LOADER(ILOADER) / 1440.0))
            LET DES.DUE = ¤LAND¤
            CALL HOME.TRUCK GIVING 2, ITRUCK, ILOADER AND DES.DUE
          ELSE
            LET TIME = (EMP + 25. + TRAV.FULL(FOR,BLK,1)) / 60.
            IF (((TIME.V - START.TRUCK(ITRUCK)) * 24.) + TIME) IS GT WORK.TRUCK
              LET DES.DUE = ¤LAND¤
              CALL HOME.TRUCK GIVING 3, ITRUCK, ILOADER AND DES.DUE
            ELSE
              ACTIVATE A LAND.ARRIVAL GIVING ITRUCK AND ILOADER IN EMP MINUTES
              ADD EMP TO TRAV.TIME(ITRUCK)
            ALWAYS
          ALWAYS
        ALWAYS
        RETURN
    END


    SUBROUTINE INPUT
        DEFINE I AND J AS AN INTEGER VARIABLE
        READ STREAM
        LET SEED.V(STREAM) = SEEDS(STREAM)
        SKIP 2 CARDS
        READ I, DAYS.OF.HAULAGE
        LET ENDSIM = REAL.F(I)
        SKIP 2 CARDS
        READ N.LOADER, N.HARV, N.FOREST, NO.OF.TRUCKS
        LET NO.OF.LOADERS = N.LOADER
        RESERVE LOADS.AREA, T.LOADS.AREA, WE.HOURS AND TONS.AREA AS 2
        RESERVE NTRUCK.TYPE AS 3
        RESERVE ALLOW.FOREST AS N.FOREST
        RESERVE IDENT.HARV, TOTAL.H.LOADS, TRUE.LOADS AND PRIORITY AS N.HARV
        RESERVE TIME.IN,BEGIN.WE.IN,BEGIN.WE.OUT AND TIME.OUT AS NO.OF.TRUCKS
        RESERVE OVERNIGHT AS NO.OF.TRUCKS
        RESERVE SCHED.HOURS AS N.LOADER BY 2
        RESERVE POS.LOADER AND LOAD.TIME AS N.LOADER BY 3
        RESERVE LDR.INDEX AS N.LOADER+1 BY N.LOADER
        RESERVE LOAD.WT AND MILL.TIME AS 3 BY 3
        RESERVE POS.HARVESTER AS N.HARV BY 2
        RESERVE ALLOW.LOADER AS N.LOADER BY N.HARV
        RESERVE BEGIN.LOADER, CYCLE, ICYCLE, TRAV.EMP, FULL, EMPTY, IFULL,
                        IEMPTY AND BEGIN.T.LOADER AS N.FOREST BY 5
        RESERVE NTRUCK.LOADER AS 2 BY N.LOADER BY N.FOREST
        RESERVE TRAV.FULL AS N.FOREST BY 5 BY 3
        RESERVE WEEKLY.POS AS DAYS.OF.HAULAGE BY 3 BY N.LOADER
        RESERVE WK.TK AND WEEKLY.HOURS AS DAYS.OF.HAULAGE BY N.LOADER
        CREATE EVERY LOADER(N.LOADER)
        FOR I = 1 TO N.LOADER, DO
        LET U.LOADER(I) = 1
        LOOP
        CREATE EVERY FOREST(N.FOREST)
        SKIP 2 CARDS
        FOR I = 1 TO 3, DO
        READ MILL.TIME(I,1) , MILL.TIME(I,2) , MILL.TIME(I,3)
        LOOP
```

```
          SKIP 2 CARDS
          FOR I = 1 TO N.FOREST, DO
          READ NAME(I) AS T *
          READ STATE(I)
          READ BEGIN.LOADER(I,1), BEGIN.LOADER(I,2), BEGIN.LOADER(I,3),
          BEGIN.LOADER(I,4), BEGIN.LOADER(I,5)
          READ BEGIN.T.LOADER(I,1), BEGIN.T.LOADER(I,2), BEGIN.T.LOADER(I,3),
          BEGIN.T.LOADER(I,4), BEGIN.T.LOADER(I,5)
          FOR J = 1 TO 5, DO
          READ TRAV.FULL(I,J,1) , TRAV.FULL(I,J,2) , TRAV.FULL(I,J,3)
          LOOP
          READ TRAV.EMP(I,1), TRAV.EMP(I,2), TRAV.EMP(I,3), TRAV.EMP(I,4),
          TRAV.EMP(I,5)
          LOOP
          READ FULL.SHIFT
          SKIP 2 CARDS
          FOR I = 1 TO 3, DO
          READ LOADWT(I,1) , LOADWT(I,2) , LOADWT(I,3)
          LOOP
          READ LDWT.LIMIT
          SKIP 2 CARDS
          FOR I = 1 TO N.LOADER, DO
          READ LOAD.TIME(I,1) , LOAD.TIME(I,2) , LOAD.TIME(I,3)
          LOOP
          READ LOAD.SHIFT
          SKIP 2 CARDS
          READ I
          LET INTERVAL = I / 1440.0
          SKIP 2 CARDS
          READ SHIFT
          SKIP 2 CARDS
          READ WB.HOURS(1) , WB.HOURS(2)
          SKIP 2 CARDS
          READ NIGHT.TIME
          LET NIGHT.TIME = NIGHT.TIME / 24.
          SKIP 2 CARDS
          FOR I = 1 TO N.LOADER, DO
          READ POS.LOADER(I,1), POS.LOADER(I,2), POS.LOADER(I,3), NLAND(I)
          ADD NLAND(I) TO N.TRUCK
          LOOP
          LET NOLAND = N.TRUCK
          READ LFIXED, LVARCOST, LWAGES
          READ TFIXED, TVARCOST, TWAGES
          READ WORK.HRS, WORK.TRUCK
          CALL CREAT.TRUCKS
          RETURN
      END


      SUBROUTINE LDR.NIGHT
          DEFINE I AND JJ AS AN INTEGER VARIABLE
          FOR I = 1 TO NO.OF.LOADERS, DO
          LET HOURS = (FINISH.LOADER(I) - START.LOADER(I)) * 24.0
          ADD HOURS TO P.L.TIME(I)
          ADD HOURS TO D.L.TIME(I)
          LET WORK = LDR.WORK(I) / 60.0
          IF WORK IS GT (HOURS + 0.1)
             PRINT 1 LINE WITH HOURS, WORK AND I AS FOLLOWS
               FOR ***.* HOURS, WORK TIME OF ***.* FOR LOADER *
          ALWAYS
```

```
          LET IDLE = ABS.F(HOURS - WORK)
          ADD WORK TO D.L.WORK(I)
          ADD WORK TO P.L.WORK(I)
          ADD IDLE TO D.L.IDLE(I)
          ADD IDLE TO P.L.IDLE(I)
          ADD 1 TO P.DAY.L.WORK(I)
          ADD 1 TO D.DAY.L.WORK(I)
          CALL COST GIVING LFIXED, LWAGES, HOURS, WORK, LVARCOST YIELDING TOTPAY
          ADD TOTPAY TO PAY.L.WORK(I)
          LOOP
          RETURN
      END


      SUBROUTINE COST GIVEN TOTFIX,WAGES,TIMWRK,OPTIME,VARCOST YIELDING TOTPAY
          LET TOTPAY = 0.
          CALL PAY GIVEN WAGES, TIMWRK YIELDING TOTPAY
          LET TOTPAY = TOTPAY + TOTFIX + (OPTIME * VARCOST)
          RETURN
          END


      SUBROUTINE PAY GIVEN WAGES, TIMWRK YIELDING TOTPAY
          LET TIME1 = 0.
          LET TOTPAY = WAGES * 8.0
          IF TIMWRK IS LE 8.0
            LET TOTPAY = TOTPAY * 1.15
            RETURN
          ELSE
          IF TIMWRK IS LE 10.0
            LET TIME1 = TIMWRK - 8.0
            LET TOTPAY = TOTPAY + (TIME1 * WAGES * 1.5)
          ELSE
            IF TIMWRK IS LE 18.0
              LET TIME1 = TIMWRK - 10.0
              LET TOTPAY = TOTPAY + (TIME1 * WAGES * 2.0) + (2.0 * WAGES * 1.5)
            ELSE
              PRINT 1 LINE WITH TIMWRK AS FOLLOWS
                  A TIME OF ***.* HOURS IS NOT POSSIBLE
            ALWAYS
          ALWAYS
          LET TOTPAY = 1.15 * TOTPAY
          RETURN
          END


      SUBROUTINE DAY.CLEAR
          DEFINE I AND J AS INTEGER VARIABLES
          LET NOMILL = 0
          LET NOLAND = 0
          LET D.LOADS = 0
          LET D.TONS = 0.
          LET D.TRK.TIME = 0.
          FOR I = 1 TO N.LOADER, DO
          LET D.L.TIME(I) = 0.
          LET D.L.WORK(I) = 0.
          LET D.L.IDLE(I) = 0.
          LET D.T.TIME(I) = 0.
          LET D.T.WORK(I) = 0.
          LET D.T.IDLE(I) = 0.
```

```
      LET LDR.WORK(I) = 0.
      LET D.L.TONS(I) = 0.
      LET D.L.LOADS(I) = 0
      LET D.DAY.L.WORK(I) = 0
      LOOP
      FOR I = 1 TO N.TRUCK, DO
      LET TRAV.TIME(I) = 0.
      LOOP
      RETURN
  END


  PROCESS MORNING
      DEFINE I, JJ, FOR, BLK, ILOADER, IST, IFIN AND K AS INTEGER VARIABLES
      ACTIVATE A CLOSE.WB AT NIGHT.TIME
      IF WEEKDAY.F(TIME.V) IS GE 2 AND WEEKDAY.F(TIME.V) LE (DAYS.OF.HAULAGE+1)
         CALL LDR.NIGHT
      ALWAYS
      IF TIME.V GE (ENDSIM-0.5)
         CALL REPORT
         STOP
      ELSE
      IF WEEKDAY.F(TIME.V) IS LT (DAYS.OF.HAULAGE+1)
         IF NOMILL+NOLAND NE N.TRUCK
            PRINT 1 LINE WITH TIME.V AND NOMILL+NOLAND AS FOLLOWS
         AT TIME ***.****, ONLY *** TRUCKS RETURNED HOME
            STOP
         ELSE
         ADD 1 TO T.DAYS.HAULAGE
         ADD 1 TO P.DAYS.HAULAGE
         CALL DAY.CLEAR
         LET IST = 1
         LET IFIN = NLAND(1)
         FOR ILOADER = 1 TO NO.OF.LOADERS, DO
         LET FOR = POS.LOADER(ILOADER,1)
         LET BLK = POS.LOADER(ILOADER,2)
         LET TIME = TRUNC.F(TIME.V) + (BEGIN.LOADER(FOR,BLK) / 24.0)
         ACTIVATE AN OPEN.LOADER GIVING ILOADER AND TIME NOW
         LET START.LOADER(ILOADER) = TIME
         LET PERIOD.WORK(ILOADER) = 0.
         LET STOP.PERIOD(ILOADER) = TIME
         LET DUE.L.FINISH(ILOADER) = TIME + (WORK.HRS / 24.0)
         LET TIME = TRUNC.F(TIME.V) + (BEGIN.T.LOADER(FOR,BLK) / 24.0)
         FOR I = IST TO IFIN, DO
         IF STATUS.TRUCK(I) EQ ¤FIN¤
            IF DEST.TRUCK(I) EQ ¤LAND¤
               LET START.TRUCK(I) = TIME
               ACTIVATE A START.UP GIVING I AND ILOADER AT TIME
               ADD INTERVAL TO TIME
            ELSE
               LET TIME1 = TRUNC.F(TIME.V) + 0.3125
               ACTIVATE A WB.ARRIVAL GIVING I, ILOADER AND .IN AT TIME1
               LET START.TRUCK(I) = TIME1
            ALWAYS
            LET DEST.TRUCK(I) = ¤LAND¤
         ALWAYS
         LET STATUS.TRUCK(I) = ¤NOTFIN¤
         LOOP
         LET IST = NLAND(ILOADER) + IST
         LET IFIN = NLAND(ILOADER+1) + IFIN
```

```
          LOOP
        ALWAYS
    END


    PROCESS START.UP
        DEFINE ILOADER AND ITRUCK AS INTEGER VARIABLES
        LET ITRUCK = CTRUCK
        LET ILOADER = DLOADER
        CALL SCHEDULER GIVING ITRUCK AND ILOADER
    END


    PROCESS OPEN.LOADER
        DEFINE I AND ILOADER AS INTEGER VARIABLES
        LET ILOADER = CLOADER
        LET TIME = ATIME
        LET TIME = (TIME - TIME.V) * 1440.
        REQUEST 1 LOADER(ILOADER)
        WAIT TIME MINUTES
        RELINQUISH 1 LOADER(ILOADER)
    END


     SUBROUTINE CREAT.TRUCKS
        DEFINE I AS AN INTEGER VARIABLE
        CREATE EVERY TRUCK(N.TRUCK)
        ADD N.TRUCK TO P.NTKS
        FOR I = 1 TO N.TRUCK, DO
        LET STATUS.TRUCK(I) = ¤FIN¤
        LET DEST.TRUCK(I) = ¤LAND¤
        LET TYPE(I) = 2
        LOOP
        RETURN
    END


    PROCESS LAND.ARRIVAL
        DEFINE ITRUCK, HARV, FOR, BLK AND ILOADER AS INTEGER VARIABLES
        DEFINE DES.DUE AS AN ALPHA VARIABLE
        LET ITRUCK = ATRUCK
        LET ILOADER = ALOADER
        LET ARR.LAND(ITRUCK) = TIME.V
        REQUEST 1 LOADER(ILOADER)
        LET FOR = POS.LOADER(ILOADER,1)
        LET BLK = POS.LOADER(ILOADER,2)
        LET TRAV = TRAV.FULL(FOR,BLK,1)
        LET LDTM = LOAD.TIME(ILOADER,1)
        IF (TIME.V + ((TRAV + LDTM) / 1440.)) LE NIGHT.TIME
          LET WAIT.LOADER(ILOADER) = (TIME.V - ARR.LAND(ITRUCK)) * 1440.
  'AGAIN' LET TIME.TO.LOAD = NORMAL.F((LOAD.TIME(ILOADER,1) * LOAD.SHIFT),
                                     LOAD.TIME(ILOADER,2), STREAM)
          IF TIME.TO.LOAD IS LT LOAD.TIME(ILOADER,3)
            GO TO AGAIN
          ELSE
          ADD TIME.TO.LOAD TO LDR.WORK(ILOADER)
          WORK TIME.TO.LOAD MINUTES
          ADD TIME.TO.LOAD TO PERIOD.WORK(ILOADER)
          IF ((TIME.V - STOP.PERIOD(ILOADER)) * 24.) IS GE 5.0
            LET TIME = ((TIME.V-STOP.PERIOD(ILOADER))*1440.)-PERIOD.WORK(ILOADER)
```

```
        IF TIME IS LT 20.0
           WAIT (20.0 - TIME) MINUTES
        ALWAYS
        LET PERIOD.WORK(ILOADER) = 0.
        LET STOP.PERIOD(ILOADER) = TIME.V
     ALWAYS
     RELINQUISH 1 LOADER(ILOADER)
'LOOP' IF TYPE(ITRUCK) EQ 1
        LET LDWT(ITRUCK) = NORMAL.F(LOADWT(1,1),LOADWT(1,2),STREAM)
     ELSE
        LET MEAN = LOADWT(TYPE(ITRUCK),1) - LOADWT(TYPE(ITRUCK),3)
        LET WT = LOG.NORMAL.F(MEAN,LOADWT(TYPE(ITRUCK),2),STREAM)
        LET LDWT(ITRUCK) = WT + LOADWT(TYPE(ITRUCK),3)
     ALWAYS
     IF LDWT(ITRUCK) IS GT LDWT.LIMIT
        GO TO LOOP
     ELSE
     LET FOR = POS.LOADER(ILOADER,1)
     LET BLK = POS.LOADER(ILOADER,2)
     LET HARV = POS.LOADER(ILOADER,3)
     LET MEAN = (TRAV.FULL(FOR,BLK,1) - TRAV.FULL(FOR,BLK,3)) * FULL.SHIFT
     LET TRAV = LOG.NORMAL.F(MEAN,TRAV.FULL(FOR,BLK,2),STREAM)
     LET TRAV = TRAV + (TRAV.FULL(FOR,BLK,3) * FULL.SHIFT)
     LET ORIGIN(ITRUCK) = STATE(FOR)
     ADD 1 TO TOTAL.H.LOADS(HARV)
     IF (FRAC.F(TIME.V) + (TRAV / 1440.)) IS GT 0.9700
        LET DES.DUE = "MILL"
        CALL HOME.TRUCK GIVING 4, ITRUCK, ILOADER AND DES.DUE
     ELSE
        ACTIVATE A WB.ARRIVAL GIVING ITRUCK,ILOADER AND .IN IN TRAV MINUTES
        ADD TRAV TO TRAV.TIME(ITRUCK)
     ALWAYS
     LET FINISH.LOADER(ILOADER) = TIME.V
   ELSE
     RELINQUISH 1 LOADER(ILOADER)
     LET DES.DUE = "LAND"
     CALL HOME.TRUCK GIVEN 5, ITRUCK, ILOADER AND DES.DUE
   ALWAYS
END


PROCESS CLOSE.WB
   LET RESULT = NORMAL.F(WB.HOURS(1),WB.HOURS(2),STREAM)
   IF RESULT GT 7.5
      LET RESULT = 7.5
   ALWAYS
   IF TIME.V LT 0.5
     ACTIVATE A MORNING IN 15 MINUTES
     REQUEST 1 WB(.IN)
     WAIT RESULT HOURS
     RELINQUISH 1 WB(.IN)
   ELSE
     ADD 1.0 TO NIGHT.TIME
     LET TIME = TRUNC.F(TIME.V) + 1.0104
     ACTIVATE A MORNING AT TIME
     IF WEEKDAY.F(TIME.V) IS LE (DAYS.OF.HAULAGE+1)
        LET DIFF = (24.0 - (FRAC.F(TIME.V) * 24.0))
        LET RESULT = RESULT + DIFF
        REQUEST 1 WB(.IN)
        WAIT RESULT HOURS
```

```
            RELINQUISH 1 WB(.IN)
          ALWAYS
        ALWAYS
END


PROCESS WB.ARRIVAL
     DEFINE ILOADER, FOR, BLK, DEST AND ITRUCK AS INTEGER VARIABLES
     DEFINE DES.DUE AS AN ALPHA VARIABLE
     LET DEST = DESTINATION
     LET ITRUCK = BTRUCK
     LET ILOADER = BLOADER
     IF DEST EQ .IN
        IF TIME.V GT NIGHT.TIME OR FRAC.F(TIME.V) LT 0.1250
           LET DES.DUE = "MILL"
           CALL HOME.TRUCK GIVEN 6, ITRUCK, ILOADER AND DES.DUE
        ELSE
         IF WEEKDAY.F(TIME.V) GE (DAYS.OF.HAULAGE+1),
            LET DES.DUE = "MILL"
            CALL HOME.TRUCK GIVEN 7, ITRUCK, ILOADER AND DES.DUE
          ELSE
            LET TIME.IN(ITRUCK) = TIME.V
            REQUEST 1 WB(DEST)
            LET WAIT.TIME(DEST) = (TIME.V-TIME.IN(ITRUCK))*1440.
            LET BEGIN.WB.IN(ITRUCK) = TIME.V
            REQUEST 1 ATTENDENT(1)
            WORK 0.25 MINUTES
            RELINQUISH 1 ATTENDENT(1)
            RELINQUISH 1 WB(DEST)
            LET UT.WB.IN = UT.WB.IN + (TIME.V - BEGIN.WB.IN(ITRUCK)) * 1440.
            LET MEAN = MILL.TIME(TYPE(ITRUCK),1) - MILL.TIME(TYPE(ITRUCK),3)
            LET TIME = LOG.NORMAL.F(MEAN,MILL.TIME(TYPE(ITRUCK),2),STREAM)
            LET TIME = TIME + MILL.TIME(TYPE(ITRUCK),3)
            CALL WB.STATS GIVING ILOADER AND ITRUCK
            ACTIVATE A WB.ARRIVAL GIVING ITRUCK, ILOADER AND .OUT IN TIME MINUTES
         ALWAYS
        ALWAYS
      ELSE
        LET TIME.OUT(ITRUCK) = TIME.V
        REQUEST 1 WB(DEST)
        LET WAIT.TIME(DEST) = (TIME.V-TIME.OUT(ITRUCK))*1440.
        LET BEGIN.WB.OUT(ITRUCK) = TIME.V
        REQUEST 1 ATTENDENT(1)
        WORK 0.25 MINUTES
        RELINQUISH 1 ATTENDENT(1)
        RELINQUISH 1 WB(DEST)
        LET UT.WB.OUT = UT.WB.OUT + (TIME.V - BEGIN.WB.OUT(ITRUCK)) * 1440.
        CALL SCHEDULER GIVING ITRUCK AND ILOADER
      ALWAYS
END


SUBROUTINE WB.STATS GIVEN ILOADER AND ITRUCK
     DEFINE ITRUCK AND ILOADER AS INTEGER VARIABLES
     ADD 1 TO D.LOADS
     ADD 1 TO P.LOADS
     ADD 1 TO T.LOADS
     ADD LDWT(ITRUCK) TO D.TONS
     ADD LDWT(ITRUCK) TO P.TONS
     ADD LDWT(ITRUCK) TO T.TONS
```

```
          ADD LDWT(ITRUCK) TO D.L.TONS(ILOADER)
          ADD LDWT(ITRUCK) TO P.L.TONS(ILOADER)
          ADD LDWT(ITRUCK) TO T.L.TONS(ILOADER)
          ADD 1 TO HARV.LOADS
          ADD 1 TO LOADS.AREA(ORIGIN(ITRUCK))
          ADD 1 TO T.LOADS.AREA(ORIGIN(ITRUCK))
          ADD LDWT(ITRUCK) TO TONS.AREA(ORIGIN(ITRUCK))
          ADD LDWT(ITRUCK) TO T.TONS.AREA(ORIGIN(ITRUCK))
          ADD LDWT(ITRUCK) TO MILL.STOCKPILE
          ADD 1 TO D.L.LOADS(ILOADER)
          ADD 1 TO P.L.LOADS(ILOADER)
          ADD 1 TO T.L.LOADS(ILOADER)
          RETURN
      END


      SUBROUTINE HOME.TRUCK GIVEN CHECKPOINT, ITRUCK, ILOADER AND DESTIN
          DEFINE ITRUCK, CHECKPOINT AND ILOADER AS INTEGER VARIABLES
          DEFINE DESTIN AS AN ALPHA VARIABLE
          LET FINISH.TRUCK(ITRUCK) = TIME.V
          LET STATUS.TRUCK(ITRUCK) = ¤FIN¤
          LET DEST.TRUCK(ITRUCK) = DESTIN
          LET TIME = (FINISH.TRUCK(ITRUCK) - START.TRUCK(ITRUCK)) * 24.0
          IF TIME GE 0.0
             ADD TIME TO D.T.TIME(ILOADER)
             ADD TIME TO P.T.TIME(ILOADER)
             LET WORK = TRAV.TIME(ITRUCK) / 60.0
             IF WORK IS GT (TIME + 0.1)
                PRINT 2 LINES WITH TIME.V, TIME, WORK, ITRUCK ,
                  START.TRUCK(ITRUCK), FINISH.TRUCK(ITRUCK) AND CHECKPOINT AS FOLLOWS
        AT TIME **.***, FOR TOTAL TIME ***.*, A WORK TIME OF ***.* FOR TRUCK **
       START = ***.****           FINISH = ***.****        CHECK POINT = **
             ALWAYS
             LET IDLE = TIME - WORK
             IF IDLE LT 0.0
                IDLE = 0.
             ALWAYS
             ADD WORK TO D.T.WORK(ILOADER)
             ADD WORK TO P.T.WORK(ILOADER)
             ADD IDLE TO D.T.IDLE(ILOADER)
             ADD IDLE TO P.T.IDLE(ILOADER)
             ADD TIME TO D.TRK.TIME
             ADD TIME TO P.TRK.TIME
             ADD TIME TO T.TRK.TIME
             ADD 1 TO P.NTKS
             ADD 1 TO T.NTKS
             CALL COST GIVING TFIXED, TWAGES, TIME, WORK, TVARCOST YIELDING TOTPAY
             ADD TOTPAY TO PAY.T.WORK(ILOADER)
          ALWAYS
          IF DESTIN EQ ¤MILL¤
             ADD 1 TO NOMILL
             IF NOMILL GT NO.OF.TRUCKS,
                PRINT 1 LINE AS FOLLOWS
               FAULT       NOT ENOUGH ROOM IN ARRAY OVERNIGHT
                STOP
             ELSE
          ELSE
             ADD 1 TO NOLAND
          ALWAYS
          RETURN
```

```
         END


          SUBROUTINE REPORT
               DEFINE I AND J AS INTEGER VARIABLES
               USE UNIT 10 FOR OUTPUT
               FOR I = 1 TO N.LOADER, DO
               LET LOADS = T.L.LOADS(I) / P.DAY.L.WORK(I)
               LET TONS = T.L.TONS(I) / P.DAY.L.WORK(I)
               LET LHRS = P.L.TIME(I) / P.DAY.L.WORK(I)
               LET THRS = P.T.TIME(I) / P.DAY.L.WORK(I) / NLAND(I)
               LET LWORK = P.L.WORK(I) / P.DAY.L.WORK(I)
               LET TWORK = P.T.WORK(I) / P.DAY.L.WORK(I) / NLAND(I)
               LET LIDL = P.L.IDLE(I) / P.DAY.L.WORK(I)
               LET TIDL = P.T.IDLE(I) / P.DAY.L.WORK(I) / NLAND(I)
               LET LCOST = PAY.L.WORK(I) / P.DAY.L.WORK(I)
               LET TCOST = PAY.T.WORK(I) / P.DAY.L.WORK(I)
               LET TOTCOST = LCOST + TCOST
               LET COST.PER.TONNE = (PAY.L.WORK(I) + PAY.T.WORK(I)) / T.L.TONS(I)
               PRINT 1 LINE WITH WORK.HRS, NLAND(I), LOADS, TONS, LHRS, LWORK, LIDL,
                THRS, TWORK, TIDL, LCOST, TCOST, TOTCOST AND COST.PER.TONNE AS FOLLOWS
         **. ** **.* ****.* **.* **.* **.* **.* **.* **.* ***.** *****.** *****.** **.**
               LOOP
               USE UNIT 6 FOR OUTPUT
               RETURN
          END
```

@RESUME,M

APPENDIX 6.2

Example of a data deck used in experiments

```
NRA652*LOADSIM(6).DATA1(35)
5
NO. OF DAYS, HAULAGE DAYS PER WEEK
28 5
NO. OF LOADERS(MAX), NO. OF HARVESTERS, NO. OF FORESTS, NO. OF TRUCKS(MAX)
4 13 9 80
THE MEAN,STD DEV,MIN AND MAX OF THE TIME TRUCKS SPEND IN THE MILL(REAL, MINS)
14.66 3.24 3.66
13.12 2.67 7.09
12.69 2.64 7.21
TRAVEL TIMES FULL FOR FOREST AND BLOCK, MEAN, STD AND SHIFT
¤BATLOW¤
1
5.5 5.25 0. 0. 0.
3.1 2.75 0. 0. 0.
149.42 27.13 118.2
170.98 29.98 117.2
0. 0. 0.
0. 0. 0.
0. 0. 0.
0.92 0.86 0. 0. 0.
¤GREEN HILLS¤
1
5.5 5.25 5.25 5.25 5.25
2.75 2.9 2.9 3.1 3.4
164.22 24.68 125.97
160.56 22.33 125.95
160.23 25.33 121.76
144.62 23.95 115.56
131.02 16.6 97.22
0.82 0.85 0.89 0.86 0.83
¤CARABOST¤
1
5.5 5.75 5.5 0. 0.
4.0 4.25 4.0 0. 0.
99.26 12.11 70.18
98.79 12.16 64.05
107.45 14.45 81.53
0. 0. 0.
0. 0. 0.
0.38 0.9 0.84 0. 0.
¤SHELLEY¤
2
5.75 0. 0. 0. 0.
4.4 0. 0. 0. 0.
97.47 11.43 71.26
0. 0. 0.
0. 0. 0.
0. 0. 0.
0. 0. 0.
0.86 0. 0. 0. 0.
¤MYRTLEFORD¤
2
5.5 6. 0. 0. 0.
3.8 4.3 0. 0. 0.
109.42 19.86 80.96
126.68 42.53 82.51
0. 0. 0.
0. 0. 0.
0. 0. 0.
```

```
0.93 0.78 0. 0. 0.
¤BEECHWORTH¤
2
6. 0. 0. 0. 0.
4.6 0. 0. 0. 0.
97.59 39.78 72.85
0. 0. 0.
0. 0. 0.
0. 0. 0.
0. 0. 0.
0.83 0. 0. 0. 0.
¤BRIGHT¤
2
6. 0. 0. 0. 0.
4.4 0. 0. 0. 0.
107.45 14.45 81.53
0. 0. 0.
0. 0. 0.
0. 0. 0.
0. 0. 0.
0.64 0. 0. 0. 0.
¤MANNUS¤
1
5.2 0. 0. 0. 0.
3.5 0. 0. 0. 0.
119.12 13.69 85.44
0. 0. 0.
0. 0. 0.
0. 0. 0.
0. 0. 0.
0.65 0. 0. 0. 0.
¤BONDO¤
1
4.0 0. 0. 0. 0.
0.75 0. 0. 0. 0.
225.0 25.0 180.0
0. 0. 0.
0. 0. 0.
0. 0. 0.
0. 0. 0.
0.67 0. 0. 0. 0.
1.0
THE MEAN,STD. DEV.,MIN AND MAX OF THE LOADWEIGHT OF A TRUCK (REAL)
24.0 1.83 0.0
23.70 1.98 12.91
23.63 1.77 10.05
30.0
PARAMETERS FOR THE TIME TO LOAD A TRUCK
24.0 4.8 15.0
24.0 4.8 15.0
24.0 4.8 15.0
24.0 4.8 15.0
1.0
READ INTERVAL TIME BETWEEN TRUCKS ON LANDING
20
SHIFT FOR SCHEDULER
0.15
HOUR OF THE DAY THAT THE WEIGHBRIDGE WILL OPEN UP
7.449 0.095
NIGHT TIME
```

```
23.5
POSITION OF LOADER AND NO. OF TRUCKS TO LOADER
5 1 1 3
5 1 2 4
5 1 3 17
5 1 4 18
178.70 11.97 8.0
173.13 25.11 8.0

@RESUME,M
```

APPENDIX 6.3

Determination of sample size for simulation runs:

$$n = \frac{(\sigma Z_{\alpha/2})^2}{d^2}$$

where

n = required sample size

4σ = range of feasible outputs

$Z_{\alpha/2}$ = two tailed standardized normal statistic for the required probability

d = difference between the estimate and true means allowed

Sample simulation runs were conducted for some of the forest blocks. The range of the number of loads delivered for the blocks was in many cases 3 to 4. The following values were used to calculate the sample size:

$4\sigma = 4, \therefore \sigma = 1$

$Z_{\alpha/2} = 1.96$ (95% probability level)

$d = 0.5$

Therefore,

$$n = \frac{(1(1.96))^2}{0.5^2}$$

$$= 15.4$$

Using the 99% probability level, $n = 26.7$

Therefore, the simulation model would be run for twenty days.

APPENDIX 7.1

Depreciation Costs for Trucks

Assume service life of 7 000 hours

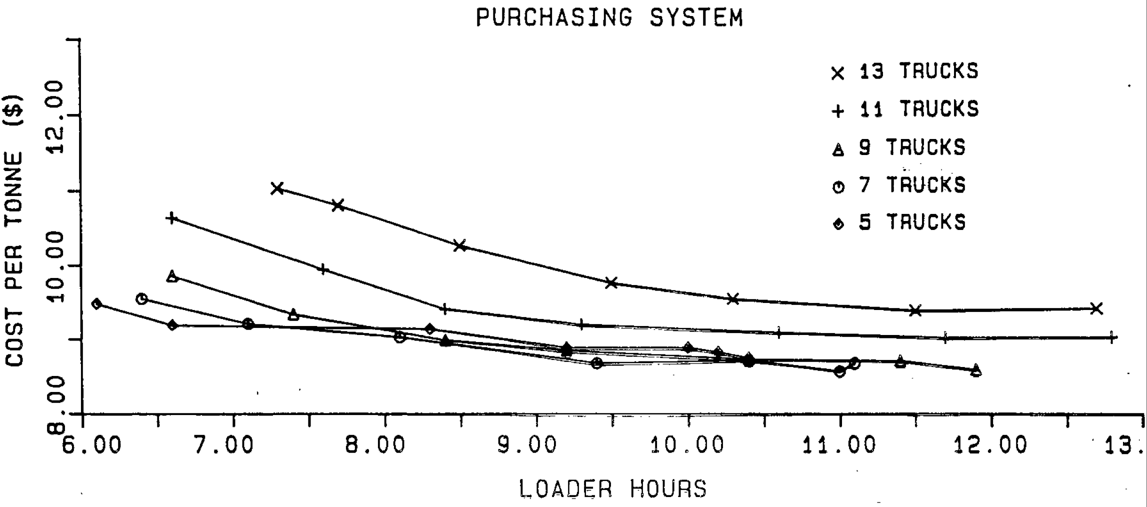
Depreciation charge = (110 000 - 27 500)/7 000 = \$11.79 per hour

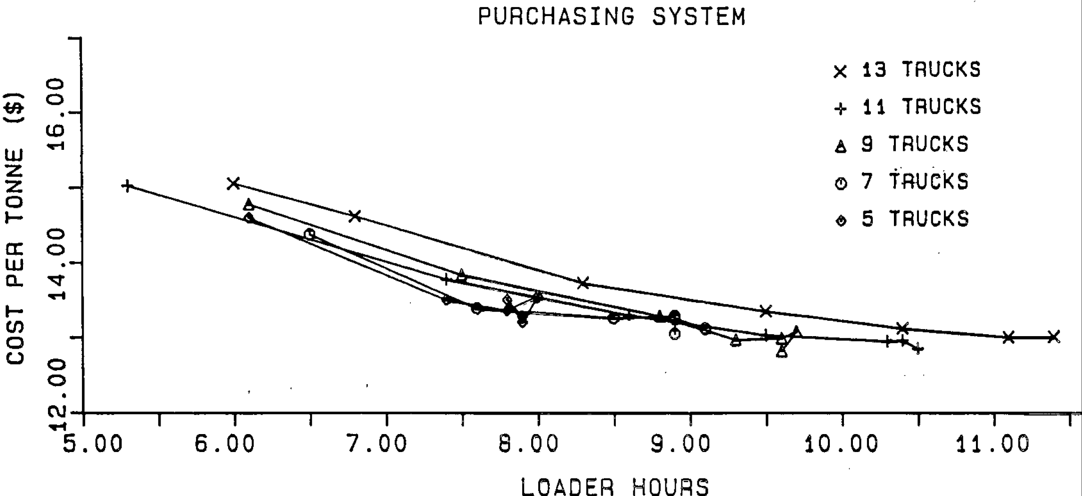
Interest

Assume 16%

Average invested capital	=	(\$68 750 + \$ 4 400)
Charges	=	\$11 704 per year
	=	\$48.77 per year

$\therefore$ Total fixed costs = \$92.54 per day.


PURCHASING SYSTEM
COST PER TONNE ($)
8.00
10.00
12.00
6.00
7.00
8.00
9.00
10.00
11.00
12.00
13.
LOADER HOURS
13 TRUCKS
11 TRUCKS
9 TRUCKS
7 TRUCKS
5 TRUCKS


PURCHASING SYSTEM
COST PER TONNE ($)
12.00
14.00
16.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
LOADER HOURS
13 TRUCKS
11 TRUCKS
9 TRUCKS
7 TRUCKS
5 TRUCKS