THE EFFECT OF ROAD GRADIENT AND LOAD ON THE SPEED OF LOG TRUCKS

by

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Thesis submitted in partial fulfilment of the
requirements for the degree of
Master of Science (Forestry)
in the Australian National University

September 1976

ORIGINALITY OF THESIS

Except where specific acknowledgement is given, this thesis is my original work.

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ABSTRACT

The speed of log trucks over selected sections of various roads was measured and the loads carried in hauling wood from the plantations in the Australian Capital Territory obtained from weighbridge dockets. Two models were derived to predict the sustained speed of log trucks, and the speed after traversing one hundred and fifty metres of an adverse grade, with respect to road gradient, truck power and gross weight.

The significance of the maximum permitted loads on log trucks is examined in relation to the costs of hauling wood in the Australian Capital Territory and the derived models are applied to determine optimum ruling grades for forest roads.

ACKNOWLEDGEMENTS

I am very pleased to have undertaken a year of postgraduate research at the Department of Forestry at the Australian National University and to again participate in some of the discussions in that Department and in extracurricular activities at the University. I must acknowledge long,stimulating and helpful discussions on data processing, statistics and data analysis with other postgraduate students, in particular Mr. Jerry Leech and Mr. Gary Archer.

A number of organizations made the study feasible. The Forestry Commission of New South Wales agreed to my request for leave of absence. The Forests Branch of the Department of the Capital Territory, Canberra, employed me for a short period while I worked on the project, provided field assistance for the survey work and for some of the data collection, made available their weighbridge dockets for the extraction of information, and officers of the Branch gave formal introductions to many of the log truck operators. The National Capital Development Commission provided instruction on the use of their radar meter and loaned it for several months while data was collected.

My supervisor, Don Stodart, encouraged me to undertake the full time study, assisted in gaining the support and help of the Government Departments and provided advice on the study proposals and comments, sometimes detailed, on the draft text.

Ms Norma Chin typed the manuscript.

My wife Chris also encouraged me to undertake the study in Canberra.

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CHAPTER ONE

INTRODUCTION

1.1 THE IMPORTANCE OF FOREST ROADING

Forest roading affects all uses and users of forests, and expenditure on roading forms a significant part of overall expenditure by Australian Forest Services. Table 1.1 indicates, for example, the magnitude of the expenditure on roading by the Forestry Commission of New South Wales. The expenditures do not include professional salaries and expenses of officers involved in roading activities. Adding an allowance of 20% for overheads, to the roading costs shown in Table 1.1,

Table 1.1

Expenditure on Forest Roading
Forestry Commission of New South Wales, 1971-74

Activity	Expenditure $		
	71-72	72-73	73-74
Roads, Bridges, Culverts, Earthworks	1,236,644	1,456,652	1,281,524
Assistance to Shires	19,456	22,751	53,483
Road Maintenance	866,572	1,082,794	1,392,039
Location Surveys	200,434	233,486	211,162
Rebates to Sawmillers	199,904	154,191	98,295
SUBTOTAL	2,523,010	2,958,874	3,036,503
Total Commission Expenditure	17,808,290	19,771,808	21,449,178
Per Cent Expenditure on Roading	14.17	14.97	14.16
Per Cent Expenditure on Roading 1)	17.17	17.96	16.99

Source: Annual Reports, Forestry Commission of New South Wales.

1) Including an allowance of 20% for overheads.

indicates that approximately 17% of total annual expenditure of the Forestry Commission of New South Wales goes towards forest roading.

The different costing and accounting procedures used by other State Forest Services makes comparison between the Services difficult. The direct costs for New South Wales, Queensland and Victoria are set out in Appendices 1.1, 1.2 and 1.3 respectively. In Queensland about 12% of Forest Service expenditure is directed toward roading and in Victoria about 9%. These percentages make no allowance for overheads.

The relative costs of different forest operations are very variable, but the practical and economic significance of road haulage is indicated by Table 1.2, which illustrates the cost structure of a hardwood sawlog operation based on a native forest in Australia. In this operation, road haulage accounts for 30% of the cost of delivering timber to the mill. The percentage would be increased substantially if the cost of road construction was included.

Table 1.2

Cost Structure of Hardwood Sawlog Operation
Native Forest: Australia
Haulage Distance: 50 Kilometres

Factor	Cost per Cubic Metre $	Per Cent of Total Cost	Cumulative Per Cent
Stumpage	3.50	31	31
Cutting	0.80	7	38
Extraction	2.30	20	58
Haulage	3.30	30	88
Overheads	1.40	12	100
TOTAL	11.30		

Source: Report of Panel 4, Harvesting. Forestry and Wood-based Industries Development Conference. Canberra, 1974.

Financial justification and the allocation of funds to forest roading are usually closely allied to the forest products industries, but the need for roads in relation to forest management and protection, is usually recognized in providing funds for road construction and maintenance. Nevertheless, forest roading affects forest values other than those directly related to wood production, for example water resource, landscape, recreational and conservation.

While some of these values are causing emerging pressures on road systems that were not designed in relation to such values, the consequent pressures on the Forest Services and their resources have not produced responses from the State Treasuries, which would cover the cost involved in modifying current practices tied closely to the economics of the production of wood and other forest products. Nevertheless the widespread concern for the environment necessitates reorientation of the economic analyses and the traditional engineering approach to forest road system design.

In the United States, it has been claimed that the planning of a truly optimum forest road system is not possible at this time, primarily because the data necessary for such an analysis is either inadequately defined or non-existent. Gardner [1971] suggests it is appropriate to use whatever rational means are available to evaluate protection of the environment.

In relation to the economic efficiency of the forest products industry, the effectiveness of road system design can be judged by hauling and travelling costs associated with the roads. It is the geometric characteristics, that is grade, vertical and horizontal curvature, length of straight between curves, width, and sight distance which primarily determine haulage efficiency for a particular unit. For example, if roading is poorly designed and constructed, long haul times and queuing delays can result, truck loads may be reduced and wear and tear on trucks can increase very dramatically.

1.2 THE CLASSIFICATION AND DESIGN STANDARDS OF FOREST ROADS

The standards of construction of forest roads are usually specified in relation to a functional classification. Geometric criteria are commonly related to the concept of design speed, but there are difficulties associated with this for forest roads. The design speed parameters are determined by the reaction of cars and are not therefore a good indication of the speed at which heavily laden or empty trucks can travel the segment of the road [Armstrong, 1972].

The system of classification used by the Forestry Commission of New South Wales is one example of a number of systems. The function and standard of the road are used to describe a road as part of an overall roading system.

In terms of function, the roads are classified as:

1. Primary Access;
2. Secondary Access;
3. Feeder;
4. Link;
5. Track.

The standards are specified in terms of road width and design speed criteria, for four classes of road.

Class A: Two-lane all-weather road with a minimum pavement width of 5.5 metres, formation width 7.3 metres and meeting the requirements of at least 50 kph design speed.

Class B: All-weather road with a minimum pavement width of 3.7 metres, formation width 5.5 metres, and meeting the requirements of at least 30 kph design speed.

Class C: Single lane, substantially all-weather road, with a minimum pavement width of 3 metres, formation width 4.2 metres, with passing places, and meeting the requirements of at least 20 kph design speed.

Class D: Roads or tracks capable of use by conventional vehicles under dry or good conditions only and/or which do not meet the minimum 20 kph design speed criteria.

The geometric parameters for various design speeds are given in Table 1.3.

The Forestry Commission of New South Wales uses a relatively

Table 1.3

Design Speed Criteria for Forest Roads
Forestry Commission of New South Wales

Geometrical Parameters	Nominal Design Speed kph					
	100	80	60	50	30	20
Alignment						
Minimum Radius Curve (metres)	460	200	80	60	30	15
Minimum Length of Straights (metres)	80	60	40	20	20	20
Grade (Per Cent)						
Sustained Maximum :	4%	6%	6%	7%	8%	10%
Permissible Grade 1) :	6% (700)	8% (500)	8% (600)	8% (300)	10% (500) 12½% (150)	12½%

1) Figures in brackets show the lengths in metres for which the permissible grade is allowed.

simple scheme to classify existing roads. It takes into account the main factors affecting speed (surface, grade, curves and width) and provides a uniform way of classifying existing roads by standard. Details of this system are shown in Appendix 1.4.

The approach to road classification by the Forestry Commission of New South Wales is typical of that adopted by many Forest Services and companies. Matthews [1942] outlines a system used by a large private firm in the United States, and Forbes [1961] describes the approach adopted by the United States Forest Service.

The determination of the standard of construction of roads, and the determination of the classification of roads, should be associated with the formulation or development of a roading plan.

1.3 FOREST ROADING PLANS

A forest roading plan sets out the optimal access for a forest or group of forests in relation to the projected management and harvesting operations. The preparation of the roading plan is one of the basic requirements for well planned management policies, and can avoid the piecemeal or ad hoc approach that seems to have been a characteristic of some forest roading programmes.

Theoretical techniques, described by Matthews (1942), Mandt (1973), Kirby (1973) and others are helpful in the preparation of a roading plan and can be used as guides for optimal planning but, as is stressed by Adamovich (1974), the preparation of a roading plan will always entail elements of both intuition and analysis based on practical experience and theoretical knowledge. The whole forest, its topography, physiography, anticipated major production zones and all other public and official uses should be considered in designing the layout of the road access system.

The enactment of environmental protection legislation in some countries has forced reviews of the standards and construction practices associated with forest roads. Whereas there have been tendencies to provide improved engineering standards to enable higher safe traffic speeds, there is now a tendency to lower some standards to lessen the environmental impact of roads by, for example, reducing the volume of earthworks.

In responding to a requirement to reduce the environmental impact of roads by reducing standards of construction, a consequence would be increased haulage costs for wood but there is very little recent information relating road standards to truck performance.

The major objective of this study was to obtain information which would enable truck performance, measured in terms of speed, to be related to the gradient of the road. This was seen as a contribution toward providing basic data that would enable improved selection of optimal standards for haulage roads in particular forests.

1.4 THE STUDY APPROACH

Over the past twenty years there has been a significant increase in the power of trucks used for log hauling. On the other hand the axle loads permitted on trucks has remained static in most States and thus it seemed that there may have been an increase in power relative to the loads hauled and consequently speeds maintained by trucks. It was concluded therefore that a review of maximum road gradients specified for forest roads based on quantitative measurements of actual log truck speeds on roads would make an effective and useful contribution to the general problem of optimizing forest road standards.

The speed of trucks on long adverse grades would obviously be related inter alia, to the load on the truck, and the load also has a considerable influence on the economics of haulage. It was decided therefore to link the investigation of actual log truck speeds on particular gradients with a study of the variability of the loads hauled by log trucks.

The transport of logs from the plantations of the Australian Capital Territory was particularly suited to the study. Weighbridge data were available and the trucks hauled within the Australian Capital Territory and also to New South Wales, where much lower loads are permitted, and a relatively large variation in loads hauled by trucks of the same type could be measured.

The approach adopted in the study was to measure the speeds of log trucks over surveyed sections of roads of various gradients and to obtain the load carried by the truck when its speed was measured by reference to weighbridge dockets.

The data were then analysed to develop a model for log truck speeds. The model is presented in Chapter four. The model is then applied to determine the optimum gradient of roads for a range of road construction costs and for a range in the size of the forest operation dependent on the road, as measured by assumed annual traffic volumes of log trucks.

CHAPTER TWO

DATA COLLECTION AND PROCESSING

2.1 TRUCK LOADS

Wood from the plantations in the Australian Capital Territory is sold primarily by using a system which sets an estimated stumpage rate for the particular compartment (or group of compartments) prior to the commencement of the logging operations. At the completion of the logging on each area, an adjustment of the estimated stumpage is calculated. The adjustment is based on volume measurements of sample loads measured throughout the operation. All loads are weighed, and the volume measurements of the sample loads enable conversion of the total tonnage to a volume and log size class distribution for that area.

The weighbridge dockets record information from which the variability of the loads, within and between truck types hauling from the plantations, can be calculated. Speed readings on particular trucks could be matched with the load data recorded by the weighbridges.

Two weighbridges are in use, a public one at Kingston, and one operated by the A.C.T. Forests Branch at the mill of Integrated Forest Products Pty. Ltd.

The following information is recorded on a numbered docket at the Kingston weighbridge for each load of wood:

Truck registration
Gross weight
Tare weight

> An average value is used for the individual trucks unless the truck is new or has been modified, in which case the trucks are weighed after unloading.

Nett weight
Date
Origin of timber (for example Pierce's Creek)
Compartment number
Product destination.

The information on the dockets from the Kingston weighbridge was transcribed in chronological order on computer coding forms. The time when the load was weighed was obtained from the information on diary sheets kept by a Forest Branch employee stationed at the weighbridge.

The dockets at the weighbridge at Integrated Forest Products are automatically stamped with:

Date
Time of arrival
Gross weight
Time out
Tare weight
Market (usually Integrated Forest Products).

The operator at the weighbridge records:

Truck and trailer numbers
Nett weight
Forest of origin
Compartment
Product type
Sample loads.

The A.C.T. Forests Branch imposes a limit of forty eight tonnes gross vehicle weight on all loads. If a load is substantially above this, the driver is required to unload some of the wood to bring the gross weight below the allowable limit. The broken down load is then measured as two loads. Such occurrences are obvious on the weighbridge dockets. In coding the data from the weighbridge at Integrated Forest Products on computer coding forms, a symbol was used to indicate that two loads may in fact represent one load hauled along the road.

Weighbridge data were collected for two accounting periods, from 23rd June 1975 until the 30th August 1975. The coded data were punched on to computer cards for subsequent calculations. A computer program was prepared to check that the data was correctly transcribed by scanning the information for irregularities and errors. The listing for this program is shown in Appendix 2.1.

2.2 TRUCK SPEEDS

2.2.1 Sites for Measurement of Speed

Selection of Sites

The basic requirement of the sites was a range of grades over which log trucks would be travelling at a frequency that would enable information to be gathered at a reasonable rate. The radar meter was on loan for about three months and a full day in the field for only one or two truck loads could not be justified.

Each section of road selected as a study site had to be of sufficient length for the effect of grade on speed to be substantial. Preliminary measurements had indicated that this should preferably be a straight, of at least 150 metres. In reconnaissance surveys for possible sites, this was an important parameter which limited the number of sites available.

The A.C.T. Forests Branch provided information on the current and proposed cutting programme to assist in the selection of roads where log truck traffic could be expected. Unfortunately, wet weather during the field measurement phase of the study disrupted the cutting plan to some extent. The special arrangements associated with salvaging wind-thrown trees also added to the disruption of the cutting plan. For example, at one site (number five), selected because two current operations were supposed to be in hand, the radar was set up early in the morning but no log trucks had appeared after five hours. The operation had been diverted to another area. In the event, obtaining the speed measurements for a range of road conditions and trucks became a very time consuming exercise.

The selection of long, straight and continuous grades on forest roads in the A.C.T. proved virtually impossible, as in general these roads are of low standard. This, together with low numbers of log trucks passing along them because of the dispersed nature of the operations, made it more effective to select sites on the public roads leading to the forests. Four sites were selected along the Mt. McDonald Road between the Uriarra Forestry Settlement and the Cotter Reserve. Virtually all the wood hauled from Uriarra Forest must go over these sites.

Location of Sites

The general location of the sites was as follows. Sites 1, 7, 8 and 9 were located on the Mt. McDonald Road. Sites 2 and 5 on the Laurel Camp Road, which is the access road to Pierce's Creek Forest. Sites 3 and 4 were on the Cotter Road above the Cotter pumping station. These two sites provided long, continuous grades. Site 6 on the Paddy's River Road was the steepest site chosen. Site 10 was on the Brindabella Road and like site 6 was downhill with the load. The location of the sites is shown in Figure 2.1.

Ground Surveys

The following information was required at each site:

Grade
Pavement Width
Length of Section
Horizontal Curvature.

The survey information was obtained quite simply with an Abney level, Suunto compass and metric band or tape, but nevertheless required a number of days in the field. The procedure was to measure grade, distance, pavement width and bearing from each successive station to the next along the road. Notes were made on the surface type and any other factors likely to affect speed. The field survey information was then plotted in the office as plan views and longitudinal sections. The surveyed profiles for the selected sites are shown in Figures 2.2.

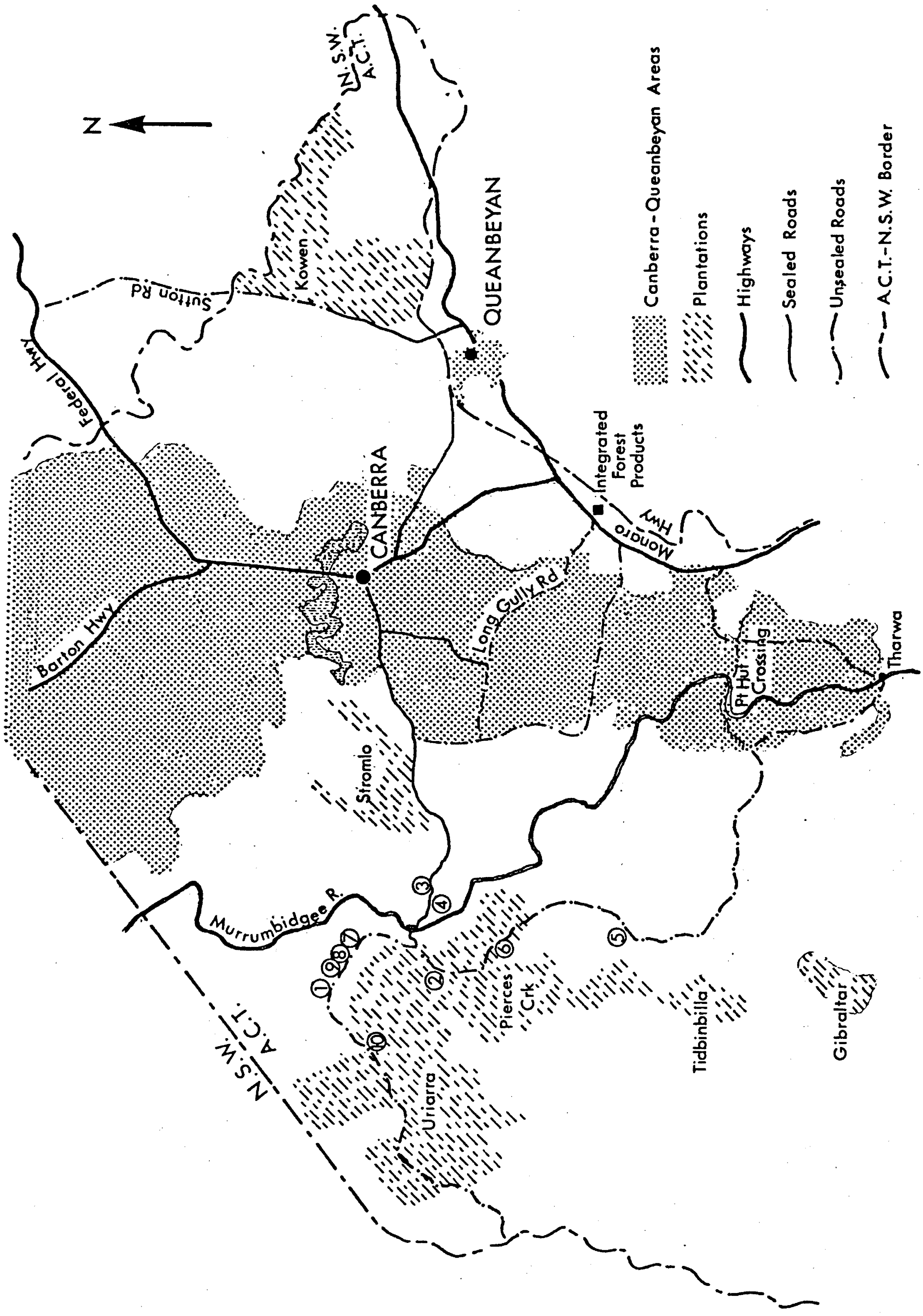
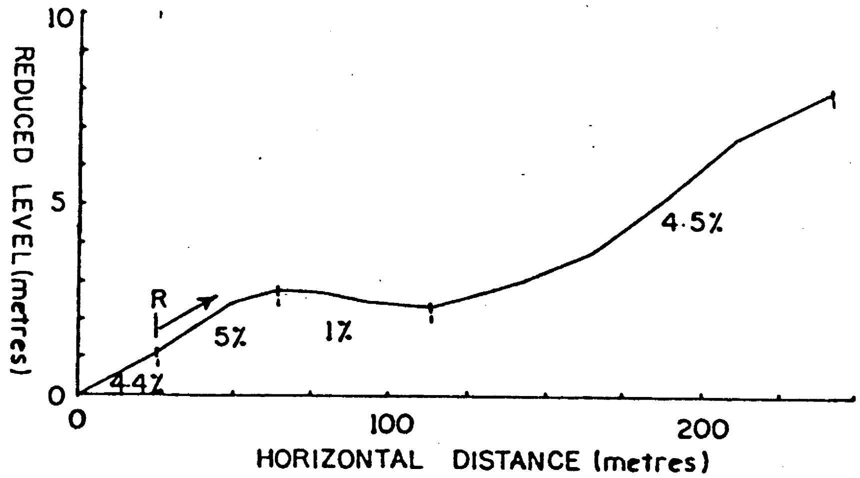


Figure 2.1. Location of study sites.

SECTION 2



SECTION 1

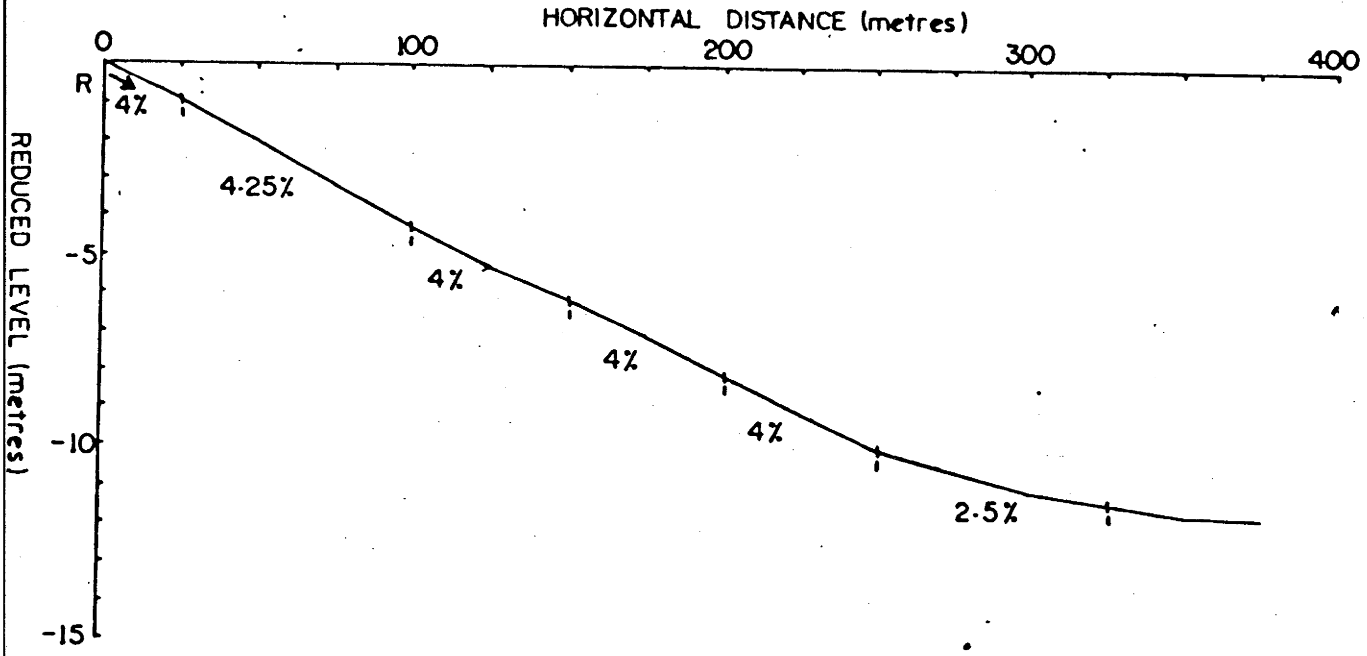


Figure 2.2.1. Profiles Sites 1 and 2.

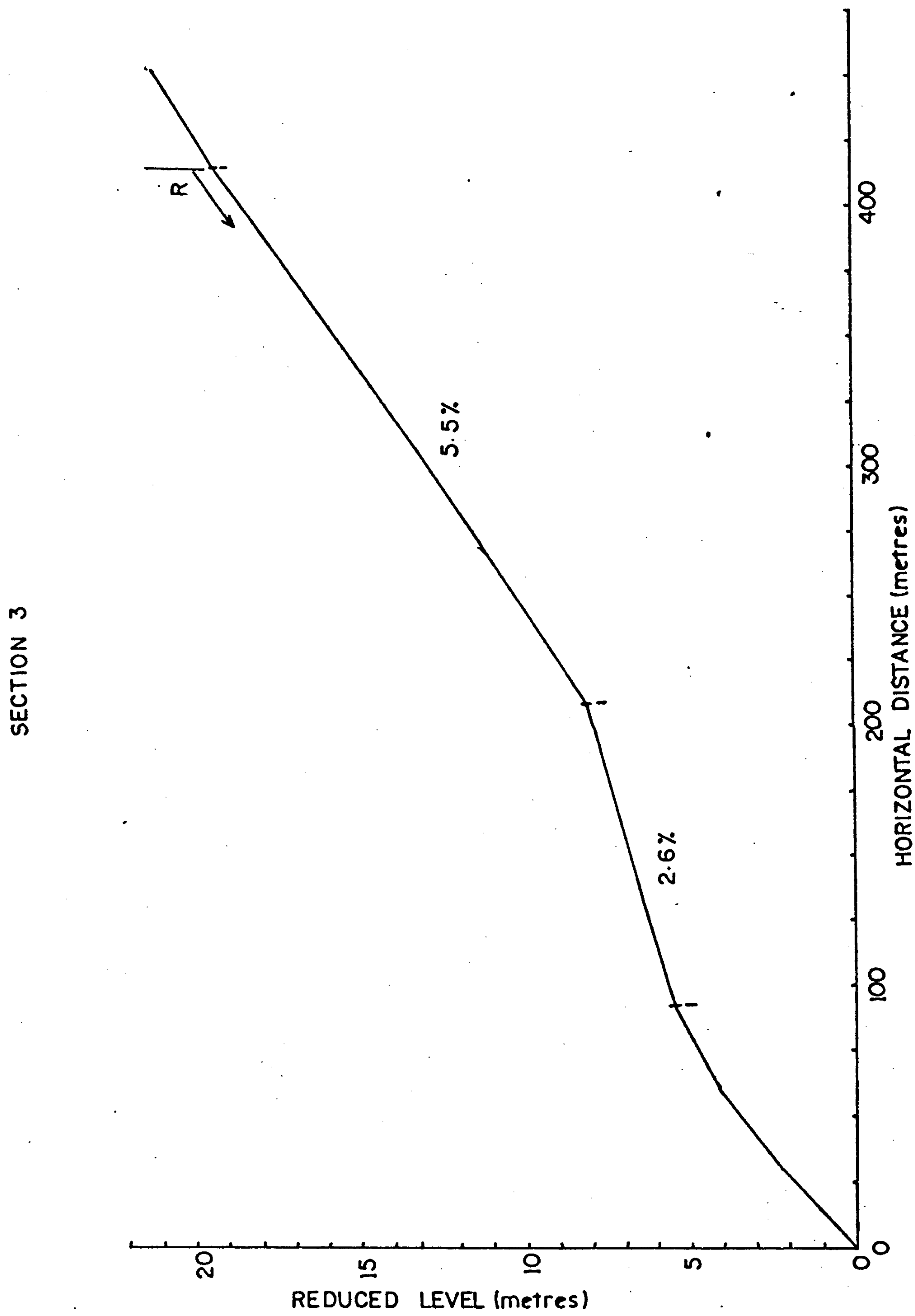
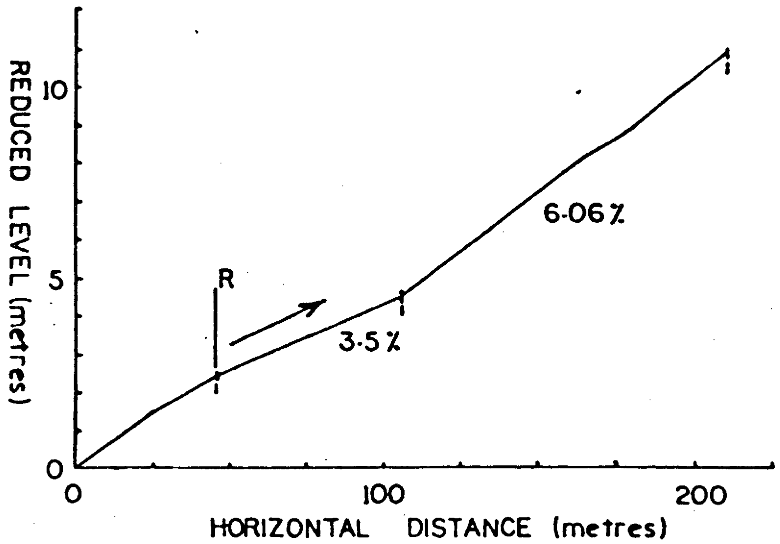


Figure 2.2.2. Profile: Site 3.

SECTION 5



SECTION 4

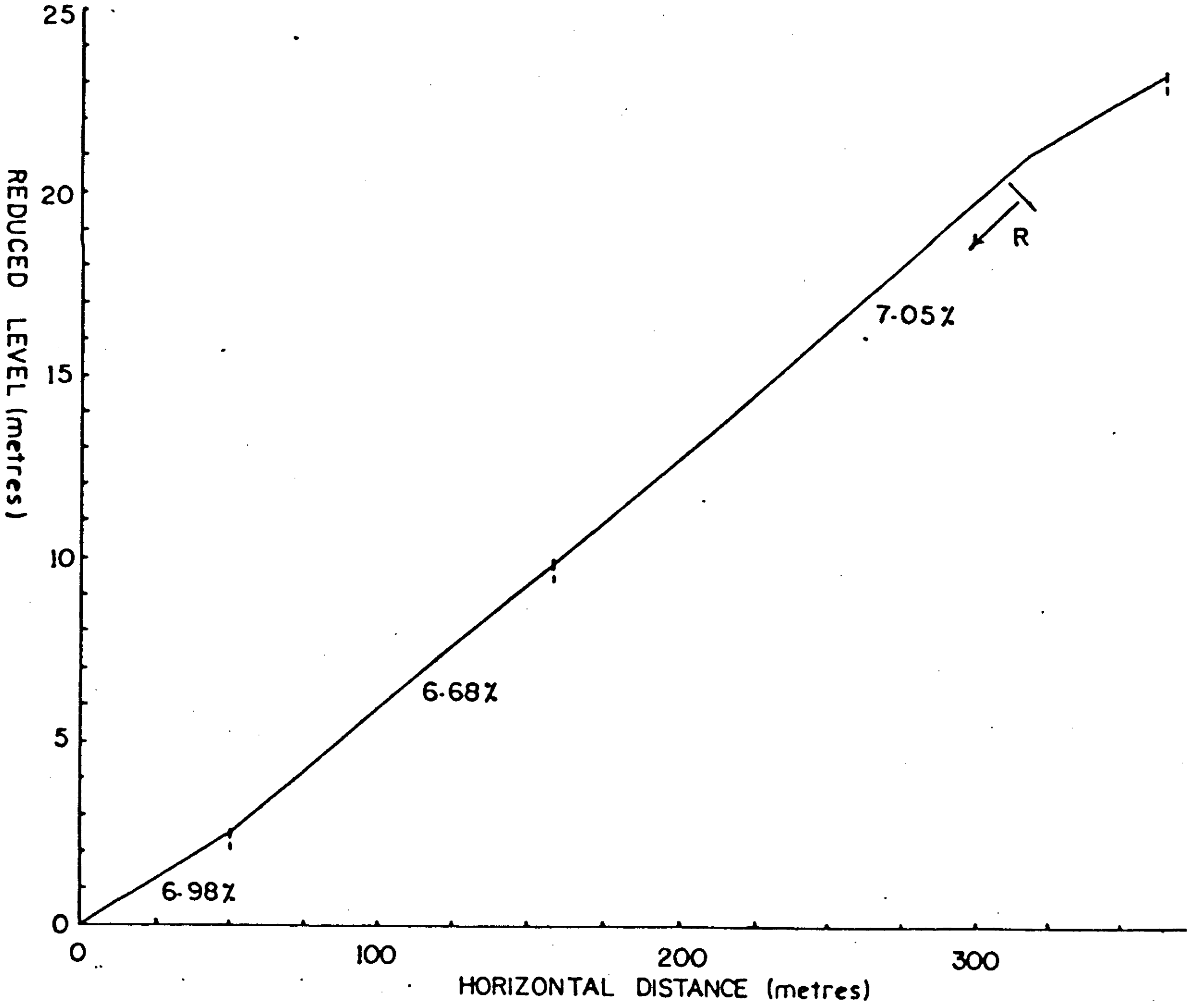


Figure 2.2.3. Profiles: Sites 4 and 5.

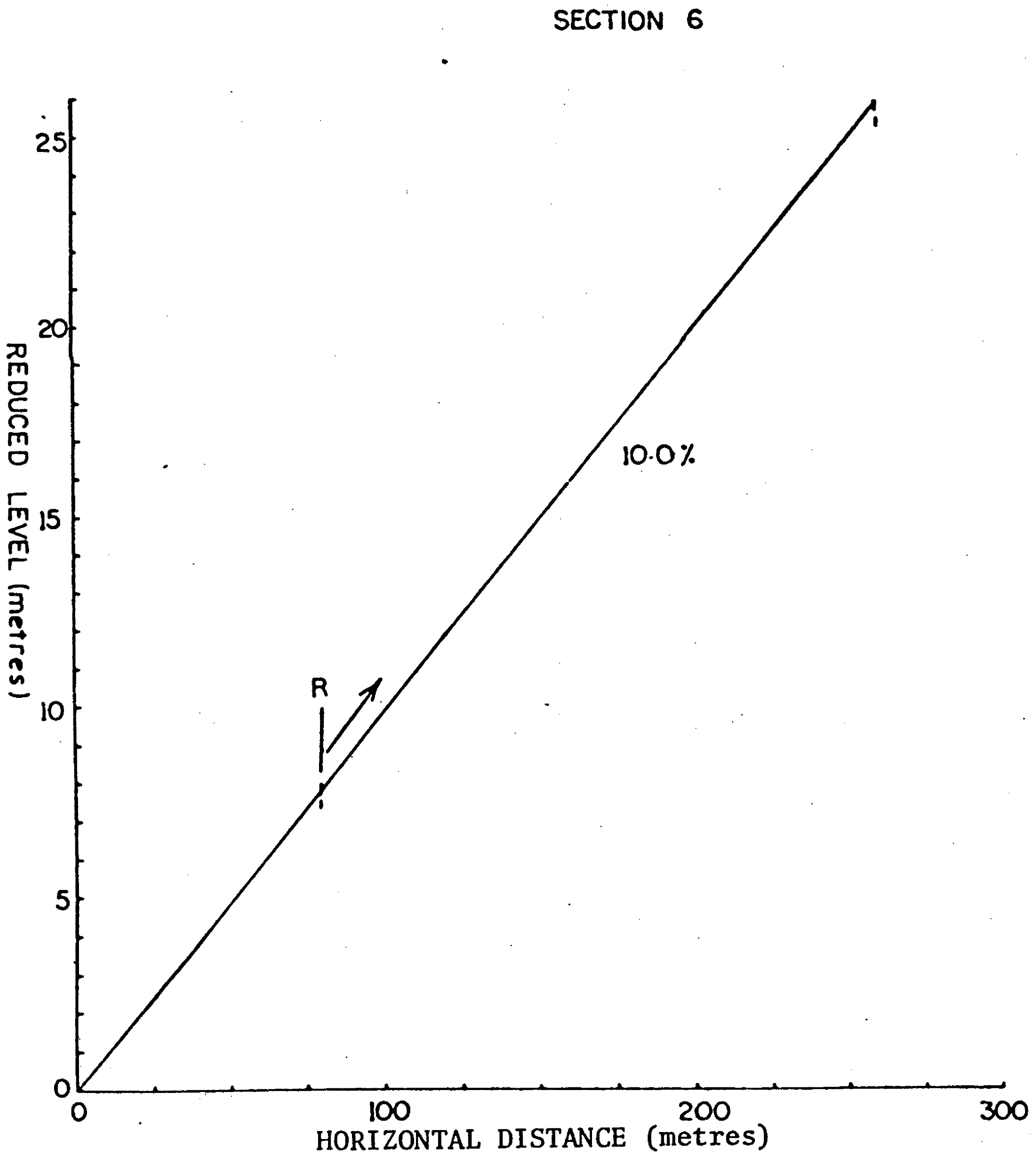
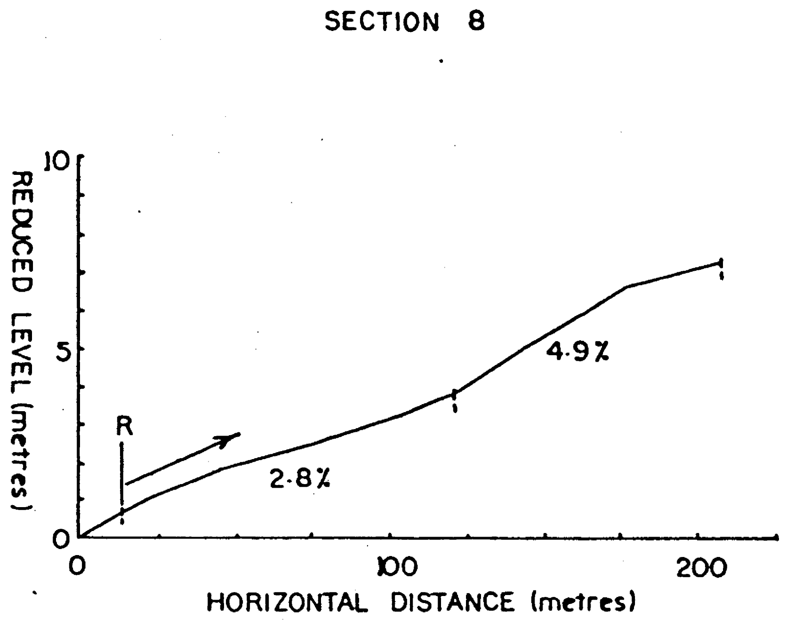


Figure 2.2.4. Profile: Site 6.



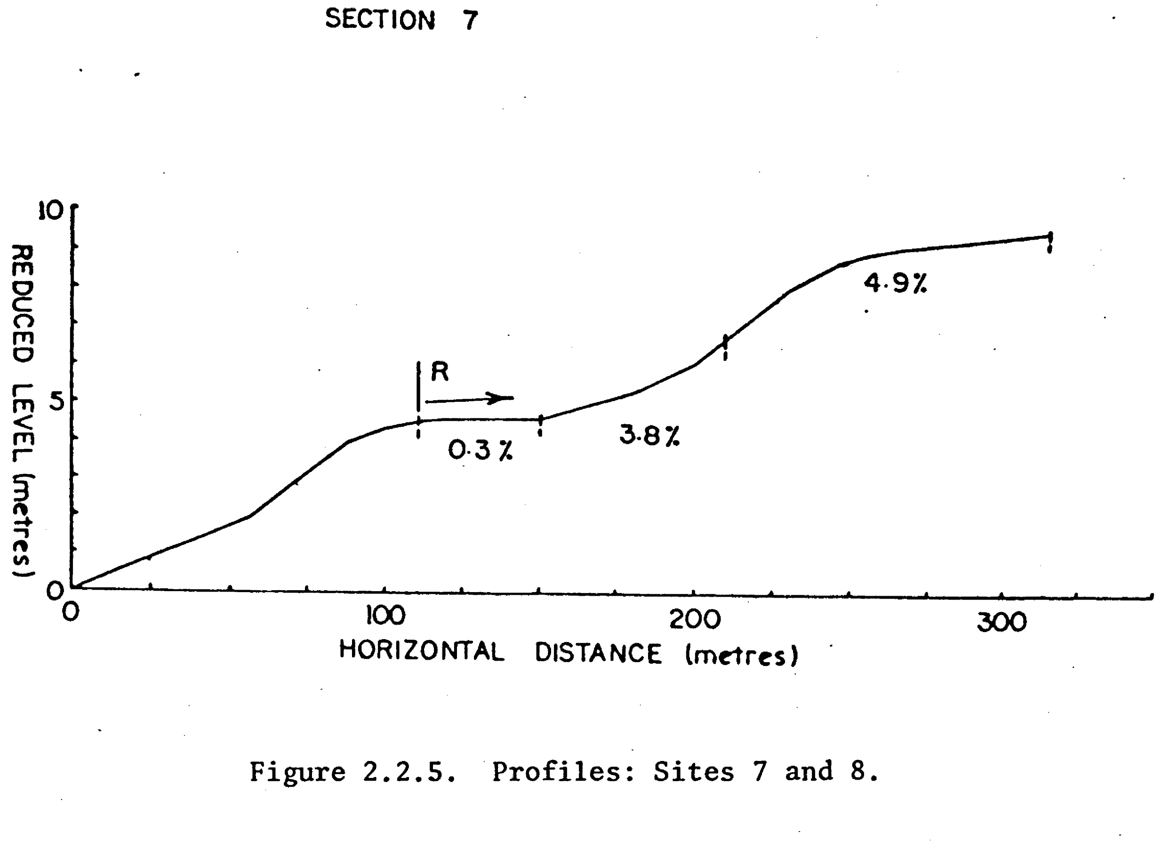
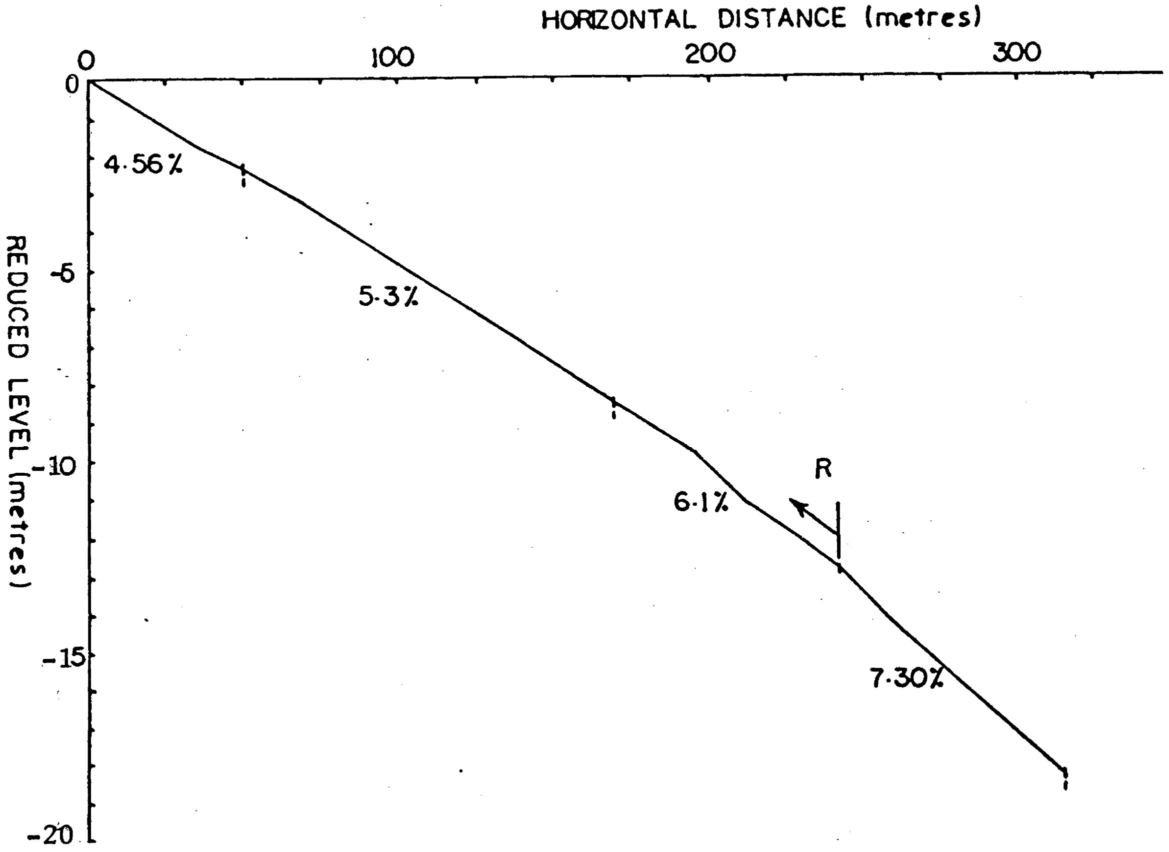


Figure 2.2.5. Profiles: Sites 7 and 8.

SECTION 10



SECTION 9

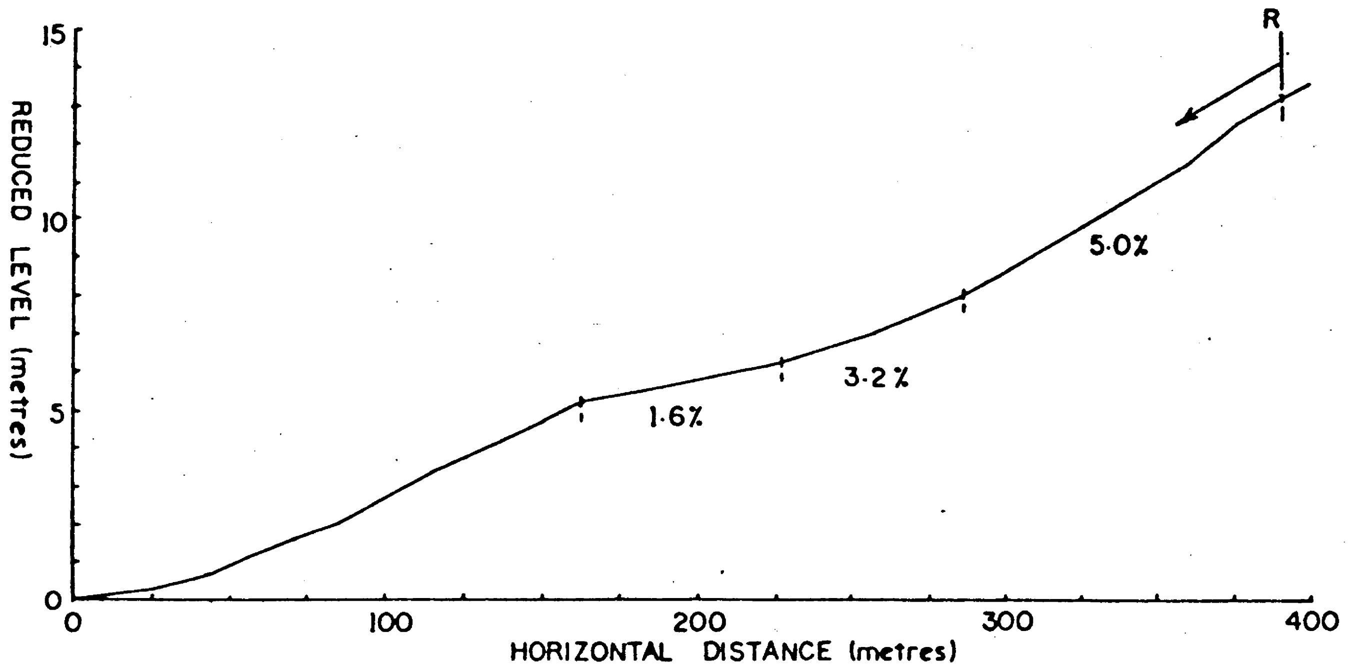


Figure 2.2.6. Profiles: Sites 9 and 10.

The letter 'R' on these plans indicates the position of the radome and the direction in which it is pointing, the radome being the signal transmitting and receiving aparatus.

Description of Sites

Site 1: Mt. McDonald Road

The radar was located at the top of the grade and about 450 metres from a T intersection with a road to Uriarra Forest Station. Approaching trucks negotiated several curves and an adverse grade, and then, approximately 500 metres away came down a short hill on to the flat near the intersection. The grades over the 400 metres leading to the radar meter were then:

400 to 250 metres	2.5% rise
250 to 100 metres	4.0% rise
100 to 25 metres	4.25% rise
25 to 0 metres	4.00% rise.

The 4% grade continued for a further 50 metres before levelling and entering a corner.

The average pavement width for the site was 5.6 metres and the surface was compacted gravel in reasonable condition.

Site 2: Laurel Camp Road

Leaving the radar in the direction of the beam there was a 5% rising grade for 40 metres, followed by a 1% fall for 50 metres and then 4.5% rising for 90 metres. This was the extent of the radar beam's line. The grade continued rising at 4.5% into two curves beyond the limit of the meter.

This site did not prove very useful as far as grade effects were concerned as alignment and a narrow, rough pavement also caused reductions in speed.

The average pavement width was 3.8 metres with a gravel surface in fair condition.

Site 3: Cotter Road

The pavement of the Cotter Road had a bitumen surface.

The radar was at the top of a slope and loaded trucks climbed toward it. The grades going down from the radar were as follows:

0 to 107 metres	5.7% falling
107 to 207 metres	5.2% falling
207 to 323 metres	2.6% falling.

The grade then increased to 6% (falling) for 92 metres around a horizontal curve of 205 metres radius to the location of site 4.

Site 4: Cotter Road

The radar was directed down the grade which was as follows for distances from the radar:

0 to 207 metres	7.1% falling
207 to 271 metres	6.6% falling

These sections were followed by a horizontal curve of approximately 190 metres radius and the road moved away from the direction of the radar beam. The grades were then 7% (falling) for 44 metres and 5% (falling) for another 50 metres.

Site 5: Laurel Camp Road

This site had to be abandoned. It was not used by log trucks at the time of field measurements because of wet weather. However, speed measurements for several other vehicles were recorded.

The radar was at the bottom of a slope and pointing up it. The grades for distances from the meter were as follows:

0 to 60 metres	3.5% (rising)
60 to 164 metres	6.0% (rising).

The average pavement width was 3.2 metres and the surface natural gravel in a fair condition.

Site 6: Paddy's River Road

The Paddy's River Road is a bitumen surfaced, two-lane road and at this site there was a constant 10% falling grade for 180 metres along a straight to the radar. The straight continued for another 80 metres past the radar before entering a curve.

Site 7: Mt. McDonald Road

The radar beam was aimed up the slope and as the majority of the trucks travelled up the slope their speeds were measured as they moved away from the meter.

Referring to Figure 2.2.5, the road was straight from the meter, at the 105 metre mark to about 250 metres. A horizontal curve of approximately 55 metres radius preceded the radar meter position. The geometry of the grade at this site was relatively complex. The horizontal curve preceding the meter was at a rising grade of 4.6%. In the signal path there were rising grades of 0.25% for 40 metres, 3.8% for 60 metres and then 4.9% for 40 metres. The 3.8% and 4.9% grades were equivalent to 4.25% over the 100 metres.

Average pavement width was 6 metres with a gravel surface.

Site 8: Mt. McDonald Road

The radar was aimed upslope at this site, the grades being 2.8% for 100 metres and then 4.9% for 60 metres. The straight then entered a 180 metre radius curve.

The average pavement width was 6.6 metres with a gravel surface.

The site was uphill from site 9. A horizontal curve of 110 metre radius with a grade of 5% separated the two sites.

Site 9: Mt. McDonald Road

The radar was at the top of the slope on the 110 metre radius curve separating site 9 from site 8. The profile, going down away from the radar was:

0 to 100 metres	5% (downhill)
100 to 160 metres	3.2% (downhill)
160 to 210 metres	1.6% (downhill).

A horizontal curve of 270 metre radius with a grade of 3.7% followed.

The average pavement width was 6.6 metres with a gravel surface.

Site 10: Brindabella Road

The radar was set up on a horizontal curve of 120 metres radius and above a 7.3% grade. Loaded log trucks moved down the grade. The grades moving away in the direction of the radar beam were as follows:

0 to 60 metres	6.1% (downhill in direction of trucks)
100 to 180 metres	5.3% (downhill in direction of trucks).

Beyond this straight was a grade of 4.6% around a horizontal curve of 200 metres radius.

The average pavement width was 5 metres with a gravel surface.

2.2.2 Speed Measurement

Equipment

A Traff-O-Matic, Model S-5, Radar Speed Meter and Graphic Recorder were borrowed from the National Capital Development Commission. This was the only radar meter available in Canberra with a Graphic Recorder.

The equipment measures the instantaneous speeds of moving vehicles and is a portable unit easily mounted on any vehicle with a 12 volt electrical system. It comprises four major components:

(i) Radio Frequency Head Assembly (Radome);

(ii) Amplifier and Power Supply Assembly;

(iii) Indicator Assembly (meter with speed scale and needle indicator);

(iv) Graphic Recorder.

Details of the specifications of the Radar Speed Meter are given in the technical manual provided by the manufacturers.1) The operating range of the unit was 0 to 160 kilometres per hour with a stated accuracy of plus or minus 3.2 kilometres per hour. The unit operates on the Doppler principle, that is on the change in the frequency when a wave is reflected from a moving target. The radome consisted of a radar transmitter and receiver and the meter detected the change in frequency in the reflected signal and converted it to the speed of the vehicle. The speed was indicated on the Indicator Assembly and Graphic Recorder.

A three position switch on the Amplifier and Power Supply Assembly provided for one of three ranges to be selected. The ranges were approximately 50, 100 and 150 metres with the radome one metre above the ground, and an unobstructed line of sight. In all the ranges, signals could be obtained for distances over twice the nominal range. The speed readings for the study were taken with the radome 1.5 metres above the ground to gain a longer unobstructed view.

Field Set-up of Equipment

Preliminary testing of the equipment in the field and the suggested operational procedures in the manual led to a number of important requirements when setting up the equipment in the field.

The equipment had to be set up as far as possible off the road to avoid interference with the traffic flow, still keeping the angle between the path of the vehicle and the radar beam at less than ten degrees. This was to ensure that the error in the readings, due to the inclination of the radar beam to the line of travel, was less than 2%.

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1) 'Manual for Traff-O-Matic Radar Speed Meter Model S-5', Service Manual 7002B. Automatic Signal Division, Laboratory for Electronics, Inc., Norwalk, Connecticut, U.S.A., 1964.

The amplifier and power supply assembly required at least five minutes to warm up before readings could be taken. After this warm-up period, a calibration check was carried out, using a calibration tuning fork supplied with the equipment. The vibrating tuning fork was held vertically 7 - 15 cm in front of the radome and the frequency corresponded to an approaching speed of 64 kilometres per hour (40 mph).

Field Recording Procedures

Two cams were fitted to the graphic recorder enabling a choice of two chart drive speeds, namely 15 cm per hour or 15 cm per minute. After initial test runs it was considered that a chart drive of 15 cm per hour produced charts which enabled interpretation only in terms of maximum speed. The faster drive speed was therefore used and this produced a profile from which speeds at 2.5 second intervals could be obtained.

Examples of charts obtained with each of the two drive speeds are shown in Appendix 2.2.

A record was kept of every vehicle for which speed measurements were taken but only the data for log trucks was processed. The following information was recorded on the chart of the meter:

Time
Vehicle Make and Type (for example, Volvo G88 Semitrailer)
Registration Number of Prime Mover (and trailer if applicable)
Loaded or Empty
Direction of Travel with respect to Grade (that is up or down).

Notes were also made of any features regarding the performance of the truck during its passage through the measuring site which might assist subsequent interpretation of the performance of the vehicle and driver.

The following information was noted for vehicles other than log trucks:

Time
Vehicle Make and Type
Government or Private Vehicle

Direction of Travel with respect to Grade (that is up or down). The nature of the load usually carried was also noted for trucks and whether the truck was loaded.

It was convenient to record some of this information directly on the charts, along with the vehicle make and type. On some occasions it was possible to note on the charts the time, and such other events as gear changes and interference from other vehicles.

Problems Associated with Field Measurements

It was expected that the radar meter would attract attention and possibly cause normal performance to be modified. It was very desirable for example to avoid drivers slowing down to enable a closer look at the instrument set-up. In two cases, trucks actually stopped at the set-up and the driver enquired what was being measured.

An endeavour was made to contact all log truck drivers and explain to them the nature of the measurements, request that they disregard the meter as far as possible, and assure them that it was not a radar speed trap. The efforts made seemed to be fairly successful and most log truck drivers were aware of the position of the meter and many of them subsequently saw the charts. Nevertheless, it was not always possible to make contact with drivers before taking measurements and on several occasions trucks obviously slowed down. In these cases the data was discarded, somewhat reluctantly as sometimes only six trucks would be measured in one day. On one occasion, the driver of an unloaded vehicle was moving at an almost "breakneck" speed and it was assumed that this was a deliberate response to his knowledge of the location of the meter and, although the reading was discarded for the purposes of this study, a speed of 120 kilometers per hour for an unloaded log truck on a gravel road is worth noting.

The radome of the instrument had no "aiming device" and it was often difficult to aim the radar beam. At some sites, initial measurements had to be discarded because of incorrect aiming of the beam, resulting in poor signal recording. The direction of the radome was adjusted on these occasions. It was particularly difficult to aim the radome on long steep slopes.

It is common with microwave multipath transmission for signal cancellation to occur when a vehicle comes within range. The indicator needles swing up to the speed reading and then drop momentarily towards zero, one or more times. This phenomena sometimes made interpretation of the charts more difficult, and an example is shown in Appendix 2.3.

There were also occasional problems with the ink flow in the pen of the chart recorder, particularly on cold mornings when the temperature was about zero, and some recordings were lost because the ink did not flow.

The needle on the graphical recorder sometimes rose slowly and gave speeds which were less than those shown on the indicator assembly. This was often pronounced in the first few seconds of the signal from a distant, fast-moving vehicle approaching the meter. When a vehicle passed the radome the signal often showed a kick up but this was easily distinguishable from the rest of the recording and probably due to the angle between the beam and the vehicle path exceeding ten degrees.

Intermittent signals were often obtained when log trucks were travelling at less than 10 kilometers per hour and this was contrary to the claims of the manufacturers that continuous measurements could be obtained down to zero speed.

A most frustrating problem was interference to, or masking of, the main signal by vehicles travelling in the opposite direction or overtaking the slower moving log trucks. At times it seemed that with only three vehicles per hour passing the meter two would always pass at the same time.

There was also a psychological difficulty with boredom while waiting for trucks. It was very important to note all the relevant information and check for malfunction of the equipment at the time of the readings and this period of intense concentration often followed substantial periods without activity.

Location of Vehicles on Road Profiles at Time of Speed Measurement

The actual position of the radome was noted on the survey profiles and recorded with reasonable accuracy on the graphs produced by the Chart Recorder for each vehicle passage. This information was necessary to fix recorded vehicle positions with respect to the position of the vehicle on the ground.

The position of the radome on the chart was used as a base point and the fraction of time to the next 2.5 second interval on the graph paper was recorded, on data coding forms, as the first time interval. The speed at the radome and at 2.5 second intervals was also recorded on the coding forms. This information was subsequently computed to determine the speed at various points along the road at the site.

The information on whether the truck was approaching or leaving the radar provided the record as to whether the truck was ascending or descending the grade, for the radar was always located at the same position at each site. Table 2.1 summarizes the radar position and the usual direction of travel of loaded trucks but it was necessary to check each trip as some trucks passed empty in the loaded direction.

The data on the coding forms was punched on to computer cards and a program written to check for any errors or irregularities.

2.3 TRUCK CAPACITIES

The following data was required for each truck:

- Configuration
  - Number of axles
  - Tabletop, semitrailer, jinker, etc.
- Power rating
- Maximum legal loads under New South Wales traffic regulations and restrictions imposed by the A.C.T. Forests Branch.

Table 2.1

Radar Positions and Direction of Travel

Site Number	Radar Position1)	Usual Direction of Loaded Trucks2)
1	Top	Uphill towards
2	Bottom	Downhill towards
3	Top	Uphill towards
4	Top	Uphill towards
5	Bottom	Downhill towards
6	Bottom	Downhill towards
7	Bottom	Uphill away
8	Bottom	Uphill away
9	Top	Uphill towards
10	Bottom	Downhill towards

1) With respect to grade.

2) With respect to radar.

Data Collection

Information on the configuration of the trucks was collected in the field concurrently with other data collection and also from officers and employees of the A.C.T. Forests Branch.

Data on power ratings was obtained from the truck drivers at the weighbridges through the co-operation and assistance of employees of the Forests Branch. Additional information on Volvo trucks was obtained from discussions with the Volvo (Australia) dealer in Queanbeyan.

In answer to a written request the Department of Main Roads, New South Wales, provided information on the regulations in that State regarding maximum axle loads and loaded weights. This information is in Appendix 2.4 and enables permissible loads to be assessed.

In the Australian Capital Territory, the only limitations applied to the loads carried by log trucks is that imposed by the Forests Branch, that is loads in excess of 48 tonnes on semitrailers must be unloaded at the weighbridge to bring the gross load down to 48 tonnes.

Although apparently straightforward, a number of difficulties were encountered in collating the information on configurations and power ratings.

The configurations of trucks can be changed and the manufacturer's information had to be checked. For example, a Leyland truck had the chassis of its prime mover lengthened and a longer tray added. The truck had previously towed a trailer and carried short logs on the truck and the trailer.

The collection of individual truck power ratings presented some difficulties. Manufacturers express the power rating in two ways. The first is an indication of the power produced by the motor (SAE), the second the power delivered to the drive shaft (DIN). Volvo, for example, use the second method.

Power varies with the state of repair and tuning of the motor but there was no practicable way to account for this in this study and the rated values nominated by the manufacturers have been used.

Several of the trucks hauling the logs had modified motors fitted to the trucks or other modifications such as different injectors. In such cases, reliance had to be placed on the information supplied by the driver and wherever possible this was discussed personally. In the cases where this was not possible, information collected at the weighbridge from the driver was accepted after checking against manufacturers specifications.

As discussed later, for the purpose of this study all trucks were grouped at specific horsepower ratings.

CHAPTER THREE

ANALYSIS OF LOG TRUCK SPEEDS IN THE A.C.T.

PART A : INTRODUCTION

3.1 EXAMINATION OF RADAR DATA

Introduction

As previously indicated in Chapter Two, the analogue charts obtained from the radar meter gave information on the velocity of the vehicles with respect to time. While this would be adequate for many applications of the radar meter, including speed checks, it was necessary in this study to relate the speed of the vehicle to the position on the road.

The first step was to plot the velocity of each truck with respect to distance from the meter, so that the velocity at any point on the road profile could be determined.

In the preliminary analysis of the data to develop and check the methods, information from selected sites and trucks was computed and plotted manually. It seemed that patterns could be determined in the velocity of trucks at certain points on the road profiles and it was then decided to prepare all the graphs for the ten sites. The information for each particular truck travelling in one direction at a site was plotted on one graph. One hundred and fifteen graphs were prepared from two hundred and seven field charts. Examples of the graphs are shown at Appendix 3.1.

The method developed was to obtain truck velocity at 2.5 second intervals from the analogue charts recorded by the radar meter and code this information for computation by a computer. The data were computer sorted in chronological order according to site, truck, and direction of travel.

The distance travelled by the truck in each time interval was calculated assuming the mean velocity for the time interval. Beginning at time zero, when the truck passed the radar meter, the speed at the various distances from the meter was calculated by accumulating the distance travelled in successive time intervals.

The road survey profiles for each site were then superimposed on the graphs so that the speeds could be co-ordinated with various road geometry factors. This could be done with an accuracy of plus or minus ten metres, as the radar position had been marked on the site surveys. The main source of inaccuracy in relating the speed to the ground survey was in determining, on the field charts, when the truck actually reached or passed the radar meter. As noted previously, the speed and time at the radar meter constituted the datum for the computation of the speed-distance graphs.

There were several gradients at each site, and the speed at each change of grade was extracted and then also speeds at intervals of 50 metres. In some cases the charts had irregularities near the 50 metre intervals (e.g. from gear changes). Speeds were then taken at 25 metre intervals to try to get a more accurate estimate of the speed with respect to distance.

In addition to plotting the information for visual study, the speed-distance information was tabulated as computer print-out along with the vehicle identification, direction of travel and gross weight. Examples of the print-out are shown in Appendix 3.2.

The maximum speed and the reduction from this over particular uphill gradients were recorded and the graphs examined to select those which could be used to formulate models to predict the speeds of log trucks on various grades in terms of the parameters measured in this study.

The measured parameters were weight, gradient of road, initial (or approach) speed. The power of the truck was also known.

The ratio, power to weight, was adopted for the testing of model formulations. Power was expressed in watts and weight in kilograms. This ratio was used by Byrne *et al.* [1960] for travel time predictions on various grades.

The relationships which might exist between speed (used as the dependent variable) and power to weight and grade (as the independent variables) were examined using manual techniques; to try and ascertain the form that relationships derived from the data might take and to make preliminary comparisons with theoretical relationships such as power related to velocity for a given load. The theoretical relationships are outlined by Byrne *et al.* [1960] and Armstrong [1972].

It became clear that computerized techniques would have to be adopted to best test and validate models and the statistical techniques available were therefore reviewed in relation to the analysis of this data.

PART B : ANALYTICAL PROCEDURES

3.2 STATISTICAL CONSIDERATIONS

In many areas of research where controlled experiments are not practicable, the techniques of multiple regression analysis are commonly used to quantify the effects of different X-variables on some response Y. The determination of the relationship of a dependent variable Y, with a number of independent variables Y_i is commonly required in forestry research, and is the problem encountered in this study.

Specific reference to the use of linear regression analysis techniques in forestry research is made in Freese [1964], Snedecor and Cochran [1967], Draper and Smith [1966] and Leech [1973]. Linear analysis refers to linearity in the parameters of the type

$$Y = \beta_0 + \beta_1 Z_1 + \beta_2 Z_2 \dots \beta_p Z_p + E ,$$

where Z can represent any functions of the basic independent variables

X_1, X_2,X_3....X_k; β_o,β_1 etc. represent coefficients (which are constants) and E is an error term.

Non-linear regression analysis refers to functions which are non-linear in the parameters, for example

$$Y = \frac{\theta_1}{\theta_1 - \theta_2} \left[e^{-\theta_2 t} - e^{-\theta_1 t} \right] + \varepsilon.$$

Non-linear regression analyses are less commonly used as they have not been integrated into a theory of the same degree of generality as that which applies to the linear case (Snedecor and Cochran, 1967; Freese, 1964).

In this study, an approach using linear regression analysis was adopted for three main reasons:

1. Although considerable time had been spent in the field, the amount and range of the data obtained was limited by both the time available for collection and the sites and trucks available for observation. More refined analyses would not therefore improve the results obtained.
2. The form of the true model was not available by simple theoretical considerations and therefore there was no indication that non-linear forms would actually be required.
3. Package computer programs which could be independently handled and interpreted were readily available for linear regression, and in particular, the REX program (Grosenbaugh, 1967).

A number of the more general problems in multiple linear regression analysis were applicable to this study. In this type of analysis, the response of the dependent variable (Y) is gauged against the effects of different independent variables (X's). It was not possible in the type of measurements made in this study to ensure that X values other than power, weight and grade were not related to Y (speed) in the sampled population. These other values are discussed in Section 3.4.1.

If one or more other related X values exist, the estimated value of the coefficients of X in the computed regression from the sample would not be unbiassed estimates of the population's coefficients (Snedecor and Cochran, 1967). The estimate of a particular regression coefficient may then be over- or underestimated. The amount of bias in the coefficients depends on the variables that have not been measured and it is difficult to make a judgement on the magnitude of the bias.

However, where the primary objective of the analysis is to provide an accurate prediction of Y rather than separate the effects of the various independent variables, the bias may be of assistance. If the unknown variables were good predictors of Y and have stable relationships with particular X variables, then the prediction of Y would be improved as the coefficients of the independent variables incorporate the effects of the unknowns.

The REX program [*op. cit.*, p.34] uses a least squares type of linear regression analysis. Four major assumptions are made in this type of analysis. The assumptions concern the residuals (or errors) present. Therefore, after fitting a curve to the data to form a mathematical model, it is necessary to ascertain whether the residuals exhibit tendencies which confirm, or at least do not deny, the assumptions. The assumptions are:

1. Homogeneity of the variance;
2. There is no measurement error;
3. There is no serial correlation between residuals;
4. The residuals follow a normal distribution.

1. Homogeneity of the Variance

The fitting of an unweighted regression assumes that the dependent variable has the same degree of variability (variance) for all levels of the independent variables [Freese, 1967]. That is to say that the sample data is from a population for which the variance is homogeneous and the variance of the residual term of the regression is constant over the range of the regression data. If the variance was heterogeneous, then the estimates of coefficients in the regression would be less precise than if homogeneous.

Whether or not the variance is homogeneous, the estimates of the regression coefficients will be unbiassed [Johnston, 1960].

More precise estimates of the coefficients can be obtained in cases where the variance is heterogeneous by using weighted regression fitting procedures (Freese, 1964; Snedecor and Cochran, 1967). This may eliminate or reduce heterogeneity to acceptable levels. If weighting is not used in such cases, the estimates would not have minimum variance as this would be obtained from the correct weighted least squares analysis.

Three commonly used tests for homogeneity of variance are discussed by Leech (1973). Leech favours Bartlett's test (Bartlett, 1937), as it allows for differing numbers of observations. The test procedure is also outlined by Freese (1964) and this test was adopted in analysing the data in these investigations. Snedecor and Cochran (1967) urge caution when using the test as it is sensitive to non-normality in the data, particularly kurtosis, and with long tailed distributions (positive kurtosis) can give erroneous verdicts of heterogeneity.

The procedure in testing for homogeneity of variance in this study was as follows. If heterogeneous trends were evident, a weighting factor was developed which was then used in the development of the regression models. When a model had been selected it was further tested using Bartlett's technique. The data was arranged in order according to the dependent variable and then divided into approximately equal groups. The variance within each group was then calculated and a value for chi-squared obtained. This was tested against the "Accumulative Distribution of Chi-square" as given in Table 4 of Freese (1967) for the desired probability level. The assumption of homogeneity was rejected if the calculated value was greater than that in the Table. If rejected, the weighting factor was redetermined and again applied to the data. The revised model was then tested again and the "cut and trial" procedure continued until Bartlett's test did not reject the assumption of homogeneity.

2. Measurement Error

Reliable estimates of the coefficients derived by regression analysis require the variables to be measured essentially without error as this is one of the assumptions in the analysis. Measuring instruments are not perfect and these types of errors must occur. Procedures for fitting a regression when both the dependent and independent variables are subject to error are described by Snedecor and Cochran [1967] and Mandel [1964].

Leech [1973] suggests that when measurement error occurs with the dependent variable, but this error is unbiassed, "then the mean square residual will be inflated resulting in a reduced level of significance in the analysis of variance". However, this problem is relatively minor providing that the regression explains a large amount of the variation. When measurement errors occur in the independent variables, Leech [1973] considers that providing the errors are unbiassed and the completed regression model is applied to "data measured with the same source, frequency and degree of error as the data used to develop the model", then these errors would have little effect.

Mandel [1964] warns that special care should be exercised to ensure that data is not subject to cumulative errors. In these cases, the fitted regression can greatly underestimate the true error of the measurement and this can result in a poorly fitting regression unless the analysis takes the cumulative nature of the errors into account.

3. Serial Correlation

Mandel [1964] defines a series of values in which each element is correlated with a neighbouring one, as having serial correlation.

Correlation between residuals when a regression model is fitted to successive observations is an example of serial correlation. The errors corresponding to different points would not be statistically independent and one of the basic requirements for fitting a linear model by the least squares principle would be violated, that is that for the sample units the deviations of the Y values from the regression surface must be independent of each other [Freese, 1964].

Where straight lines are fitted by the least squares principle and serial correlation exists, then the estimate of the gradient is unbiased but the estimate of the variance of the gradient is always badly in error. This can lead to serious overestimation of the precision of the data [Mandel, 1964].

If serial correlation exists in general linear regression analysis, that is where not only straight lines are fitted, then the estimates of the regression coefficients are unbiassed but the predictions of the dependent variable will be inefficient and have large sampling variances [Leech, 1973; Johnston, 1960].

The Durbin-Watson "d" statistic [Durbin and Watson, 1950, 1951] was calculated and used as a test whether serial correlation was likely to cause problems in the analyses in this study. Johnston [1960] outlines means of recourse should serial correlation be present.

4. Normality of Residuals

In linear regression analysis, it is assumed that the residual or error term in the regression is normally distributed. This assumption of normality of residuals in multiple linear regression analysis models is required for the standard tests of significance in regression, but not for the other standard properties of the regression estimates [Snedecor and Cochran, 1967].

Snedecor and Cochran also describe tests for skewness and kurtosis, two conditions which indicate that the distribution is not normal. The tests involve examination of moment statistics, for example, the third moment about the mean is related to skewness and the fourth moment about the mean is related to kurtosis.

Skewness is a condition where the distribution about the mean is not symmetrical. One definition of this condition in relation to the normal curve, quoted by Weatherburn [1962], is that skewness equals the mean minus the mode all divided by the standard deviation. In the tests of the data in this study, the sample estimate of the coefficient of skewness was calculated by $g = \frac{m_3}{m_2^{3/2}}$,

where m_3 = sum of the cubed deviates divided by the number of deviates;

m_2 = sum of the squared deviates divided by the number of deviates.

This "g" value was tested against the one tailed, 5% significance level table (Table A6) in Snedecor and Cochran [1967].

In a normal distribution, the coefficient of kurtosis has a value of 3 [Snedecor and Cochran, 1967], and is basically an indicator of whether the distribution curve is flat topped or peaked. In the test suggested by Snedecor and Cochran a sample estimate of the amount of kurtosis is given by

$$g_2 = \frac{m_4}{{m_2}^2} - 3 ,$$

where m_4 is the sum of the deviates individually raised to the fourth power, divided by the number of deviates and m_2 as in the test for skewness above. Subtraction of the values of 3 for a normal distribution results in peaked distributions showing positive kurtosis values and flat topped distributions as negative kurtosis values. The values obtained by the test in this study were interpreted in relation to Table A6ii, a "Table for Testing Kurtosis" in Snedecor and Cochran.

When skewness or kurtosis are recognized in data, suitable transformations of the data using weighting factors can be used to correct the problem.

3.3 COMPUTER PROGRAMS FOR REGRESSION ANALYSIS AND STATISTICAL TESTING

Computer Programs

The REX-Fortran 4 system [Grosenbaugh, 1967] was used to do the multiple linear regression analysis. The program is very flexible and has a wide range of application for curve fitting. The main use in this analysis was to screen various combinations of independent variables to find the regressions which best fitted the data and at the same time meet the theoretical and practical expectations of form. Initial runs for testing regressions were done using a weighting factor of 1.0 but modification to incorporate weighting factors was relatively simple and the data was weighted after initial results indicated that this procedure would improve the regressions.

The version of the REX program on file at the Univac 1108 computer facility at the Australian National University also calculated the Durbin-Watson "d" statistic [Durbin and Watson, 1950, 1951]. However, at the commencement of the analysis of the data of this study, the University facility was not available for a period of seven weeks and much of the initial computation was done on a small Hewlett-Packard 2100 computer in the Department of Forestry. The full capabilities of the REX program could not be made available on this machine. A program was therefore written which calculated the Durban-Watson "d" statistic, the sum of the deviates raised to the first, second, third and fourth powers for testing skewness and kurtosis and the information necessary to do Bartlett's test of the homogeneity of the variance [Bartlett, 1937]. A listing of this program is at Appendix 3.3.

Significance Level in Statistical Testing

Probability levels of 1% or 5% are usually chosen in deciding whether to reject the null hypothesis test in statistical analyses. In testing, two kinds of errors are likely to be made [Snedecor and Cochran, 1967; Mandel, 1964]. Where a sample causes rejection of the null hypothesis when it is true, the error is Type I. If a sample causes acceptance of the null hypothesis when it is false, a Type II error occurs. Minimizing the occurrence of both error types is desirable but the reduction of the probability of a Type I error increases that of Type II error. Leech [1973] states that a compromise between the two types of error should be sought.

The level of significance selected provides some assurance against an unwarranted rejection of the hypothesis but it does not indicate whether the data was sufficient for testing that hypothesis [Mandel, 1964].

In the analysis carried out in connection with this study, the amount of data available, the range of data and the large number of factors that could affect relationships between speed and gradient lead to the adoption of the 5% level of testing.

PART C : A GRADIENT MODEL FOR LOG TRUCK SPEEDS

3.4 MODEL FORMULATION

3.4.1 Selection of Parameters

The main objective of the analysis was to explore the effect of grade on the speed of log trucks. While it would be desirable to be able to predict the acceleration or deceleration of vehicles under all road and vehicle conditions, there was insufficient data to develop such a model. The analysis was therefore concentrated on the concept of "sustained speed" to enable economic comparisons of various ruling grades under different traffic conditions, rather than the determination of models which would enable simulation of actual log truck speeds along roads with varying geometric characteristics.

Concept of Sustained Speed

Sustained speed is defined as the speed maintained on an extended straight uphill grade. Trucks moving up steep uphill grades would slow down,that is lose momentum, until the torque developed by the engine was only sufficient to drive the vehicle uphill at that speed. On flatter grades, sustained speed was the actual speed maintained up the hill by the vehicle and thus could be determined by the driver rather than the power of the vehicle.

The following factors therefore have some effect on the sustained speed:

Power of the vehicle;
Gross vehicle weight;
Grade;
Nature and condition of road surface;
Width of roadway;
Sight distance;
Crossfall;
State of repair of truck;
Traffic density;
Surface area of the front of the truck and road;

Driver characteristics.

Examination of all these factors would be impracticable in a single study and practical limitations were therefore applied to the scope of parameters incorporated into the model formulation process.

Range of Gradients Analysed

The concept of sustained speed is designed to define the speed a truck would hold in carrying loads over extended straight inclines. Where grades are below 5 per cent, or power to weight ratios are high, the length of slope required to reach a sustained speed is probably greater than occurs in most typical forest roads or haulage routes. Grades of this magnitude over long lengths are not common in the Australian Capital Territory, and data collection on grades flatter than about 5% was virtually impossible with the resources available. It was also impractical to obtain measurements on grades steeper than 10% as the few grades steeper than this, and of sufficient length, were either not used by the traffic during the study period or other factors such as horizontal curvature or antecedent grade had a major influence on the speed.

Truck Power Ratings

The truck power is obviously a very important factor in determining speeds on grades.

The trucks for which speed measurements were obtained in this study were grouped into four power categories.

The smallest, table top Internationals with bogey drive, had power ratings of about 95 kilowatts. Next was a grouping comprising International semitrailers with power ratings around 160 kilowatts. Volvo semitrailers constituted the larger and higher powered trucks and were grouped into two classes, 200 and 245 kilowatts respectively. However, power ratings would vary between trucks and, with time, for individual trucks in each group.

The rated power of trucks is given in two ways by manufacturers. Some manufacturers state the power output of the engine at certain revolutions per minute, that is the SAE rating, whereas Volvo trucks for example are rated in terms of DIN, the power delivered to the drive at certain revolutions per minute. The DIN rating therefore allows for power used in various parts of the truck, for example pumps, fans, etc.

The DIN rating of trucks was adopted for this analysis, and where SAE ratings were supplied by the manufacturer, approximate DIN ratings were assessed after consultation with truck agents and representatives. The DIN rating was selected as it is as easy to obtain as SAE, and is a more accurate rating of the truck in relation to potential sustained speeds. Byrne *et al.* (1960) apparently used an SAE rating but modified this estimate by using a ratio of effective power to rated power, that is a rating approaching in concept the DIN rating. In their study, the ratio of effective power to rated power was varied with elevation of the truck above sea level.

In this study, the effect of altitude was not incorporated as all data were collected at the one locality and at similar altitudes.

Gross Vehicle Weight and Power to Weight Ratios

The gross vehicle weight of a truck of a certain power rating is also an important factor in determining speeds on various uphill grades and particularly sustained speed.

Table 3.1 and Figure 3.1 illustrate power to weight relationships for the four most common log truck types used in the A.C.T. forests. The curves give some guidelines for the limits of the practical power to weight ratios.

Table 3.2 shows the power to weight ratios of the log truck types shown in Table 3.1 and Figure 3.1 when loaded in accordance with the average loads hauled during the period of this study and for the legal loads in New South Wales.

It would seem virtually impossible in practice to have a power weight ratio of less than two. For example, a large Volvo (245 kW power)

Table 3.1

Power to Weight Ratios and Gross Vehicle Weights for Selected Log Trucks

Power to Weight Ratio[1]	Gross Vehicle Weight — Tonnes			
	Truck Type — Kilowatts			
	95[2]	160[3]	200[4]	245[5]
1	97	164	201	246
2	48	82	101	123
3	32	55	67	82
4	24	41	50	62
5	19	33	40	49
6	16	27	34	41
7	14	23	29	35
8	12	21	25	31
9	11	18	22	27
10	10	16	20	25
11	9	15	18	22
12	8	14	17	21
13	7	13	15	19
14	7	12	14	18
15	6	11	13	16
16	6	10	13	15
17	6	10	12	14
18	5	9	11	14
19	5	9	11	13
20	5	8	10	12

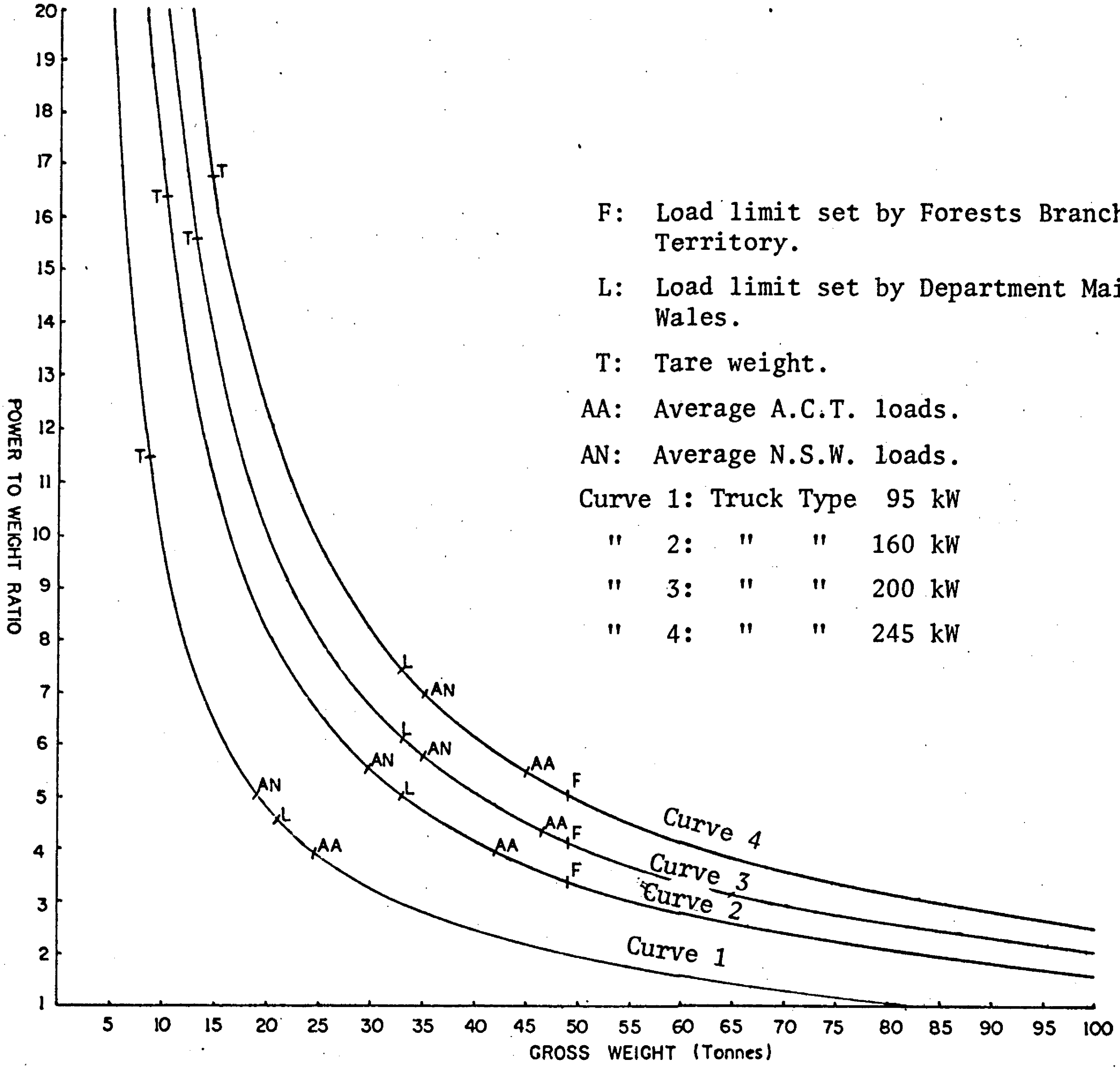
1) Power in kilowatts gross weight in tonnes.

2) International tabletop truck — 130 horsepower.

3) International semitrailers — 220 horsepower.

4) Volvo semitrailers — 270 horsepower.

5) Volvo semitrailers — 330 horsepower.



F: Load limit set by Forests Branch, Australian Capital Territory.

L: Load limit set by Department Main Roads, New South Wales.

T: Tare weight.

AA: Average A.C.T. loads.

AN: Average N.S.W. loads.

Curve 1: Truck Type 95 kW
" 2: " " 160 kW
" 3: " " 200 kW
" 4: " " 245 kW

Figure 3.1. Power to weight ratios for log trucks.

Table 3.2

Power to Weight Ratios for Selected Log Trucks

Truck Type	Tare Weight Kilograms	Power to Weight Ratio				
			Weight			
		Tare	Average[5] A.C.T.	Average[5] N.S.W.	Legal Limit[6] N.S.W.	Maximum[7] A.C.T.
International Tabletop[1]	8,300	11.5	3.9	5.1	4.6	-
International Semitrailer[2]	10,000	16.4	3.9	5.6	5.0	3.4
Volvo Semitrailer[3]	13,000	15.6	4.4	5.8	6.2	4.2
Volvo Semitrailer[4]	14,500	16.8	5.5	7.0	7.5	5.2

1) 95 Kilowatts, 130 Horsepower.

2) 160 Kilowatts, 220 Horsepower.

3) 200 Kilowatts, 270 Horsepower.

4) 245 Kilowatts, 330 Horsepower.

5) Weight based on average loads measured in this study (see Chapter Four).

6) Weight based on legal local limits applicable in New South Wales (See Appendix 2.4).

7) Weight based on maximum load accepted at weighbridge by A.C.T. Forests Branch, viz. 48 tonnes.

would need a gross weight of 123 tonnes to have a power to weight ratio of two. This gross weight is far in excess of the rather generous 48 tonnes maximum allowed by the A.C.T. Forests Branch and the 33 tonnes allowed in New South Wales.

Table 3.2, and Figure 3.1, illustrate the power to weight ratios of the trucks when unloaded (tare weight) and this ranges from about 11.5 for the small tabletop Internationals to 16.8 for the larger Volvos. The significance of the larger loads allowed in the A.C.T. as compared to New South Wales is also shown. Power to weight ratios are lower by about 33% for haulage in the A.C.T. as compared to New South Wales.

3.4.2 Literature Review

Byrne *et al.* [1960] developed a series of graphical approximations relating travel time (speed), grade of the road in per cent, and a B factor. The B factor was calculated by multiplying the horsepower by one thousand times the ratio of effective to rated horsepower (E) and dividing this by the gross vehicle weight in pounds. The graphs consisted of a series of hand drawn approximately parabolic lines, but little information on the basic data and the curve fitting procedures was given in the paper.

Truck power ratings and computing facilities and technology available for multiple regression analysis have all increased considerably since the work by Byrne and for these reasons a comprehensive comparison of the data obtained in this study with the useful results presented by Byrne *et al.* was not undertaken. A first examination suggested that the early work gave conservative estimates of vehicle speeds. Furthermore, the examination did not produce a consistent mathematical relationship between the lines as would be expected from curves produced from a derived model. However, the work of Byrne *et al.* provided confirmation that practical results could be obtained by formulating models for the prediction of log truck speeds on long grades on the basis of measured values of speed, gradient truck power and gross vehicle weight.

Draper and Smith [1966] define three types of models which are commonly used:

(1) The functional model;
(2) The control model;
(3) The predictive model.

Functional models can be obtained between a response and the independent variables when the true functional relationships between the response and the independent variables are known from theoretical considerations. While such a model would be most desirable, it was clear that this could not be developed in this study and it seems unlikely that they will be developed. Such factors as air resistance by the truck and load, driver capability, tuning and servicing of the motor, road surfaces and geometric standards and weather conditions suggest that for practical purposes relationships based on statistical analysis of measured data would be more productive.

Where there are uncontrollable independent variables, response of th dependent variable cannot be accurately predicted even if the functional model is known completely. However, if the variables can be controlled in artificial or experimental situations a control model can be obtained. It was not feasible to control the variables by experimental situations in this study and control models were not therefore an alternative approach in planning this study.

Draper and Smith suggest that when the "functional model is very complex and when the ability to obtain independent estimates of the effects of control variables is limited, one can often obtain a linear predictive model which, though it may be in some senses unrealistic, at least reproduces the main features of the behaviour of the response under study." Linear predictive models have great value where data is complex and many factors apparently influence the response in the dependent variable. Multiple linear regression techniques are particularly important in analyses of these models and the availability of modern computers has facilitated their use in the development of models. These predictive models are particularly useful for highlighting the importance of major variables and provide useful starting points for further examination of response in the dependent variables.

The procedures adopted in this study for the collection of data and for data processing had in mind a predictive model and subsequent review of the literature and initial analysis of the data confirmed that this approach was the only feasible method.

3.4.3 Selection of Model Form (Shape)

Several preliminary and complementary approaches were used to examine possible practicable relationships which could be verified by rigorous statistical analysis of the data.

Hand drawn plots of the data indicated a trend for curvature and radiation of the regression lines.

Regressions calculated from least squares analysis using the Hewlett-Packard 9100 desk calculator and plotter gave further indications of trends in some of the selected practicable relationships. This approach, using the Hewlett-Packard 9100 was tedious and slow, and every regression examined had to have the data individually keyed in because of the limited storage capacity on this calculator. However, it was convenient for the preliminary analysis and confirmed that multiple linear regression analysis was desirable.

Examination of the power to weight relationships in respect of the trucks commonly used in logging, see Figure 3.1, also indicated that the regressions would tend to converge at about a power to weight ratio of two.

In addition to preliminary statistical interpretations, a number of practical rationalisations were formulated and these set constraints and requirements on the model shape. They are discussed below.

In the normal range of grades encountered in forest roading, it is reasonable to assume that speed would not decrease if the power to weight ratio is increased and it would be expected that on a particular grade, the sustained speeds of logging trucks would increase as the power to weight ratio increased. In formulating mathematical relationships for curve fitting and testing by statistical methods, it was assumed that speed on adverse grades would tend to increase as the power to weight ratio increased.

It was also accepted that there would be a maximum speed at which trucks travel. This maximum speed would depend inter alia on road characteristics, the driver and the mechanical performance of the truck. The collection of sustained speeds on grades of less than 4 per cent was not feasible on roads in the Australian Capital Territory. However, the speed recordings obtained showed that many modern trucks are capable of speeds of up to 120 kilometres per hour when unladen and travelling on low grades. It was concluded therefore that an appropriate upper limit for the speed range of a model determined to relate the parameters of this study would be 100 kilometres per hour. In practical terms it would be unrealistic to contemplate trucks maintaining such speeds on forest roads and the upper range of 100 kilometres per hour ensured that the model developed covered the range of practical speeds.

The maximum grade that should be considered for a forest road is about 17 per cent (1 in 6). However, a grade of this order would only be adopted for temporary feeder roads although short sections of steeper grade may be constructed by contractors wishing to shorten snigging distances. Grades greater than 14 per cent can cause problems in wet conditions and tractors are often used to assist trucks up such grades. Grades greater than 12.5 per cent would result in a classification of Class "D" under the New South Wales Forestry Commission guidelines for forest roading. Roads of "D" class would be expected to constitute only a small percentage of overall road length in any haul, as roads of this class adversely affect the royalty rates calculated for logs. The rates are based, inter alia, on costs of hauling to the mill, and unless the log volumes hauled along a road are very small, upgrading of the road would be undertaken to increase the royalty.

It was decided to set an upper limit of 14 per cent for road gradient in developing a model based on the parameters measured in this study. This value actually involved extrapolation from the data as measurements on grades as steep as this was not possible in the Australian Capital Territory. It was assumed, in relation to formulating the shape corresponding to mathematical relationships, that for a given increase in load, deceleration would be greater on flatter grades, than on steeper ones. This assumption was based partly on observed effects and partly on the physical examination of the rate at which power is converted to potential energy, as outlined in Appendix 3.4.

Thus in summary the factors initially selected to determine the model were:

- curves would give a better fit to the data than straight lines.
- that a power to weight ratio of about two would constitute a datum, that is modelling or curve fitting would not be extended beyond this value.
- for any one gradient the smaller the load on an individual truck the higher the expected speed of that truck subject to constraint by a maximum speed.
- modelling or curve fitting would not extend beyond a grade of 14%.
- modelling or curve fitting would not extend beyond a speed of 100 kilometres per hour.

3.4.4 Multiple Linear Regression Analysis

As previously discussed, the "REX" program (Grosenbaugh, 1967) was used to examine the data and to fit various curves to it to determine valid relationships between the measured parameters based on rigorous statistical analysis.

In the first instance, the REX program was run on the Hewlett-Packard 2100 computer in the Department of Forestry. Problems were encountered with rounding errors and matrix inversions and as soon as the Univac 1108 Computer became available this facility was used to re-run and check all the models developed on the Hewlett-Packard 2100. It was unfortunate that the main University computing facilities were undergoing major modification over a period of seven weeks coinciding with the data analysis associated with this study.

The procedure followed using the REX program was to examine straight line forms for fitting the data. Gradients and intersects were varied using combinations of the independent variables. Various curved forms were then examined and those giving better fits were statistically tested for significance of the terms in the regression with both "t" and "F" tests [Freese, 1967].

3.4.5 Examination of Model Forms

Over eighty different models were examined using the REX program. They were constructed with various combinations of Grade and Power to Weight ratios. A selection of these is listed in Appendix 4.3.

Many of the eighty model forms were eliminated because of a very poor fit with the data. Those which seemed to fit the data reasonably well, that is had a high coefficient of determination, were tested for the significance of each regression coefficient using a "t" test as mentioned above. The models not rejected using this test were then further culled by rejecting those with more than four independent terms, thus leaving the simpler of the statistically tested models.

At this stage, the models still under consideration were plotted on graph paper and those exhibiting obvious irregularities in form were discarded. A number of models also were discarded as the regression lines crossed in the range of the data. Examination of the graphical plots eliminated all but one form and this, the culmination of a long cut and trial process, was adopted and subsequently validated.

The form of the mathematical model adopted for validation was

$$S = \frac{b_0}{P} + \frac{b_1 P}{G^2} + b_2 ,$$

where S = speed in kilometers per hour;

P = power to weight ratio (watts divided by kilograms);

G = grade in per cent; and

b_0, b_1, b_2 are regression coefficients.

The model selected for validation was

$$S = -\frac{86.86}{P} + \frac{46.96\ P}{G^2} + 31.89\ .$$

3.5 STATISTICAL VALIDATION OF SELECTED MODEL

Test of Significance of Regression Terms

An "F" test as outlined by Freese [1967] was carried out on the regression to test the significance of the individual forms.

The result of the test are summarized below representing 1/P as X1 and P/G^2 as X2.

Source	dF Degrees of Freedom	SS Sum Squares	MS Mean Squares
Reduction due to			
X1,X2	2	9,851.47	
X2	1	8,678.95	
Gain due to			
X1	1	1,172.52	1,172.52
Residuals	56	2,147.20	38.34
Total	58	11,998.68	

$$\frac{F_1}{56\ dF} = \frac{1172.52}{38.34} = 30.58\ .$$

Comparing this F value with Table 3 in Freese [1967] for the distributions of F, namely 4.02 at the 5% level, the addition of the term X1 gives a significant contribution to the regression.

Source	dF Degrees of Freedom	SS Sum Squares	MS Mean Squares
Reduction due to			
X1,X2	2	9,851.47	
X1	1	8,349.94	
Gain due to			
X2	1	1,501.53	1,501.53
Residuals	56	2,147.20	38.34
Total	58	11,998.68	

$$\frac{F_1}{56\ dF} = \frac{1501.53}{38.34} = 39.16\ .$$

Again by comparison with Table 3 of Freese [1967], X2 gives a significant contribution.

Thus, at the 5% level both 1/P and P/G^2 gave significant gains. The coefficient of determination for this regression was $R^2 = 0.821$, indicating that 82 per cent of the variation in speed, the dependent variable, was associated with the regression.

Test for Homogeneity of Variance

Bartlett's test (*op. cit.*, p.36) was used and the results of the test are on page 55. The data was separated into five groups according to ascending values of the dependent variable, that is speed.

Pooled with group variance

$$\bar{S}^2 = \frac{\Sigma\ SS_i}{\Sigma\ (n_i - 1)} = \frac{1325.55}{54}$$

$$= 24.5472$$

and

$$\log \bar{S}^2 = 1.3900.$$

Testing for homogeneity

Group	Variance S^2	n - 1	S.S.[1)]	log S^2	(n - 1) log S^2
1	2.14	11	23.49	0.33041	3.63455
2	2.27	11	24.99	0.35603	3.91628
3	9.21	11	101.35	0.96426	10.60686
4	16.63	11	182.91	1.22089	13.42981
5	99.28	10	992.81	1.99686	19.96862
K = 5[2)]		54[3)]	1325.55		51.55612

1) Corrected sum of squares.
2) Number of groups.
3) Sum = 54.

$$\chi^2_{4df} = 2.3026[(1.39)(54) - 51.55612]$$

$$= 54.12033.$$

Referring to Table 4 [Freese, 1967], the value of χ^2 for the "Accumulative distribution of chi-square" is 9.49. Therefore the test rejected the hypothesis of homogeneity of the variance and indicated that a weighting factor should be incorporated in the regression. However, as discussed previously, caution should be exercised with Bartlett's test as it can give poor results if non-normality exists in the residuals, especially kurtosis.

Tests were therefore carried out for normality of the residuals [Snedecor and Cochran, 1967] and at the 5% level neither kurtosis nor skewness were significant and a weighting factor was therefore developed [Leech, 1973].

3.6 DEVELOPMENT OF WEIGHTED REGRESSION MODEL

3.6.1 Selection and Testing of First Weighting Factor

The data had been arranged into five cells of ascending speeds for testing for homogeneity of variance. The cells were approximately of equal size. The variance of these cells was plotted against their average speed, and a curvilinear relationship fitted to this data and developed as the weighting factor. This was used in the multiple linear regression analysis by inserting it into the TRNX subroutine of the REX program.

The first weighting factor chosen was $1.6 \times 10^{-5} \times S^4$ and was used to examine the model form previously selected in the unweighted analysis, that is

$$S = \frac{b_0}{P} + \frac{b_1 P}{G^2} + b_2 .$$

The regression obtained was

$$S = -\frac{67.04}{P} + \frac{40.14 P}{G^2} + 26.52 .$$

3.6.2 Statistical Validation of First Weighted Model

To determine whether the weighting factor had been satisfactory and had overcome the problem of the heterogeneity in the variance, Bartlett's test was again carried out.

The calculated chi-square value was 10.12 and this still exceeded the tabulated value of 9.49 [Table 4, Freese, 1967]. The test therefore again rejected the assumption of homogeneity of the variance and although the weighting factor had improved the model it was still not adequate.

3.6.3 Selection of Second Weighting Factor and Calculated Regression

The graph prepared in connection with the determination of the first weighting factor was re-examined and another which seemed to improve the fit to the data was developed.

Byrne *et al.* (1960) suggest that the power required to move a vehicle could be approximated by the following equation:

$$P = WGV + WRV + KAV^3,$$

where W = Gross weight of vehicle (tons);
G = Grade (per cent);
V = Speed of travel (miles per hour);
R = Rolling resistance coefficient;
K = Air resistance coefficient;
A = Projected frontal area of vehicle and load (square feet).

The major problems encountered with developing a validated model to fit the measured parameters were associated with the higher values of speed. At higher speeds air resistance becomes more significant. On this basis, and on that of the above formula, it seemed that a weighting factor incorporating the third power of speed could improve the model to the point of statistical validation.

The adopted weighting factor was $8.0 \times 10^{-4} \times S^3$.

All the models previously examined using an unweighted analysis were re-run with the REX program using the adopted weighting factor to check if the model forms previously rejected, would be improved by weighting to the extent that they should be adopted in preference to the form under consideration. The most improved model was

$$S = \frac{-38.09}{P} + \frac{12.54\,P}{G} + 15.62,$$

but it was still rejected in favour of the form of the model adopted for testing because its behaviour in the lower range of power to weight ratios was less satisfactory.

The model adopted based on an analysis using the weighting factor was

$$S = -\frac{73.79}{P} + \frac{45.14\ P}{G^2} + 27.76\ .$$

A "t" test after Freese [1967] and as previously outlined was used to determine whether the terms still made significant contributions. The results are summarized below

for b_0/P, t (calculated) = 7.59

for b_1P/G^2, t (calculated) = 6.59 .

At the 5% significance level the "t" value from Table 2 in Freese [1967] was 2.02, and it would therefore be concluded that both terms significantly improved the regression. The coefficient of determination was 0.81, that is 81% of the variation of speed (S), was associated with the regression. It is to be expected that weighting of a regression would reduce the coefficient of determination and this proved to be the case as in the unweighted model the coefficient of determination was 82%.

3.7 STATISTICAL VALIDATION OF THE WEIGHTED MODEL

Test for Homogeneity of Variance

Bartlett's test of homogeneity of variance was again used.

The calculated chi-square value with four degrees of freedom was 2.28. The chi-square value from Table 4 in Freese [1967] was 9.49. Thus the assumption of homogeneity of variance in the weighted regression analysis was not rejected.

Measurement Error

The analyses undertaken and previously described assumed that there were no measurement errors. In practical terms this was not the case as all measurements involve errors inherent in the measuring equipment. The important consideration was the relative influence of these errors on the model tolerances and whether bias was likely to compound the effects of the errors.

The dependent variable speed was measured with the one radar meter for which the manufacturers claimed an accuracy of plus or minus 3.2 kilometres per hour. As the meter was re-calibrated, usually twice a day, it was assumed that errors in measurement were unbiassed, random variables with a mean distribution of zero, and were normally and independently distributed. The instrument error was thus taken as insignificant in a statistical sense.

Grade was measured with an Abney level which was regularly checked to ensure that it was calibrated correctly. The order of accuracy of the instrument used, in terms of the calibration interval, was plus or minus 0.07%. Grade was taken to the nearest 0.1% for calculation purposes. It was assumed therefore that measurement error and fluctuations in grade on the profiles on which speed was measured would be minor in their effect and unbiassed.

The power to weight ratios were calculated from truck manufacturer's power ratings and government weighbridge measurements (to the nearest 10 kg). They were the best measurements available within the time and financial constraints of this study and it is assumed that they are unbiassed and adequate.

Serial Correlation

As previously discussed, the Durbin-Watson "d" statistic was adopted to test for serial correlation. It was computed at 1.94. By comparison with tabulated values of the statistic [Freese, 1967], the assumption that there was no serial correlation was not rejected.

Normality of the Residuals

The two tests outlined by Snedecor and Cochran [1967] for skewness and kurtosis were carried out on the residuals. The listing of the computer program written to calculate the residuals is at Appendix 3.4.

a. Skewness

The calculated value was 0.4938 compared with 0.4962 from Table A6 in Snedecor and Cochran. Therefore the assumption that the residuals do not have a skew distribution was not rejected. However, the test was relatively close to the rejection level and this suggested that additional terms in the regression may improve the fit. This was also suggested by some of the models examined containing more terms but rejected as too complex for the amount of data used in their production or because they had unrealistic characteristics outside the data range.

b. Kurtosis

The amount of kurtosis was calculated at 0.1034. The rejection level from Table A6 in Snedecor and Cochran was much greater at 3.99 for the 5% level. Therefore the assumption that kurtosis was not significant was not rejected.

3.8 THE SELECTED MODEL

The model adopted following statistical analysis of the data was

$$S = -\frac{74}{P} + \frac{45\,P}{G^2} + 28 .$$

The graphical representation of the adopted model at 2% grade intervals is shown in Figure 3.2. The range on which data was collected for the determination of power to weight ratios is also shown in Figure 3.1. Measurements of speed were taken on grades ranging from 4 to 10 per cent. Thus Figure 3.2 is extrapolated beyond the range of the measured data.

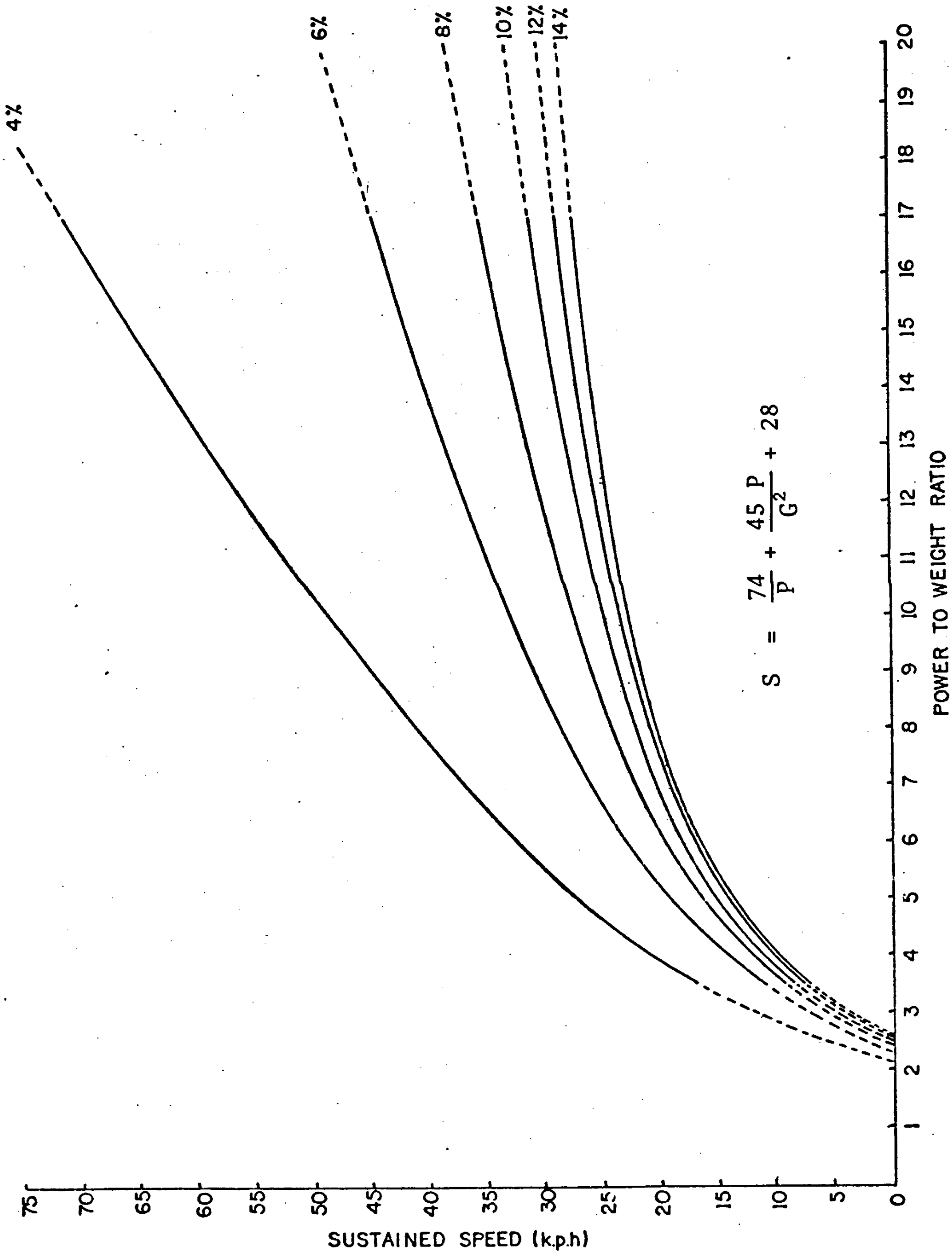


Figure 3.2. Graphical representation of sustained speed model.

PART D : A GRADIENT LENGTH MODEL FOR LOG TRUCK SPEEDS

3.9 FORMULATION OF A GRADIENT LENGTH MODEL

3.9.1 Introduction

Road gradients are commonly specified in two ways in relation to a nominal design speed, sustained maximum and a grade in excess of the sustained maximum which would be acceptable over a limited length. Both are illustrated in Table 1.3. For example that Table specifies that for a nominal design speed of 30 kilometres per hour the sustained maximum grade is 8% but a grade of 12½% would be acceptable over a length of 150 metres.

The field observations made in this study demonstrated that log trucks drop to speeds well below the nominal design speed in much shorter distances than the limited lengths specified as permissible at steeper grades in Table 1.3. Table 1.3 is based on geometric standards for rural roads which would carry substantial passenger car traffic and while a rapid reduction in log truck speeds was expected on the adverse grades it was questioned whether the specification of adverse grades as in Table 1.3 is most appropriate for forest roads.

The actual speed of vehicles after traversing a short length of an adverse grade is contingent on many factors including the approach speed, and hence the road geometry prior to the adverse grade, traffic density, speed limits and the characteristics of the driver. Taking an overall view of road networks, rather than a particular adverse grade, it can therefore be assumed that the actual speed of the vehicle after traversing a short length of an adverse grade is a random variable. On this basis a statistical 'gradient length model' could be developed from the data obtained from the observations at the sites chosen for this study.

The shortest length of steeper grade shown in Table 1.3 is 150 metres. This length is in fact one of the longer lengths with a constant grade in the forest roads of the Australian Capital Territory. It was chosen as the length of adverse grade at which the speeds of vehicles would be investigated to provide a basis for an assessment of the desirability of specifying adverse grades steeper than sustained maxima for lengths greater than 150 metres on forest roads.

3.9.2 Data Processing and Statistical Testing

The computer programs used for regression analysis and statistical testing were essentially the same as for the sustained speed model and described in the previous section. Minor modifications were made to the program used to calculate the Durbin-Watson "d" statistic, Bartlett's test and the tests for skewness and kurtosis. The level of significance for testing was again set as five per cent.

The data used in the computation of the model was derived from the radar readings and the speed of various trucks after travelling 150 metres on a constant grade was extracted from the information prepared as described in the previous section. One hundred and two observations were available for regression analysis. The range of the data was basically the same as for the sustained speed model. There were no observations on grades greater than 10% but there were additional observations for gradients of 4 and 5 per cent.

3.9.3 Selection of Model Form

While there would obviously be different factors operating to determine the speed of trucks after travelling 150 metres up a constant grade than those determining the sustained speed up a constant grade the measured parameters available for analysis were the same for the formulation of the sustained speed model and for the gradient length model. The forms of the gradient models selected for analysis were therefore made similar to those developed for the sustained speed model.

Approximately eighty models were examined using both unweighted and weighted multiple regression analysis. Thirty different regressions were graphically plotted and finally the three models defined below were selected for testing:

1. $$S = b_0/G + b_1P + b_2$$
2. $$S = b_0/P + b_1P/G + b_2$$
3. $$S = b_0/P + b_1P/G^2 + b_2$$

S = speed in kilometres per hour

P = power to weight ratio (watts/kilograms)

G = grade in per cent

b_0, b_1 and b_2 constants.

The models are represented in Figures 3.3.

The form of model 1 was very simple but outside the range of the data it develops trends which are not acceptable. Models 2 and 3 conform more to the expected shapes with such parameters and the trends seemed more appropriate outside the data range.

3.9.4 Statistical Validation of Models

Models 2 and 3 were tested first.

The "t" test for the significance of the contributions of each term in the models indicated that model 2 was unsatisfactory if unweighted. All terms in model 3 gave significant contributions in both weighted and unweighted analyses.

Bartlett's test for homogeneity of variance rejected this assumption in all cases, both unweighted and weighted, even after incorporating a correction for bias.

The unweighted form of model 1 was therefore tested. The regression obtained was:

$$S = 206.8/G + 2.696\,P - 27.82\ .$$

The "t" test indicated that each term was significant, the values being:

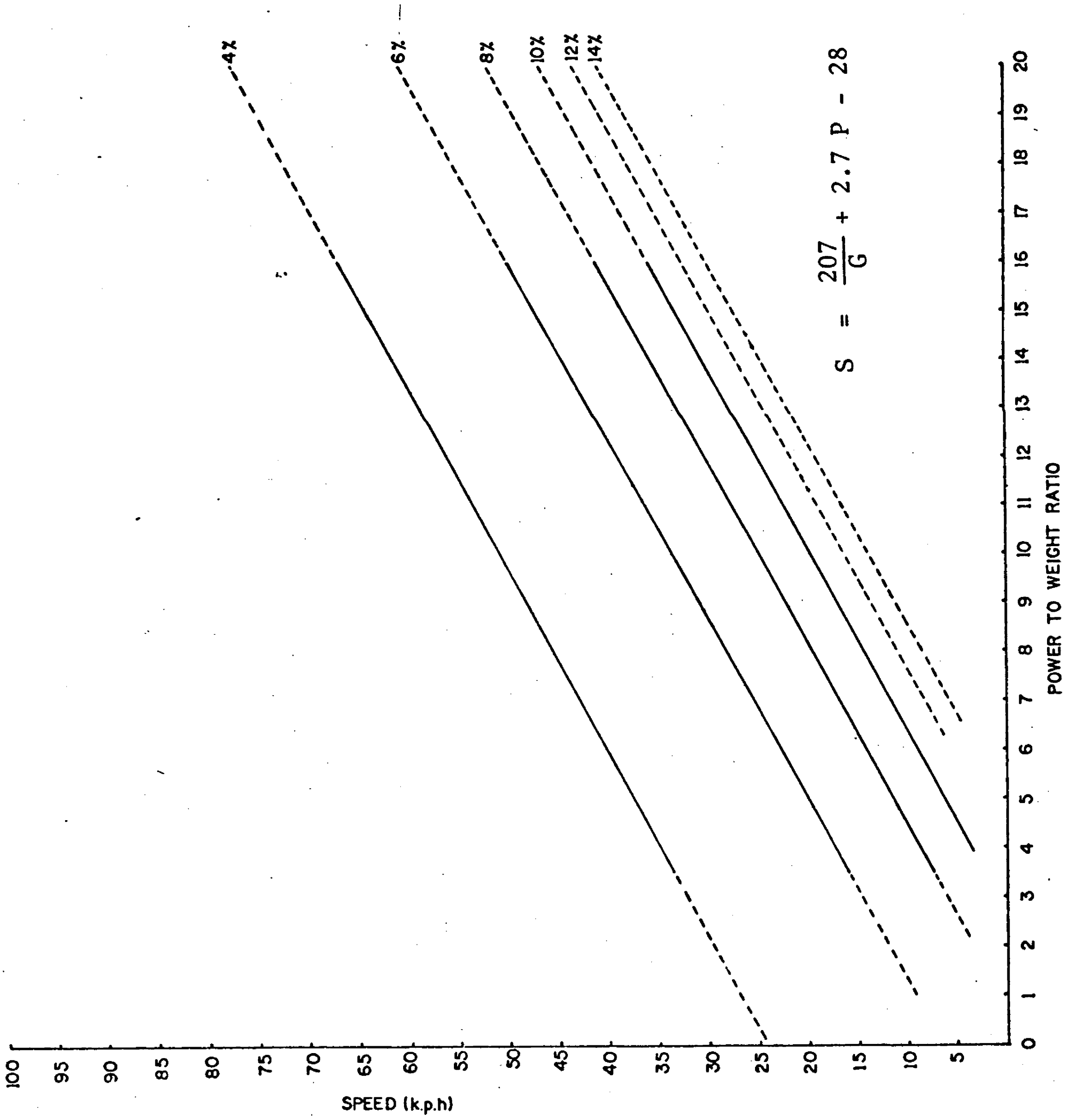


Figure 3.3.1. Representation of gradient length Model No. 1.

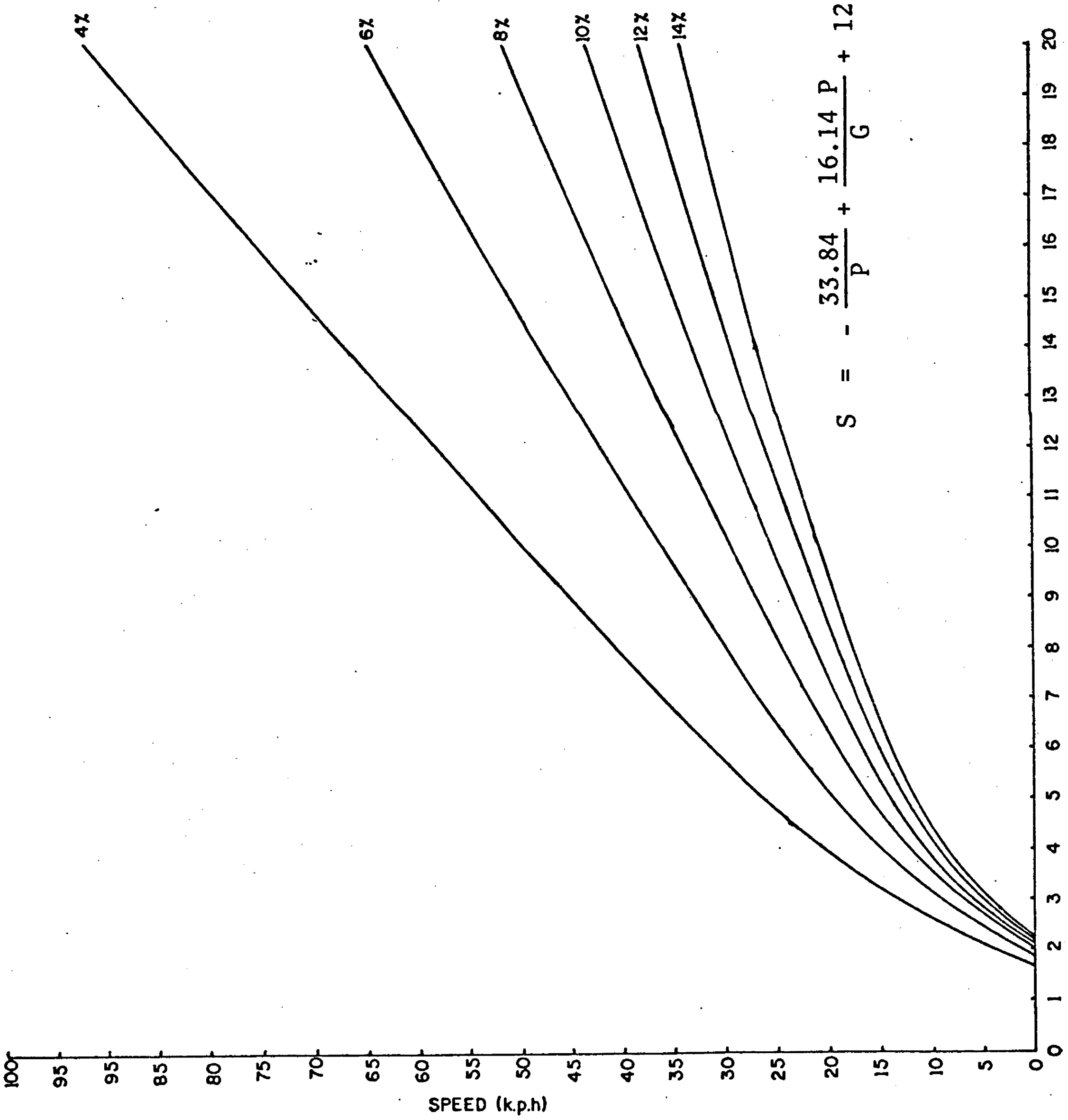


Figure 3.3.2. Representation of gradient length Model No. 2.

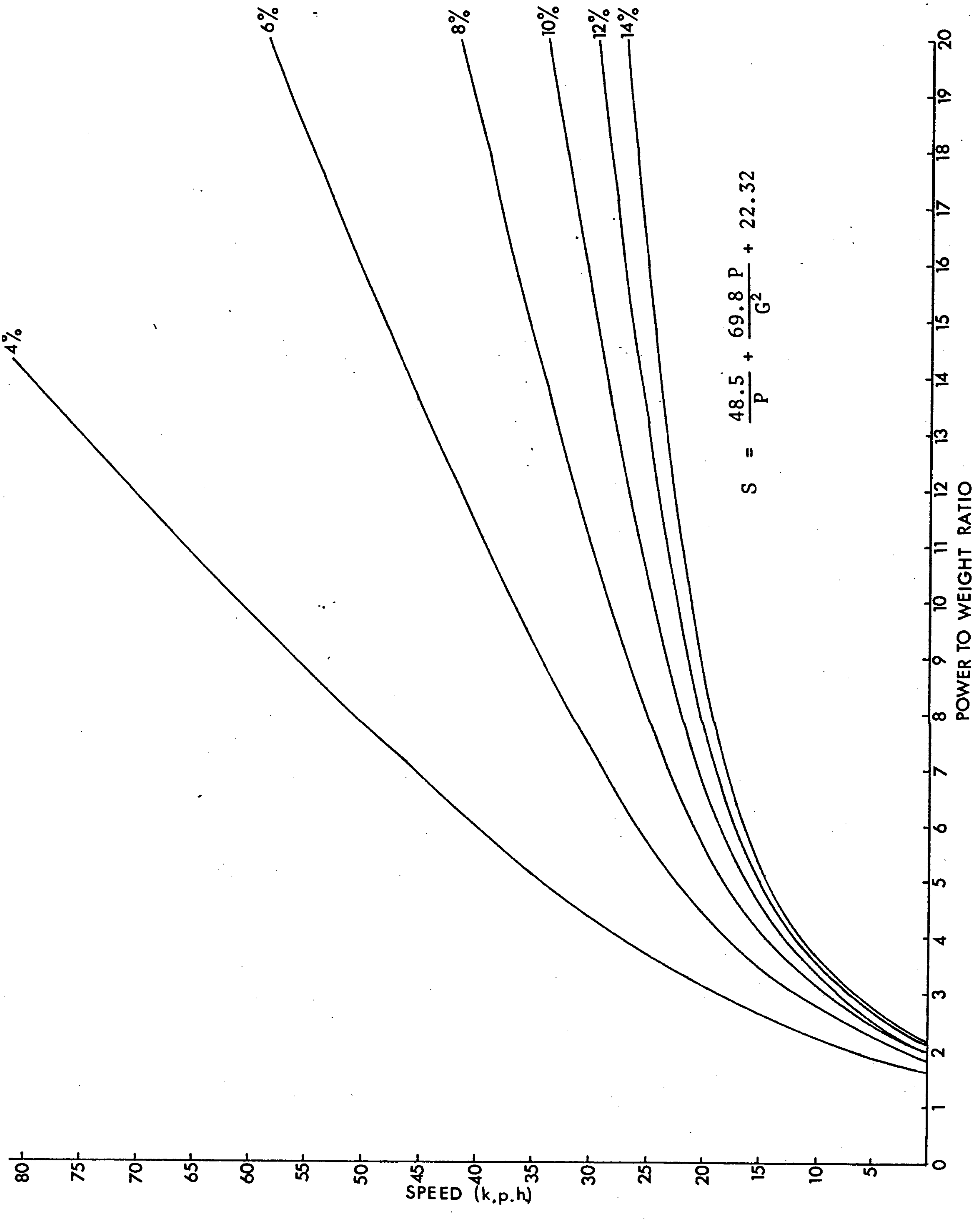


Figure 3.3.3. Representation of gradient length Model No. 3.

b_0; $t = 12.7044$

b_1; $t = 15.1673$

b_2; $t = 7.7399$

as compared with $t = 1.986$ from Table 2 in Freese [1967] for significance at the 5% level.

The coefficient of multiple determination for this regression was 0.7518 so that 75 per cent of the variation in "S" was associated with the regression.

Bartlett's test for homogeneity of variance gave a chi-square value of 12.788 for eight degrees of freedom. The value from Table 4 in Freese [1967] was 15.51 and therefore the assumption of homogeneity of variance was not rejected by the test.

The tests for skewness and kurtosis, after Snedecor and Cochran [1967], indicated that the assumption that the residuals followed a normal distribution would not be rejected.

The Durbin-Watson "d" statistic for serial correlation was calculated to be 1.8394 and as this was greater than the tabulated value of 1.74 in Snedecor and Cochran [1967] the acceptability of the regression was not altered because of serial correlation.

Model 1 was therefore accepted as the best representation of the data.

3.9.5 The Accepted Model

The simple straight line form

$$S = 207/G + 2.70\ P - 28$$

was accepted as the best available regression. However, the analysis indicated that it was only acceptable within the range of the measured data. While further refinement of the model using more appropriate weighting factors is desirable, further field measurements over a greater range of grades and traffic conditions are also necessary. Nevertheless the model provides a good basis for the review of the specification of lengths of grades in excess of sustained maximum and this is discussed in Chapter Five.

CHAPTER FOUR

ANALYSIS OF LOG TRUCK LOADS IN THE A.C.T.

4.1 PRELIMINARY ANALYSIS

The load data from the weighbridges, obtained through the A.C.T. Forest Branch, was computer-sorted according to truck identification and date and time of weighing. Twenty-one different trucks were included in the two accounting periods sampled. A computer program was written to calculate the following data for each of the twenty-one trucks. A listing of the computer program is shown at Appendix 4.1.

Number of loads in the period
Average gross vehicle weight
Average nett vehicle weight
Average number of loads per day
Total payload hauled in the period
Number of days worked
Average payload haul per work day
Standard deviation of gross loads
Standard deviation of nett loads
Coefficient of variation (per cent) of gross loads
Coefficient of variation (per cent) of nett loads.

The results are summarized in Tables 4.1, 4.2 and 4.3.

The classification of trucks shown in Table 4.1 was adopted to enable comparison of truck loads by truck type and by destination as the destination determined the maximum load allowed on the truck by regulations in New South Wales and by Forests Branch requirements in the Australian Capital Territory. Shaw [1974] in discussing the variation

Table 4.1

Truck Groups and Load Destination

Group No.	Group Type	Destination (by registration number)		
		N.S.W.	A.C.T.	Special A.C.T.
1	Volvo Semi-Trailers	FRO798	YAH268	
		FRO838	YGL658	
		FRO854	YFK109 -----	YFK109
		FRW121		
2	International Semi-Trailers	FRS232 --	FRS232	
		FSE829	FRS229	
		FSG597		
3	International Table Top Bogey Drive	FSY537	FTE265	
			YGF408	
4	International Table Top Single Drive	YDI807	FRW128	
			ZIF000	
5	Other Semi-Trailers	FRO799[1]		
		ZIF055[2] --	ZIF055	
			YFI018[3]	
6	Other Tabletop		FQA027[3]	

1) Fiat
2) Mack
3) Leyland.

in loads from Uriarra Forests did not differentiate between loads bound for mills in the Australian Capital Territory and those taken outside the Territory and some of the variation in loads would be due to a deliberate difference in the load carried because of the different destinations.

The differences in the permitted loads carried by trucks in the Australian Capital Territory and in New South Wales is very

Table 4.2

Log Truck Loads in the Australian Capital Territory
23.6.75 - 30.8.75

T.T. ≡ Table Top
B.D. ≡ Bogey Drive
S.D. ≡ Single Drive
Semi ≡ Semi-trailer

Truck Registration Number	Truck Type and Configuration	Load Limits Applying	No. of Loads	Av. Loads Per Day	Av. Daily Haul (kg)	Total Payload in Period (kg)
FQA027	Leyland T.T.	A.C.T.	51	1.38	21,063	779,320
FRO798	Volvo Semi	N.S.W.	1	1.00	24,525	24,525
FRO799	Fiat Semi	N.S.W.	4	1.00	18,876	75,505
FRO838	Volvo Semi	N.S.W.	36	1.00	21,825	785,700
FRO854	Volvo Semi	N.S.W.	2	1.00	21,347	42,695
FRS229	International Semi	A.C.T.	85	1.73	54,541	2,672,515
FRS232	International Semi	A.C.T.	2	1.00	28,770	57,540
FRW121	Volvo Semi	N.S.W.	2	1.00	20,930	41,860
FRW128	International T.T.S.D.	A.C.T.	41	1.46	17,267	483,475
FSE829	International Semi	N.S.W.	14	1.00	16,581	232,140
FRS232	International Semi	N.S.W.	28	1.00	17,566	491,850

Table 4.2 (cont'd)

Truck Registration Number	Truck Type and Configuration	Load Limits Applying	No. of Loads	Av. Loads Per Day	Av. Daily Haul (kg)	Total Payload in Period (kg)
FSG597	International Semi	N.S.W.	5	1.00	19,764	98,820
FSY537	International T.T.B.D.	N.S.W.	10	1.00	11,828	118,285
FTE265	International T.T.B.D.	A.C.T.	142	2.78	43,233	2,204,880
YAH268	Volvo Semi	A.C.T.	242	4.05	132,235	7,900,440
YDI807	International T.T.S.D.	N.S.W.	5	1.67	18,560	55,680
YFI018	Leyland Trailer/T.T.	A.C.T.	55	1.72	33,453	1,070,490
YFK109	Volvo Semi	S/A.C.T.	5	2.56	57,285	111,885
"	" "	A.C.T.	59	2.56	79,511	1,832,460
YGF408	International T.T.B.D.	A.C.T.	101	2.46	39,010	1,599,410
YGL658	Volvo Semi	A.C.T.	74	3.08	95,570	2,293,685
ZIF000	International T.T.S.D.	A.C.T.	3	1.00	10,923	32,770
ZIF055	Mack Semi	N.S.W.	36	1.06	19,927	677,535
Totals			1004			23,717,150

Table 4.3

Log Truck Load Distributions
Australian Capital Territory

Truck I.D.	Destin-ation	Average Gross Wt (kg)	Average Nett Load (kg)	Standard Deviations		Coefficients of Variation %	
				Gross Wt	Nett Load	Gross Wt	Nett Load
Group 1: Volvo Semi-trailers							
FRO798	N.S.W.	36,025	24,525	Only one load in period			
FRO838	N.S.W.	36,142	21,825	1483.675	1545.916	4.11	7.08
FRO854	N.S.W.	35,562	21,347	1290.470	1290.470	3.63	6.05
FRW121	N.S.W.	35,550	20,930	3111.270	3111.270	8.75	14.87
YAH268	A.C.T.	46,515	32,651	3055.418	1899.884	6.57	5.82
YFK109	S/A.C.T.	37,153	22,377	2068.523	2085.378	5.57	9.32
"	A.C.T.	45,840	31,059	2145.079	2119.777	4.68	6.83
YGL658	A.C.T.	45,724	30,996	3706.217	3003.340	8.11	9.69
Group 2: International Semi-trailers							
FRS232	N.S.W.	28,266	17,566	1165.011	1172.273	4.12	6.67
FSE829	N.S.W.	25,841	16,581	1095.436	1097.441	4.24	6.61
FSG597	N.S.W.	29,786	19,764	1698.550	1697.076	5.70	8.59
FRS232	A.C.T.	39,780	28,770	1555.635	1569.777	3.91	5.46
FRS229	A.C.T.	42,476	31,441	1702.850	1726.317	4.01	5.49

Table 4.3 (cont'd)

Truck I.D.	Destination	Average Gross Wt (kg)	Average Nett Load (kg)	Standard Deviations		Coefficients of Variation %	
				Gross Wt	Nett Load	Gross Wt	Nett Load
		Group 3: International Tabletops, Bogey Drives					
FSY537	N.S.W.	18,678	11,828	1143.114	1143.115	6.12	9.66
FTE265	A.C.T.	23,453	15,527	675.519	665.120	2.88	4.28
YGF408	A.C.T	24,349	15,836	847.931	826.802	3.48	5.22
		Group 4: International Tabletops, Single Drives					
YDI807	N.S.W.	15,366	11,136	741.798	741,799	4.83	6.66
FRW128	A.C.T.	17,283	11,792	1243.255	1007.120	7.19	8.54
ZIF000	A.C.T.	18,040	10,923	2556.422	3540.870	14.17	32.42
		Group 5: Other Semi-trailers					
FRO799	N.S.W.	30,681	18,876	2020,843	2081.432	6.59	11.03
ZIF055	N.S.W.	32,199	18,820	1524.720	1472.700	4.74	7.83
YFI018	A.C.T.	35,130	19,463	9001.453	6921.088	25.62	35.56
		Group 6: Other Tabletops					
FQA027	A.C.T.	26,267	15,281	1185.785	1185.910	4.51	7.76

significant for the economics of hauling wood from Kowen Forest. Kowen Forest will eventually be the largest of the forests forming the plantations of the Australian Capital Territory. The most direct route to the Integrated Forests Product mill is via Queanbeyan and New South Wales load limits would apply along this route. This is discussed in more detail later.

The differences are also important in formulating an appreciation of the relatively liberal maximum loads permitted on log trucks in the Australian Capital Territory and the consequences of stricter control of maximum loads. Traffic volumes on the roads in the Australian Capital Territory are building up rapidly and log trucks are regularly moving through urban areas subject to peak hour traffic. It was obvious during the study that some trucks were loading close to their maximum safe capacity and further accidents under such conditions could bring public criticism and pressures for a reduction in the size and weight limitations applicable to the log trucks, in particular that they conform more closely to loads applying in the States.

The coefficient of variation (per cent) shown in Tables 4.2 and 4.3 was calculated to facilitate comparison of variability about different sized means. It was determined by the ratio of the standard deviation to the mean as a percentage [Freese, 1967]. Table 4.3 shows that in general the coefficient of variation was less than 10%. The several exceptions will be discussed later.

4.2 FACTORS AFFECTING LOADS

Legal Limitations

Information regarding regulations by the State of New South Wales on maximum axle loads and loaded weights is at Appendix 2.4. The limits are set out in Ordinance No. 30C of the Local Government Act, 1919, as amended. The regulations provide that a driver receives a written caution if he exceeds the load limit by up to 0.5 tonnes and he may be prosecuted for greater overloads.

The penalties imposed are usually substantial and to avoid them while endeavouring to regularly carry up to the legal load limit would require a rather fine judgement at the loading site, especially where many small logs are being loaded.

Trucks hauling within the Australian Capital Territory are bound by the Forests Branch requirement of 48 tonne gross limit for semitrailers. The penalties incurred for exceeding this generous limit, unloading excess wood at the weighbridge and weighing twice, are matters of inconvenience rather than sanctions as imposed in New South Wales.

Wood Density

Wood density varies with species, age, site quality, the season, and how long it has been cut before haulage.

The forests in the Australian Capital Territory experienced severe windthrow damage in 1974. The salvage of this material took over twelve months as a market downturn occurred about the same time. Consequently many of the logs seasoned in the forest and were less dense than freshly felled standing trees. The seasoning would make judgements on the load more difficult and may have led to increased variability.

Wood from the plantations in the Australian Capital Territory is marketed on a volume basis using a variable weight conversion factor calculated for each operation. A sample load measuring system is employed to enable calculation of volumes from weight measurements. One load in ten from each compartment is measured for length and end diameters and all loads are weighed. The driver of the truck can therefore adjust his loads by judgement based on the known weights of delivered loads and it would be expected that the variation in loads would be higher at the beginning of a new operation.

Log Diameter

The variability in log diameter between operations is another factor adding to the difficulty of making an accurate judgement of the weight of a load [Shaw, 1974]. This variability also affects the loading time. The effect of smaller log sizes on loads can be seen in Tables 4.2 and 4.3 for the Volvo semitrailer, registration number YFK109, when it hauled in the A.C.T. "S" operation.

Log Length

Logs are sold from the plantations in the Australian Capital Territory in terms of set lengths. Logs must be separated into lengths and trucks only haul one or two length classes in each load. Sufficient logs of a certain length class to make up a load are not always available at a dump and smaller loads than the maximum allowable would then be hauled. Thus the availability at a dump of logs by length class can cause variability in the loads hauled.

Availability, on a dump, of particular length classes is a reflection of the coordination of the cutters with existing market outlets. At times this coordination breaks down or is affected by bole length or the cutters' arithmetical prowess.

Availability of Weighbridge Facilities

The two weighbridges used in the Australian Capital Territory do not operate on a twenty-four hour basis but virtually from 6 a.m. to 6 p.m. on week days. The Kingston weighbridge is also open from about 7 a.m. till 12 noon on Saturdays.

Truck drivers were therefore, on some occasions, under pressure to load quickly to ensure reaching the weighbridge in time for weighing. Late afternoon loads may therefore have been loaded quickly to the detriment of achieving the maximum allowable load and consequently cause variability in the loads.

However, it should be said that as a general rule, drivers preferred to get out to the forest early in the morning and arrive loaded at the weighbridge relatively early in the day and thus maximize the potential time available for hauling during that day. This routine was especially noticeable with tabletop trucks.

Several of the semitrailer prime movers operated several trailers. This system provided increased flexibility in terms of loading and fitting into the weighbridge times and thus reduced the tendency to rush loading at the expense of achieving the maximum load. The Volvo semitrailer registration number YAH268 was operated with this system and, as shown in Tables 4.2 and 4.3, heavy loads with a uniform distribution were regularly achieved.

Efficiency of the Loading Operation

Various types of loading equipment are in use in the plantations and it must be expected that the type of equipment would be a factor in how well and uniformly the trucks were loaded.

The Volvo semitrailer YFK109 is an example of where the loading equipment affected the load variability. This truck was hauling from two types of operations. At one an efficient loader and larger sized logs assisted the attainment of heavy uniform loads. At the other operation the loading equipment was not as efficient for the size of logs loaded. As shown in Tables 4.2 and 4.3, this resulted in smaller loads with a reduction of 28% and a 2.5% greater variation in the mean of the payload size. However, it should also be noted that the data available does not permit the separation of the effects of various parameters affecting the load variability and the decreased loads may also have been due to the driver taking smaller loads at the less efficient loading operation in order to reach the weighbridge in time.

Weather Conditions

The accessibility at some dumps was contingent on the weather conditions and in wet weather drivers worked only from dumps where they could be sure that their trucks would not become bogged or slip off the road. These dumps would have limited log stocks and the accretion rate would be slow at the time because of the more difficult snigging conditions. In some cases, snigging ceased while road transport continued on consolidated roads. Drivers were prepared to take a smaller load in these situations, reflecting the view that it was better to be using the trucks to haul small loads rather than have them and the drivers idle while waiting for better operating conditions.

It should also be conceded that contractors realise that apart from the greater difficulties in the haulage of heavy loads along wet and cut-up roads, because of decreased traction, the heavy loads do more damage to logging roads. Damage to roads in wet conditions often allows water into the subgrade. Maintenance is then delayed, and when commenced more work is involved, so delaying operational use of the road.

Standard of the Roads

Although the intensity of the road network in the plantations of the Australian Capital Territory is relatively high the standard is often low, particularly relative to the requirements for semi-trailers. Low radius curves, bad combinations of vertical and horizontal curves, steep gradients, incorrect superelevation to the degree of unsuitability, eroded table drains seriously detracting from the road width and overhanging trees all contribute along particular sections to reducing the load below the maximum allowable.

Availability of Logs on Dumps

The effect of wet weather on the availability of logs at dumps as a contributing factor to the variation which occurs in the loads carried by trucks has already been mentioned.

Log haulage can catch up to the snigging operations, that is the stockpile at dumps is run down, for reasons other than wet weather, for example plant breakdown, sickness and absenteeism. There is then a tendency to take smaller loads rather than wait for suitable logs.

At the time that logging of a compartment is almost complete and cleaning up is in progress the last few loads may be below the maximum allowable because that was the last of the wood at the compartment and loading could not be undertaken at the next operation. This problem is accentuated in the Australian Capital Territory because of haulage by log length class.

Safety and Bravado

The attitude of the driver towards the safety of himself, his truck and other road users and how well he can estimate the safe limits of his equipment for the prevailing conditions are also factors influencing the size and variability of loads. Thus variations in loads hauled by identical trucks will depend to a great extent on the particular driver. This was especially the case in taking the logs to a destination in New South Wales and a driver who would like to overload with respect to the weight regulations assesses the risk of a fine as a consequence of being caught with an overloaded truck by transport inspectors.

One further observation was made in relation to the skill with which drivers estimated the loads. Owner drivers were more careful with their trucks and consistently tended to load them to a limit which they had set. Employees driving company trucks tended to vary the loads more than the owner drivers. Employees driving government vehicles seemed to be more conservative in the loading of the trucks relative to owner drivers and those driving company trucks.

4.3 ANALYSIS OF RESULTS

4.3.1 Load Variation

Tables 4.2 and 4.3 show that the percentage coefficient of variation of the net loads is less than 10% for all except four cases and these are discussed below.

The Fiat semi-trailer, registration number FRO799, was hauling to New South Wales and data on only four loads was collected. The range of the payloads varied from 16.6 tonnes to 21.6 tonnes. The two lighter loads were hauled when a heavier trailer was used, thus reducing the allowable payload because of the weight limitations applicable in New South Wales. The coefficient of variation of the gross weights for this truck was 6.6% whereas the coefficient for the payload was 11.0%.

The second truck with a nett load coefficient of variation greater than 10% was a Volvo semitrailer which only hauled two loads during the period and the coefficient of variation is therefore not a reliable indication of the load variations with this vehicle.

The third truck, and the one with the greatest variation in loads was a Leyland. During part of the study period this truck was used as a tabletop plus dog trailer. However, serious problems were experienced with the dog trailer during wet weather as it slipped off narrow roads and became bogged. As well as being inconvenient and dangerous, reduced loads had to be hauled and the owners decided to extend the chassis and the tabletop tray and discard the dog-trailer. This reduced the overall payload but improved the handling and safety. This heavy and powerful truck (216 kW) also caused anomalies with the radar speed recordings as various drivers handled the truck differently with regard to speeds on grades.

The other truck with nett load coefficients of greater than 10% was the International tabletop owned by the Forests Branch. This truck was also modified during the period. A variation in truck weight of almost two tonnes for one of the loads contributed to the variation in the gross variation coefficient and the use of the truck for experimental purposes also contributed to the variability of its loads.

By way of contrast, the coefficient of variation for the four trucks making the most trips during the study period are summarized below:

Truck Type Registration Number	Number of loads	Coefficient of Variation Per Cent Gross Load	Nett Load
International Semi FRS229	85	4.0	5.5
International Table Top YGF408	101	3.5	5.2
International Table Top FTE265	142	2.9	4.3
Volvo Semi-trailer YAH268	243	6.6	5.8

These four trucks hauled 14,400 tonnes of logs in the study period. This was 60.8% of the total tonnage hauled. The nett loads had coefficients of variation of less than 6% in all cases. The two semi-trailers had standard deviations of less than two tonnes per payload and the two tabletops standard deviations of less than one tonne.

The Volvo semi-trailer registration number YAH268 is of special interest as this truck left spare trailers at the loading sites and the coefficient of variation of the gross weights was greater than for the nett loads. This was the only truck for which this result was obtained and it is concluded that this was due mainly to the differences in the weights of the trailers.

Thus there are explanations for the higher coefficients of variability and in general the coefficients of variability indicate surprisingly consistent loading by the truck operators, when considering the number of factors involved and results indicated by Shaw (1974).

Nevertheless the standard deviations shown in Table 4.3 are high in relation to the excess loads invoking a caution or a fine under the legislation applying in New South Wales. An over load less than 0.5 tonnes over the legal limit would invoke a caution while an over load of 0.5 tonnes or more would result in prosecution (*op. cit.*, p.76).

All the standard deviations shown in Table 4.3 exceed 0.5 tonnes. Freese (1967) suggests that "on the average about two thirds of the unit values of a normal population will be within 1 standard deviation of the mean. About 95 per cent will be within 2 standard deviations and about 99 per cent within 2.6 standard deviations." It is clear therefore that to avoid the risk of prosecution for overloading log hauliers would have to under-load by a considerable margin.

The difficulty is partly met in New South Wales by providing a method for assessing the permissible load, of a vehicle hauling "hardwood and brushwood" saw logs, in terms of a volume measurement but the "concession" applies only where the logs are hauled from the forest directly to a mill. However haulage of softwood logs is on a weight basis.

The variability of the loads on log trucks in the Australian Capital Territory, as determined in this study, suggests that there may be a case for special treatment of log haulage in relation to permitted loaded weights of vehicles. The data obtained in this study is not sufficient to enable a review of the provisions existing in New South Wales in relation to actual variability of log loads. A suitable approach for such a review would be to determine the probability of exceeding certain loads from an analysis of the distribution of loads now carried by log trucks in particular haulage operations.

4.3.2 The Effect of Load Size on Speed

The sustained speed and gradient length models developed in Chapter Three provide a quantitative basis for assessing the effects of load size on speed but only in relation to particular gradients. For example, using the sustained speed model represented in Figure 3.2, a Volvo semi-trailer type of truck, with a power to weight ratio of 5.4 when conforming to the A.C.T. Forests Branch requirements but a ratio of 6.9 when conforming to New South Wales regulations, would have sustained speeds of 29.5 kilometres per hour and 36.5 kilometres per hour respectively on a 4% grade. This is a difference of 24%.

While there could be savings in haulage costs as a result of increased speeds as a consequence of a reduction in loads it must be accepted that these savings are more than offset by other savings resulting from increasing loads. To argue otherwise would run counter to the practice, adopted and continued by all the hauliers in the Australian Capital Territory, of substantially increasing the loads hauled when allowed to do so.

The effect of load size on haulage costs was therefore analysed in more detail. The analysis is presented in the next section.

4.4 THE EFFECT OF LOAD SIZE ON LOG HAULAGE COSTS IN THE AUSTRALIAN CAPITAL TERRITORY

4.4.1 Introduction

Logs from the plantations in the Australian Capital Territory are hauled mainly to mills in the Australian Capital Territory but some are hauled to mills in New South Wales. The hauliers carry the permissible loads and that they do suggests that heavier loads are more economic in terms of road haulage costs. The loads accepted in the Australian Capital Territory are substantially greater than allowed in New South Wales.

However heavier loads cause additional road construction costs, particularly for bridges and pavement thicknesses. The data obtained in this study does not enable these additional costs to be estimated but it does provide a quantitative basis for assessing the effects on haulage costs of the different load sizes prevailing in the Australian Capital Territory and New South Wales. The approach adopted was to estimate the costs of hauling wood from the plantations in the Australian Capital Territory for one year under the load limits applied by A.C.T. Forests Branch and if the limitations on load size enforced in New South Wales were applied to the Australian Capital Territory. The principal assumptions are in relation to the costs of operating vehicles.

4.4.2 Log Haulage from the A.C.T. Plantations

The three major productive forest areas in the Australian Capital Territory are at Kowen, Uriarra and Pierce's Creek. The major single market is the Integrated Forest Products mill on the Monaro Highway near the intersection with the Long Gully Road. The approximate average haul distance from each of the forests to this mill is as follows:

Forest	Sealed km	Unsealed km	Total Distance km
Kowen	13	5	18
Pierce's Creek	37	3	40
Uriarra	34	16	50

At the time data was obtained for this study harvesting operations were in hand mainly at Uriarra and Pierce's Creek forests. The Kowen forest will eventually be the largest forest in the Australian Capital Territory and calculations of haulage costs for the Kowen wood have been based on observations made on the haulage of wood from Uriarra and Pierce's Creek.

The type of truck and the number of trips per day are important parameters in estimating haulage costs for they determine the number of trucks required and hence the capital invested in road haulage and on which there must be an appropriate return for the operation to remain economically viable. To compare the effect of load size on haulage cost one type of truck, a Volvo semitrailer, was selected.

About 55% of the total haulage of wood from the A.C.T. plantations during the sample period was done by Volvo semi-trailers. Seven individual trucks were used although some only hauled a few loads. The G88, G89, N10 and N12 Volvo models were represented in the load data available. The G88 and N10 models have power ratings of 190 kW at 2200 r.p.m. and the G89 and N12 models 243 kW at 2200 r.p.m. Both ratings are DIN. Volvos were chosen for the study because of their apparent popularity, and because information on them was readily available. They also had design adaptations for forest operations.

The retail price of the model designed for logging was about $50,000 at the beginning of 1976 made up of $42,000 for the prime mover and $8,000 for the trailer.

The Volvo trucks operating in the Australian Capital Territory often had trailers designed and built by different companies and so the tare weight of the vehicles varied. An average tare weight of 14 tonnes was calculated from all recordings obtained from the weighbridge.

The information on nett loads hauled by Volvo trucks, given in Table 4.4, was based on data collected for this study. The data available was separated into those hauling within the Australian Capital Territory and those hauling subject to the New South Wales regulations. The period covered by the data was 23.6.75 to 30.8.75.

Table 4.4

Average nett loads Volvo Semi-trailers

Item	Destination	
	N.S.W.	A.C.T.
Number of Loads	41	381
Total Nett Weight	894,780 kg	12,172,150 kg
Average Payload	21,820 kg	31,950 kg

Difference in average payload	10,130 kg
Total nett weight hauled	13,066,930 kg

If the total haulage of 13,066,930 kg had all been hauled within the Australian Capital Territory then only 409 trips would have been required to haul it as compared to 599 if it had all been hauled to

New South Wales. This would represent an increase in the number of trips of 46 per cent.

Where a truck was using more than one trailer and efficient loading equipment and long hours were worked then five or six loads per day could be hauled from Uriarra Forest to the mill operated by Integrated Forest Products Pty. Ltd. A more common figure obtained as an average from information collected at the weighbridge was four loads per day. The daily distance travelled by a vehicle taking four loads a day from Uriarra would be 400 kilometres, that is allowing 50 kilometres per trip.

Using this daily distance and a round trip distance of 40 kilometres it was estimated that five trips per day could be taken from the Pierce's Creek forest. Actual data was not available for the Kowen forest. Using a round trip of 36 kilometres and a total distance per day of 360 kilometres it was estimated that ten trips per day could be taken from Kowen forest. The reduction in the total distance travelled in one day as compared to the actual performance when working from Uriarra was to allow for additional coupling and uncoupling of trailers and for weighing and unloading at the mill.

The following assumptions were made to estimate the number of days worked in an average year:

(1) Sundays were not worked — 52 days off.

(2) Public holidays — 10 days off.

(3) Half days worked on Saturday except six long weekends — 29 days off.

(4) Regular truck maintenance — 12 days off.

(5) Wet weather, fire conditions — 12 days off.

On this basis it was estimated that 250 days per year could be worked by a truck.

The average load carried by Volvo semi-trailers in transporting wood within the Australian Capital Territory is 31,950 kilograms. The annual tonneage hauled and the distances travelled in one year, based on the above assumptions, are summarized in Table 4.5.

Table 4.5

Log haulage in the A.C.T.
Estimated performance of a Volvo semi-trailer.

Log Source	Loads per Day	Annual Distance km	Total Tonneage
Kowen	10	90,000	80,000
Pierce's Creek	5	100,000	40,000
Uriarra	4	100,000	32,000

If the annual tonneage shown in Table 4.5 had to be hauled under the limitations on loads enforced in New South Wales then additional loads would be necessary. On the other hand the truck speed with the smaller load may increase.

The data obtained in this study does not enable an accurate and detailed comparison between the haulage costs associated with the different weight limitations applicable in the Australian Capital Territory and New South Wales but the information on loads and travel times does enable the difference in costs to be placed in perspective.

The approach adopted for the comparison was to estimate the number of trips per day for a log truck loaded in accordance with New South Wales limitations as compared to a load accepted by the Forests Branch in the Australian Capital Territory.

The working day for log trucks in the Australian Capital Territory seemed to extend from 6.00 a.m. to 6.30 p.m. and actual driving time is probably about ten hours. There is not therefore a great deal of scope for additional trips by extending the present working hours of a truck unless the weighbridge was opened for longer hours and a second driver employed.

Observations and measurements in this study suggested that trucks, both loaded and empty, operate at speeds which are close to safety limits and often exceed legal limits. While lighter loads may therefore theoretically enable higher speeds for loaded trucks the poor standard of forest roads and the other traffic on the public roads may preclude this. The question was therefore asked if a reduction in load to the New South Wales load limits would enable one additional trip from Kowen, Pierce's Creek and Uriarra. It was concluded for the following qualitative reasons that it would not:

- trucks are operating over a long period each day;
- there would be time taken loading in the forest and at the mill for the additional trip and this would offset the reduction in loading time for the lighter loads;
- there would be no change in the time for the return journeys if the loaded weight of the truck was changed;
- increased speeds of trucks due to a reduction in load would provide only marginal savings in time relative to the above factors.

4.4.3 Haulage Costs

Original data on owning and running costs for log trucks was not collected in this study. Data was available from records kept by the Forest Branch on its two trucks but these costs would not be typical of the more active privately owned vehicles. Consequently, data from secondary sources was selected for determining costs associated with log haulage.

Special Report No. 9 of the Australian Road Research Board, published in October 1973, was the main source of cost data. The costs in that publication have been updated using the Consumer Price Index. Recent values of the index are given in Appendix 4.2. Table XIV(a) of the Special Report was used as a basis for estimating the levels of costs of operating a Volvo semi-trailer log truck. The information is shown in Table 4.6.

A cost of 38.4 cents per kilometre was adopted as the cost of operating a Volvo semi-trailer, this is approximately the mean of the corrected cost for the six axle tipper and the five axle tanker. The maximum payload of the Volvo, when loaded in accordance with New South Wales limitations, is 21.8 tonnes and lies between the six axle tipper and the five axle tanker as shown in Table 4.6.

Table 4.6

Cost data for trucks.

Item	Six Axle Tipper	Five Axle Tanker
Tare weight (tonnes)	11.8	13.4
Maximum payload (tonnes)	25.1	18.9
Gross weight (tonnes)	36.9	32.3
Annual distance (km)	85,300	139,400
Total vehicle operating costs (cents/km)	32.3	34.7
Corrected cost for set annual distance (cents/km)	34.9	41.9
Total fixed costs	56.0%1)	57.8%1)
Total variable costs	31.5%1)	29.8%1)
Overheads	12.5%1)	12.5%1)

1) Per cent of total costs.

Source: Table XIV(a), Special Report No. 9, Australian Road Research Board [1973].

Table XIV(a) in the Special Report also indicated that an increase in load of the order of that allowed in the Australian Capital Territory, as compared to New South Wales, would involve an increase in round trip cost factors of approximately 1.5 cents per kilometre. This was adopted as the difference between the total vehicle operating costs, and the costs, as at June 1970, for a vehicle carrying the average log truck loads in the A.C.T., was thus approximately 40 cents. Breaking this unit cost down in accordance with the percentages shown in Table 4.6 for fixed, variable and overhead costs gave the following:

Fixed costs	22.8 cents per kilometre
Variable costs	12.2 cents per kilometre
Overheads	5.0 cents per kilometre.

The Consumer Price Index was applied to these unit costs to update them to March 1976, the increase being 77.5 per cent. The unit costs as at March 1976 are summarized in Table 4.7.

Table 4.7

Volvo semi-trailer
Estimated costs of log haulage
cents per kilometre

Costs	N.S.W. Loads	A.C.T. Loads
Total	68.2	70.8
Fixed costs	38.8	40.2
Variable	20.9	21.7
Overheads	8.5	8.9

4.4.4 Haulage Costs from A.C.T. Forests

If a Volvo semi-trailer operated exclusively from one of the three main forests in the Australian Capital Territory the payloads and costs per tonne shown in Table 4.8 would apply over a full working year, assuming the unit costs shown in Table 4.7.

Table 4.8

Log haulage from A.C.T. forests
Estimated annual payload, haulage costs, costs per tonne.

Log Source	Distance per Year km	Annual Payload tonnes	Haulage Cost		Cost per Tonne $
			cents/km	Total $	
		A.C.T. Load Limits			
Kowen	90,000	80,000	70.8	63,720	0.80
Pierce's Creek	100,000	40,000	70.8	70,800	1.77
Uriarra	100,000	32,000	70.8	70,800	2.22
		N.S.W. Load Limits			
Kowen	90,000	55,000	68.2	60,800	1.13
Pierce's Creek	100,000	27,300	68.2	68,200	2.50
Uriarra	100,000	21,800	68.2	68,200	3.13

The costs shown in Table 4.8 are estimates only but the order of the effect of the lighter loads can be clearly seen. The lighter loads would mean an increase of nearly 33 cents per tonne for Kowen, 73 cents per tonne for Pierce's Creek and 91 cents per tonne for Uriarra.

4.4.5 Log Haulage from Kowen Forest — Australian Capital Territory

The geographic location of Kowen forest in relation to the mill at Integrated Forest Products makes the log haulage to the mill a special case. The shortest route to the mill currently involves an incursion into New South Wales. Using this route the loads would have to meet the limitations on load limits enforced in New South Wales.

The payload in one year for a Volvo semi-trailer hauling through New South Wales would be, as shown in Table 4.8, 55,000 tonnes unless fines were risked. The annual cost of haulage would be \$60,800 or \$1.13 per tonne.

Hauling this weight of timber with the 32 tonne payload that would prevail under A.C.T. limits would require 1,722 loads as opposed to 2,520 loads, a decrease of about 800 loads. The approximate haulage cost for the 1,722 loads would be

$$1722 \times 36 \times 0.708 = \$43,900$$

and only 157 working days would be required. This would leave 93 working days for further hauling from Kowen or alternatively from Pierce's Creek or Uriarra. Thus in haulage cost terms only there would be a saving of \$16,900. The cost of haulage would be \$0.80 per tonne.

Providing that regulations similar to those applicable in New South Wales are not introduced into the Australian Capital Territory considerable cost savings could be achieved by travelling a route which avoids the New South Wales roads, namely via Pialligo, Fyshwick, Hindmarsh Drive and thence to the Monaro Highway. The distance by the alternative route would be approximately 26 kilometres and the round trip 44 kilometres as the truck could return empty through New South

Wales. The information available from Special Report No. 9 (*op. cit.*, p.91) does not enable a distinction to be drawn between the cost per kilometre for loaded and unloaded trucks. Assuming 70.8 cents per kilometre the cost of the round trip which delivered 32 tonnes would be 44 × 0.708 = $31.15 or $0.97 per tonne.

The calculations suggest that there could be considerable savings in avoiding the haulage of wood from Kowen along New South Wales roads and alternative routes should be investigated in detail.

CHAPTER FIVE

REVIEW AND CONCLUSIONS

5.1 INTRODUCTION

The loads hauled by log trucks to mills in the Australian Capital Territory can be much higher than would be permitted on log trucks hauling over roads in New South Wales. The range in loads carried by log trucks in the Australian Capital Territory is therefore much greater than would be expected in New South Wales because the wood from the plantations in the Australian Capital Territory is hauled to mills in the Territory and in New South Wales. This provided the opportunity to obtain data on the speeds of log trucks with substantially different loads and in this study the speeds of log trucks over selected sections of road were measured with a radar meter. The loads on these trucks were obtained from weighbridge dockets.

The data obtained enabled the development of predictive models for the sustained speeds of log trucks and for the speeds of the trucks after travelling 150 metres up an adverse grade. It has also enabled the actual variability of loads hauled by log trucks to be compared with the excess load that would invoke prosecution in New South Wales.

The payloads of log trucks hauling only on roads in the Australian Capital Territory are much greater than for trucks carrying only the loads permitted by regulation in New South Wales. The information obtained in this study from weighbridge dockets, together with haulage costs based on published data enabled calculations to indicate the substantial savings that occur in log haulage costs in the Australian Capital Territory as a consequence of carrying the relatively heavy loads.

The predictive models developed in this study relate the speeds of log trucks to the power of the vehicle, the gross weight and the grade of the road. The sustained speed model provides basic data to determine the optimum maximum sustained grade for a forest road. The gradient length model predicts the speeds of vehicles after travelling 150 metres of an adverse grade and indicates that log trucks would reach sustained speeds over relatively short sections of road and suggests that the practice of specifying grades exceeding sustained maximum over defined lengths should be reviewed for forest roads.

5.2 THE SUSTAINED SPEED MODEL FOR LOG TRUCKS

Measured values of sustained speed were related to power of the vehicle, gross weight and road gradient. The following relationship, illustrated in Figure 3.2, was derived by analysis of the data and statistically validated.

$$S = -\frac{74}{P} + \frac{45\ P}{G^2} + 28 \ ,$$

where S = speed in kilometres per hour;

P = power to weight ratio (watts divided by kilograms);

G = grade in per cent.

The model explained 85% of the variability in speed.

5.3 THE GRADIENT-LENGTH MODEL FOR LOG TRUCKS

The speed of log trucks after travelling 150 metres up an adverse grade was extracted from the measured observations and related to power of the vehicle, gross weight and road gradient. The following relationship, illustrated in Figure 3.3.1, was derived by analysis of the data and statistically validated.

$$S = \frac{207}{G} + 2.70\ P - 28 \ .$$

The model explained 75% of the variation in speed.

5.4 VARIABILITY IN LOG TRUCK LOADS

In general the calculated coefficients of variation of gross and nett loads, shown in Table 4.3, were less than 10% and indicated consistent loading of the log trucks. Nevertheless the standard deviations of the loads hauled by all of the trucks examined are high in relation to the excess load invoking a fine under the legislation applying in New South Wales, namely greater than 0.5 tonnes, and it would be necessary for log truck operators to under-load on average by a considerable margin to avoid the risk of prosecution.

The variability of the loads on log trucks, as determined in this study, suggests that because of special difficulties in judging the weight of the load, there may be a case for special treatment of log haulage, in relation to permitted loaded weights of vehicles, when the log volume is not measured and the load is weighed at a mill.

5.5 THE EFFECT OF LOAD SIZE ON HAULAGE COSTS

On the basis of log haulage with a Volvo semitrailer the calculated differences in payloads carried by trucks hauling on New South Wales roads and those hauling within the Australian Capital Territory was such that there could be an increase in the number of trips of 46% if New South Wales regulations were applied in the Australian Capital Territory.

Based on haulage costs derived from information in Special Report No. 9 of the Australian Road Research Board, the application of the lighter loads of New South Wales to the Australian Capital Territory would result in increased haulage costs of the order of 33 cents per tonne from Kowen Forest, 73 cents per tonne from Pierce's Creek, and 91 cents per tonne from Uriarra.

The study thus indicated the order of the very substantial reductions in the haulage cost of wood that would occur if loads could be based on the capacity of existing trucks rather than allowable loads prescribed by regulation.

5.6 THE SPECIFICATION OF MAXIMUM GRADIENTS FOR FOREST ROADS

There are anomalies between the predictive models developed in this study for sustained speed and for the speed after travelling 150 metres of adverse grade.

The two models are illustrated in Figure 5.1.

The linear gradient length model predicts lower speeds than the sustained speed for grades of 8 to 10% at the lower range of the power to weight ratios.

The deficiencies and difficulties with the gradient length model have already been discussed and it was concluded that additional data was necessary to enable the development of more appropriate weighting factors. There is a special need for additional data on higher grades and for the development of improved weighting factors. In physical terms, the difficulties with the linear gradient length model, which explains only 75% of the variation compared to 85% of the sustained speed model, stem from the greater range of speeds in the trucks as they slow down to sustained speed, and the speeds in the gradient length model reflect, for example, approach speed as well as gradient; approach speed would not be reflected in the sustained speed model.

The sustained speed model is seen as the more reliable model but it would be improved with additional data covering a wider range and this would be desirable before it is applied outside the Australian Capital Territory.

Nevertheless, the two models, developed for different purposes, provide a useful basis for a review of the specification of road gradients.

5.6.1 Sustained Maximum

The determination of the geometric standards of roads is fundamentally a very complicated problem and in practice is therefore

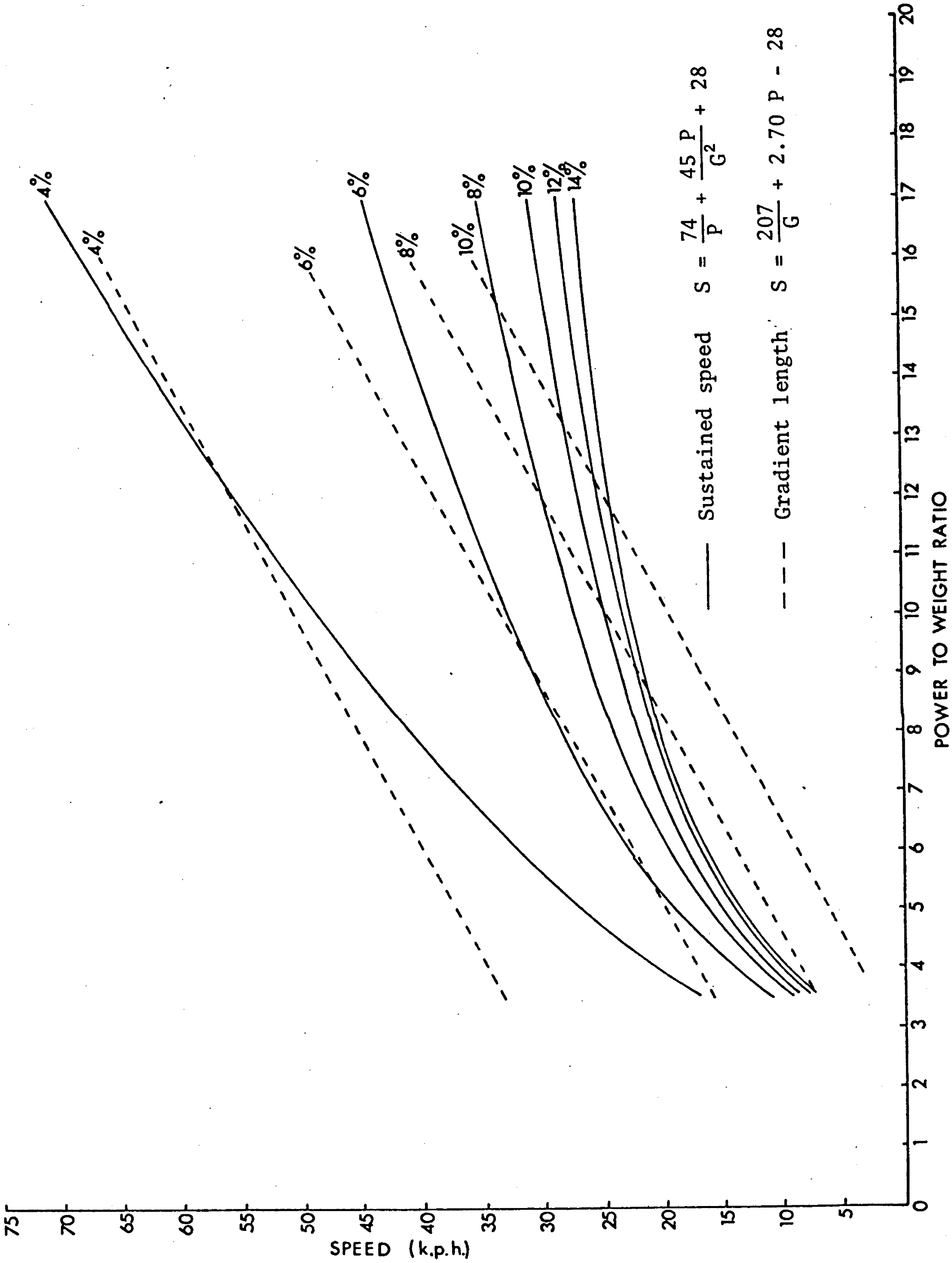


Figure 5.1. Graphical representation of sustained speed and accepted gradient length models.

usually a matter of experience and selection from prescribed standards, for example Table 1.3.

It is desirable that the standard of forest roads be related to the type of traffic on them, the use they receive, and when they are used. As the geometric standard of a road is improved at additional cost, travel time is reduced and haulage costs would usually also be reduced. The optimum standard would be that which minimizes the total costs associated with construction and maintenance of the road and the costs of haulage along it. Discounting of the costs at appropriate rates to a common time is required if the costs occur at different times.

The application of the sustained speed model to determine the optimum maximum gradient of a forest road therefore requires information on the type of truck, the number of trips, when the trips occur, construction and maintenance costs and the selection of appropriate discounting rates. The preparation of generalized charts to enable selection of the most economic maximum grade is therefore outside the scope of this study and additional data and further analysis should be undertaken before recommendations are formulated.

The results of this study suggest that steeper grades than those now generally adopted would be more economic. This is demonstrated by Table 5.1 which has been prepared using the data presented in Figure 3.2. The length of road necessary to gain a certain height increases of course as adverse grades are decreased, but the sustained speeds of trucks on the grades would increase. However Table 5.1 shows that the time to travel the section continues to increase as the adverse grades decrease.

Thus assuming that the costs of road construction and maintenance are constant per unit length and that truck costs are constant per hour of operation, then the road costs and the haul costs both increase as adverse grades are reduced from 14%. Steep maximum grades are therefore indicated as the most economic.

Table 5.1

Length and travel times for maximum grades on forest roads.

Grade	Length[1] of Road	Sustained Speed[2]		Travel Time[3]	
		Power to Weight		Power to Weight	
		6	9	6	9
per cent	km	kph		hours	
14	7.2X	16	21	0.45X	0.34X
12	8.4X	17	22	0.49X	0.38X
10	9.95X	18	23	0.55X	0.43X
8	12.5X	19	25	0.66X	0.50X
6	16.6X	22	30	0.75X	0.55X
4	25.0X	31	44	0.81X	0.57X

1) Slope length calculated from a fixed height 'X' to be gained at maximum grade.

2) Sustained speed from Figure 3.2.

3) Length of road divided by sustained speed.

5.6.2 Length of Grade Greater than Sustained Maximum

An example of the specification of a length of grade greater than sustained maximum for various design speeds is shown in Table 1.3.

The anomalies between the sustained speed and gradient length models have been discussed and are illustrated by Figure 5.1.

Given the anomalies, final conclusions cannot be reached regarding the desirability of retaining, in a specification of geometric standards for forest roads, a length for which a grade in excess of sustained maximum is permitted. Nevertheless the analysis of the data obtained in this study suggests that such a specification as shown in Table 1.3 would be inconsistent for a forest road whose major purpose and economic justification is the transport of wood.

Table 5.2 repeats the grade specifications shown in Table 1.3.

Table 5.2

Design speed criteria for forest roads,
Forest Commission of New South Wales

Grade per cent	Nominal Design Speed kph 100	80	60	50	30	20
Sustained Maximum	4%	6%	6%	7%	8%	10%
Permissible Grade1)	6% (700)	8% (500)	8% (600)	8% (300)	10% (500) 12½% (150)	12½%

1) Figures in brackets show the length in metres for which the permissible grade is allowed

Figure 5.1 shows that the speeds of log trucks, after 150 metres of an adverse grade corresponding to the permissible grade in Table 5.2, are with minor exceptions at very high power to weight ratios, less than the sustained speed at the corresponding sustained maximum grade at each nominal design speed. For example, for a nominal design speed of 80 kph the speed after 150 metres of 8% adverse grade (permitted for 500 metres) is less than the sustained speed on an adverse grade of 6% which is the sustained maximum grade for a nominal design speed of 80 kph.

There seems little point in permitting long lengths of grade greater than sustained maximum grade on forest roads when the speeds after 150 metres on the steeper grade are less than would occur on the sustained maximum grade.

There is a further indication that it is inappropriate to differentiate grades on forest roads in terms of sustained maximum grades and permitted steeper grades over specified lengths. Taking the speeds indicated by the gradient length model against the sustained speed model, see Figure 5.1, and bearing in mind the limitations of the data used to derive the models it is indicated that log truck speeds after 150 metres on an adverse grade are approaching the sustained speeds on that grade.

5.6.3 Summary

The results indicate that relatively steep maximum grades would be most economic for forest roads designed for hauling logs, that the maximum grade specified should be determined on the basis of the sustained speed that would minimize the combined cost of the road and the haulage of the wood, and that on forest roads it may be inappropriate to differentiate between sustained maximum grades and permissible grades.

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Appendix 1.1

New South Wales Forestry Commission
Road Works and Costs

Item	71-72	72-73	73-74
Construction costs	$1,256,100	$1,487,852	$1,335,007
As % Total works expenditure	13%	15%	12.5%
Maintenance costs	$820,241	$520,676	$1,190,157
As % Total works expenditure	9%	6%	11%
As $ Roading expenditure	39%	36%	47%
Roads constructed (km)	917	1,160	908
Road length maintained (km)	20,316	17,500	23,104
Road length graded (km)	11,330	12,080	11,356
Road construction by sawmillers	428	442	272
Logging rebates allowed	$199,904	$154,191	$98,295
Costs of flood damage repairs	$46,331	$52,757	$217,916

Source: Annual Report, New South Wales Forestry Commission 1973-74.

Appendix 1.2

Queensland Department of Forestry
Road Works and Costs

Item	71-72	72-73	73-74	74-75
	$	$	$	$
New construction	417,315	505,439	327,078	507,793
Maintenance	261,285	226,270	246,234	311,418
Subsidies to Shires	49,372	44,097	58,735	104,673
Payroll tax	10,946	11,009	16,929	23,284
Workers' Compensation	2,162	4,893	6,047	11,726
Fares and freight	2,351	2,367	3,412	3,554
Surveys	3,090	13,574		
TOTAL	746,521	807,649	658,435	962,448
Total Departmental Expenditure	6,277,922	7,157,642	8,639,960	11,494,179

Source: Annual Report, Queensland Forests Department 1973-74.

Appendix 1.3

Victoria Forests Commission
Road Works and Costs

Item	1972-73	1973-74
	$	$
Timber extraction roads	456,485	550,727
Road maintenance	425,960	737,424
TOTAL	882,445	1,288,151
Total Commission Expenditure	12,950,744	14,478,975

Source: Annual Reports, Victoria Forests Commission 1972-73, 1973-74.

Appendix 1.4

Sheet 1

New South Wales Forestry Commission
'Taree' Road Classification Scheme
(Imperial units)

This scheme has been prepared to give an arbitrary guide for road classification. Without attempting to accurately investigate the economics of log or sawn haulage, it takes into account the main factors which affect speed, and consequently cost of haulage. These factors are surface, grade (with and against load), curves and width.

1. GENERAL PRINCIPLES

The perfect road has been given an arbitrary points rating of 40, and from this total deductions are made for any defect in the road.

Deductions are made for each 1/10 of a mile, so that changes in surface, grade, etc., can be accurately assessed.

Each mile is classified individually, not a section of road as was previously more commonly done.

Deductions are cumulative, i.e. even if grade limits speed, deductions are still made for curves, surface, etc., if necessary.

Classification can be made when travelling either with or against load, but zero mileage must be at the mill or appraisal site, i.e., if classification is done from log dump to mill the mileage must first be run from mill to dump.

Equipment desirable is 1 clinometer (preferable) or abney, a suitable device for counting curves (e.g. a sheep counter) and a field board, etc.

Classification is best done by two officers – one driving, counting curves and noting width, the second checking surface, grade and recording deductions.

2. METHOD OF APPLICATION

Set up field board, etc., using form as per sample attached.

Record speedo reading at start of mile, drive along the road to be classified with the driver counting curves and offsider recording surface and grade with or against load as accurately as possible. This can be done to 1/20 mile on a 1/10 speedo. Grades should be checked with clinometer if necessary.

At the end of the mile, add lengths (in 1/10's) for which deductions have to be made, record curves and width, multiply out, total, take to next whole number up, subtract from 40, and classify.

3. DEDUCTIONS

These, with explanation where necessary, are as follows:

a. Surface

Deductions per 1/10 mile affected are made at the rate of

Good bitumen	—	nil	per	1/10	mile
Good gravel, poor bitumen	—	0.3	"	"	"
Poor gravel	—	0.6	"	"	"
Dirt	—	1.0	"	"	"

(i) Interpolation between these for surfaces which do not quite fit into these categories is permissible provided it is done in an unbiassed manner.

(ii) Bad bitumen includes broken, pot-holey surfaces, and bitumen 15' or less in width.

b. Grade

Grades can be measured to 1/20 mile.

Any grade more than 0.3 mile in length should be recorded in the next category down, e.g., 4 miles of 1:12 to 1:8 against the load would be recorded as 1:7.

Deductions are made as follows:

(i) With Load

Less than 1:10	Nil	per	1/10	mile
1:10 to 1:8	0.4	"	"	"
1:7	0.8	"	"	"
Steeper than 1:7	1.2	"	"	"

(ii) Against Load

Less than 1:12	Nil	per	1/10	mile
1:12 to 1:8	0.6	"	"	"
1:7	1.0	"	"	"
Steeper than 1:7	1.5	"	"	"

c. Curves

A curve is defined as "any change in alignment sufficient to affect the speed of the vehicle or necessitate work on the part of the driver to negotiate it".

Deductions for number of curves also allow for radius of curvature on the assumption that there is a direct relationship between the two.

Consequently deductions per curve increases with number, i.e., as the radius becomes smaller.

Obstacles such as ramps, narrow bridges, inverts, crossing, etc., can be included as curves (the number allowed depending on the effect on the speed).

Deductions are:

No. of Curve	Deduct Total
0	0.0
1	0.1
2	0.2
3	0.3
4	0.4
5	0.6
6	0.8
7	1.0
8	1.2
9	1.5
10	1.8
11	2.1
12	2.4

No. of Curve	Deduct Total
13	2.75
14	3.10
15	3.45
16	3.80
17	4.20
18	4.60
19	5.00
20	5.40
21	5.80
22	6.20
23	6.60
24	7.00
25	7.40

(thereafter increase at 0.5 per curve)

d. Width

Width covers both passing and sighting difficulties. A long straight but narrow section might not warrant any deductions, whereas a windy but wider section might necessitate an allowance. This factor should be used with the idea of enforcing safe driving practices in mind.

For any 1/10 mile where speed should be reduced below that appropriate to grade, surface, curves, because of passing and sighting difficulties due to width, deduct points at the rate of 0.4 pts per 1/10 mile.

Deductions are made at the rate of 0.4 pts for 1/10 mile affected.

4. EXAMPLE

0 M to 1 M from mill has the following:

Sheet 4

a. Surface

0.6 ml. good bitumen	—	nil deductions
0.4 ml. good gravel	—	(4 × 0.3) 1.2 deductions

b. Grade

0.2 ml. 1:8 with load	—	(2 × 0.4) 0.8 deductions
0.2 ml. 1:8 against load	—	(2 × 0.6) 1.2 deductions

c. Curves

13 curves	—	2.75 deductions

d. Width

Bad sighting 0.2 mile	—	(2 × 0.4) 0.8 deductions

e. Total deductions 6.75 = 7

f. Classification = 40 - 7 = 33 pts = B.

5. GENERAL

This scheme is intended as a guide. Being fairly arbitrary, it may not meet all circumstances and consequently the inspecting officer is still entitled to make his own classification should he disagree with the results given by the scheme. This should only be necessary on infrequent occasions, however.

Road turnoffs, etc., should be recorded as these are frequently of use in subsequent appraisals.

On completion of classification of a road a rough mud map drawn on the back of the form is also useful for subsequent appraisals, etc.

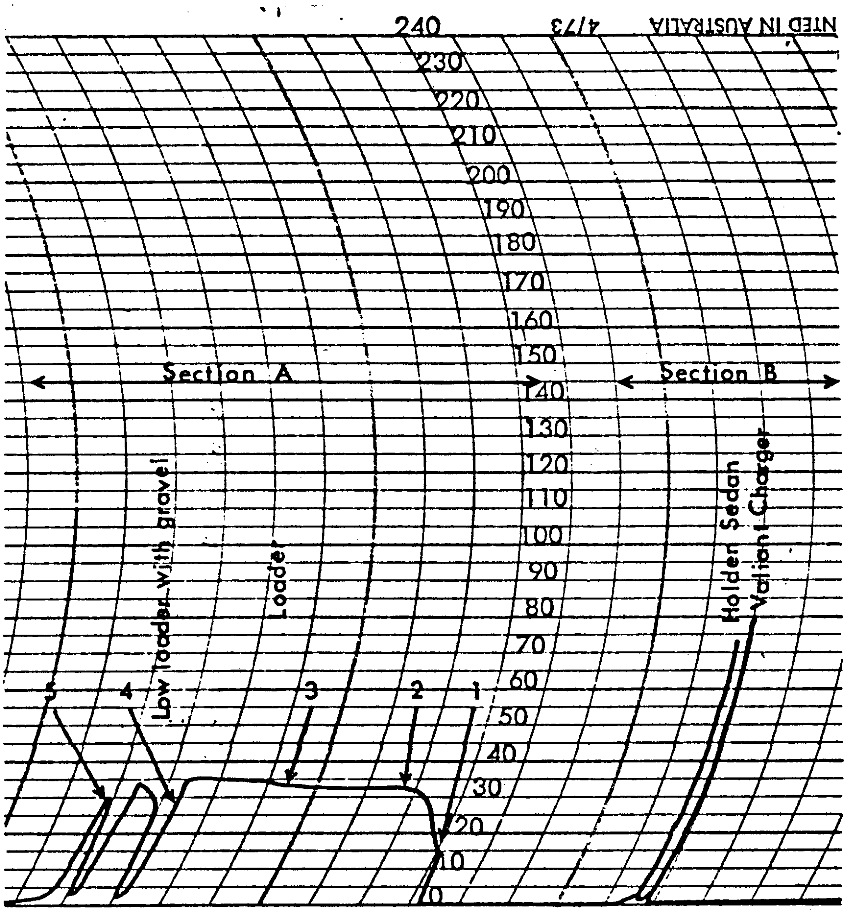
```
C         TRUCK LOAD DATA CHECK PROGRAM.
C         ..............................
C         A PROGRAM TO TEST THE PUNCHING OF THE DATA CARDS FOR A.C.T. FOREST BRANCH
C   LOAD INFORMATION, FOR A TWO MONTH ACCOUNTING PERIOD IN MID 1975.
C         THE PROGRAM READS THE CARD & TESTS THE TRUCK IDENTIFICATION, DATE, TIME IN
C   &OUT. THE NETT & TARE WEIGHTS ARE ADDED & TESTED TO SEE IF THEY EQUAL THE
C   GROSS WEIGHT. THE COMPARTMENT & FOREST NUMBERS ARE ALSO CHECKED TO ENSURE
C   THAT THEY ARE WITHIN KNOWN BOUNDS.
C         ANY CARDS WITH APPARENT ERRORS HAVE THE REGISTRATION NUMBER OF THE
C   TRUCK, DATE AND DOCKET NUMBER WRITTEN OUT SO THAT THEY CAN BE CHECKED.
C         PROGRAMMED BY T.BEATH, FORESTRY,A.N.U.,20/11/75.
C         ................................................
C
C
C                                       TREAT THE FOLLOWING VARIABLES AS INTEGERS
C
          INTEGER TRUCK,SAMPLE
C
C                                       READ IN A CARD, THEN GO THRU THE VARIOUS
C                                       TESTS BEFORE READING THE NEXT CARD.
C
       10 READ(5,100,ERR=20,END=40)
        C           TRUCK,NUM,I0,NDAY,MONTH,I1,INHR,INMIN,I2,IGROSS,I3,
        CLEAVHR,LEAVMI,I4,NTARE,I5,NETT,I6,IFOR,I7,KPT,MART,I8,NDOC,I9,
        CMACH,J0,LATE,J1,SAMPLE,J2,LOAD,J3
      100 FORMAT(A3,I3,I1,2I2,I1,2I2,I1,I5,I1,2I2,I1,I5,I1,I5,I2,2I1,
        CI3,6X,A5,I1,I5,I1,I2,I1,I2,I1,A1,I1,A1,I1)
          IF(NDAY.LT.1.OR.NDAY.GT.31) GO TO 20
          IF(MONTH.LT.6.OR.MONTH.GT.9) GO TO 20
          IF(INHR.LT.6.OR.INHR.GT.17) GO TO 20
          IF(INMIN.LT.0.OR.INMIN.GT.59) GO TO 20
          NSUM = NTARE + NETT
          IF(NSUM.NE.IGROSS) GO TO 20
          KINGST = LEAVHR + LEAVMI
          IF(KINGST.EQ.0) GO TO 30
          IF(LEAVHR.LT.6.OR.LEAVHR.GT.17) GO TO 20
          IF(LEAVMI.LT.0.OR.LEAVMI.GT.59) GO TO 20
       30 IF(IFOR.LT.1.OR.IFOR.GT.2) GO TO 20
          IF(KPT.LT.1.OR.KPT.GT.200) GO TO 20
          IF(LATE.EQ.0.AND.INHR.GT.LEAVHR) GO TO 20
          ITOT = I0+I1+I2+I3+I4+I5+I6+I7+I8+I9
          IF(ITOT.NE.0) GO TO 20
          JTOT = J0+J1+J2+J3
          IF (JTOT.NE.0) GO TO 20
          GO TO 10
       20 WRITE(6,110)TRUCK,NUM,NDAY,MONTH,NDOC
      110 FORMAT('0','CHECK DATA CARDS:',A3,I3,1X,2I2,1X,I5)
          GO TO 10
       40 END

END OF COMPILATION:          NO DIAGNOSTICS.
```

Truck Load Data Check
Program Listing

Appendix 2.2

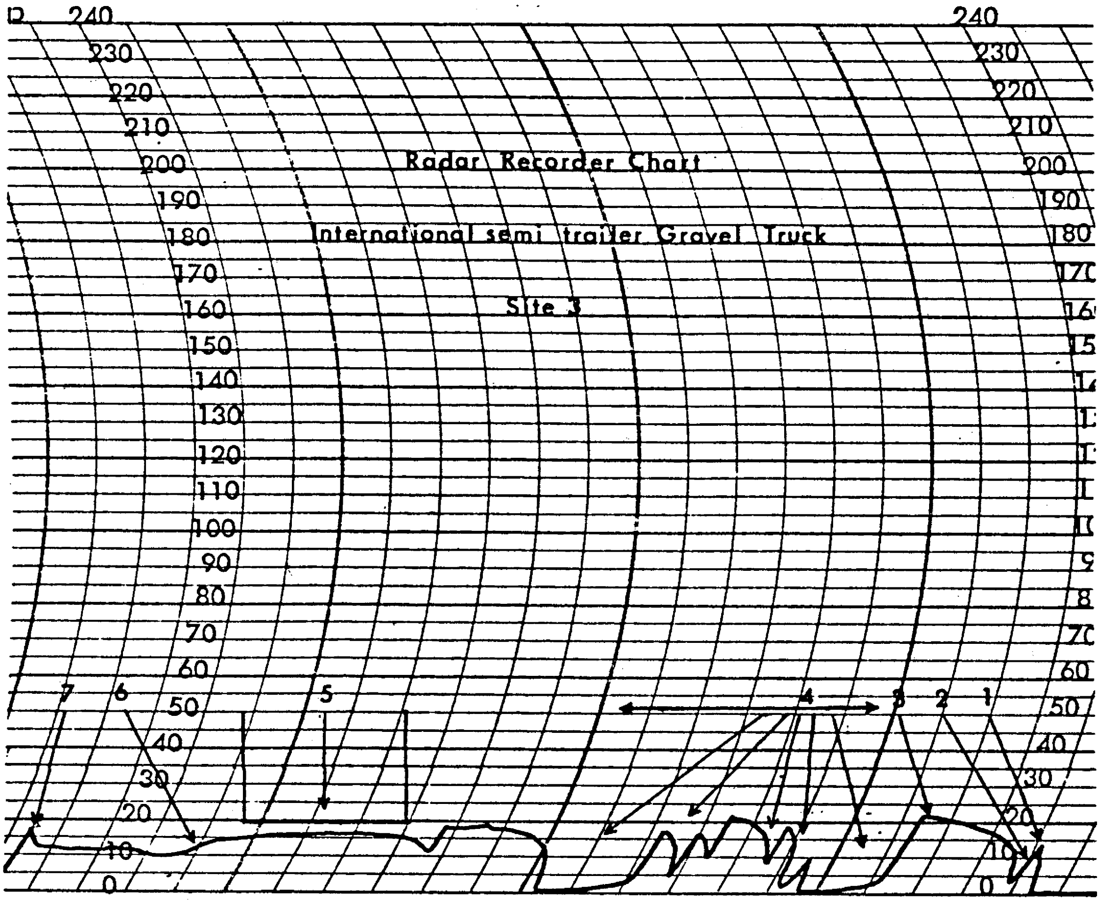
Feed Speeds of Radar Recorder Charts
Section A: 15 cm per minute
Section B: 15 cm per hour



1. Initial contact with vehicle downslope from the meter.
2. Signal stabilisation on truck speed, after 'needle problems' in the recorder, and signal irregularities from distant object.
3. Slight acceleration indicated by speed increase.
4. Signal cancellation; common with Microwave Multipath transmissions.
5. Final needle 'kick' as truck passed radome and the angle between the moving object and the beam path exceeded ten degrees.

Appendix 2.3

Radar Recorder Chart
Signal cancellation at Site 3



1. Initial contact with moving vehicle.
2. Momentary loss of signal.
3. Stabilisation of meter needle on vehicle speed.
4. Signal cancellation.
5. Stable signal indicating vehicle speed.
6. Deceleration caused by gear change.
7. Final needle 'kick' as truck passed radome and the signal path, the vehicle path angle exceeding ten degrees.

Sheet 1 Appendix 2.4

January 1974

DEPARTMENT OF MAIN ROADS, N.S.W.

SUBJECT: Ordinance No. 30C. of the Local Government Act, 1919. Haulage of Log Timber.1)

The correct method of assessing the permissible load of a vehicle hauling saw log timber, and the requirements to be followed are set out below.

It must be understood that this haulage applies to hardwood and brushwood saw logs ONLY.

Vehicles, other than rigid vehicles, engaged in the haulage of Radiata, Monterey and Cypress Pine saw logs will be regarded as legally loaded if the gross weight of the vehicle does not exceed the lesser of:

the sum of the permissible axle loads2)

or

the permissible gross load under the Table2) of Maximum Loaded Weights.

Vehicles carrying other species of timber are subject to direct weight check.

1. Method of assessing permissible load

(a) Arrive at the extreme axle spacing of the vehicle by measuring from the centre of the first axle to the centre of the last axle. (Assume this to be 11.9 metre(m),);

(b) refer to the Table of Maximum Loaded Weights on page 6 of the attached Form No. 11, taking into account the number of axles on the vehicle. (Assume this to be a five axle vehicle with dual tyres on all axles except the steering axle.);

(c) arrive at the permissible gross loaded weight of the vehicle, including tare, by using (a) and (b) above. (It will be seen

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1) Source: Personal communication, Department of Main Roads, 1st October, 1975.

2) Main Roads Form No. 11 sets out in detail the maximum axle loads and loaded weight for vehicles using main roads.

that a five axle vehicle with an extreme axle spacing of 11.7 to 12 metres is entitled to gross 31.6 tonne(t).);

(d) from this permissible gross weight of 31.6 t deduce the tare of the prime mover and jinker. (Assume this to be 10.2 t) which leaves a permissible added load of 21.4 t (31.6 t minus 10.2 t).);

(e) multiply the permissible added load by the conversion figure. These figures are:

Hardwood : 0.9 cubic metre (m^3) per tonne

Brushwood : 1.1 cubic metre (m^3) per tonne

so that, multiplying 21.4 × 0.9 m^3, a figure of 19.26 m^3 is arrived at. However, as shown later, the MAXIMUM permissible load for hardwood is 18.0 m^3, so the figure of 19.26 m^3 must be reduced to 18.0 m^3;

(f) assume the tare of the vehicle in (d) above is 12.3 t, which means the permissible added load is 19.3 t (31.6 t minus 12.3 t). Multiplying 19.3 × 0.9, the figure of 17.37 m^3 is obtained and this is the maximum permissible load in this case. In other words, this vehicle is not entitled to carry 18.0 m^3;

(g) it will be seen that the permissible cubic metre load for a five axle vehicle carrying hardwood is either the maximum of 18.0 m <u>OR</u> the figure arrived at by calculation, <u>WHICHEVER IS THE LESSER</u>;

(h) the permissible maximum loads are set out below. To carry these loads vehicles must be fitted with dual tyres on all axles except the steering axle.

	Cubic Metre (True Volume) m^3	
	Hardwood	Brushwood
Five axle vehicle (18 tyres)	18.0	23.0
Four axle vehicle (14 tyres)	13.5	17.1
Three axle vehicle (10 tyres)	10.5	13.7

<u>REQUIREMENTS</u>:

A vehicle carrying logs must conform to the undermentioned conditions:

(a) the tare weights of both the jinker and the prime mover must be readily available;

(b) the driver of the vehicle must carry a written record containing details of the measurements of the diameter and length of each log, and the number of cubic metres in the log;

(c) the measurements referred to in (b) must be clearly shown on the logs;

(d) in referring to a three, four or five axle vehicle, it is to be understood that all axles, other than the steering axle, are fitted with dual tyres. The Department will issue an assessment of the carrying capacity of a vehicle not so fitted;

(e) should any one or more of these conditions be not maintained the Department reserves the right to weigh the vehicle without assessing the total of cubic metres and to take appropriate action if the vehicle is overloaded.

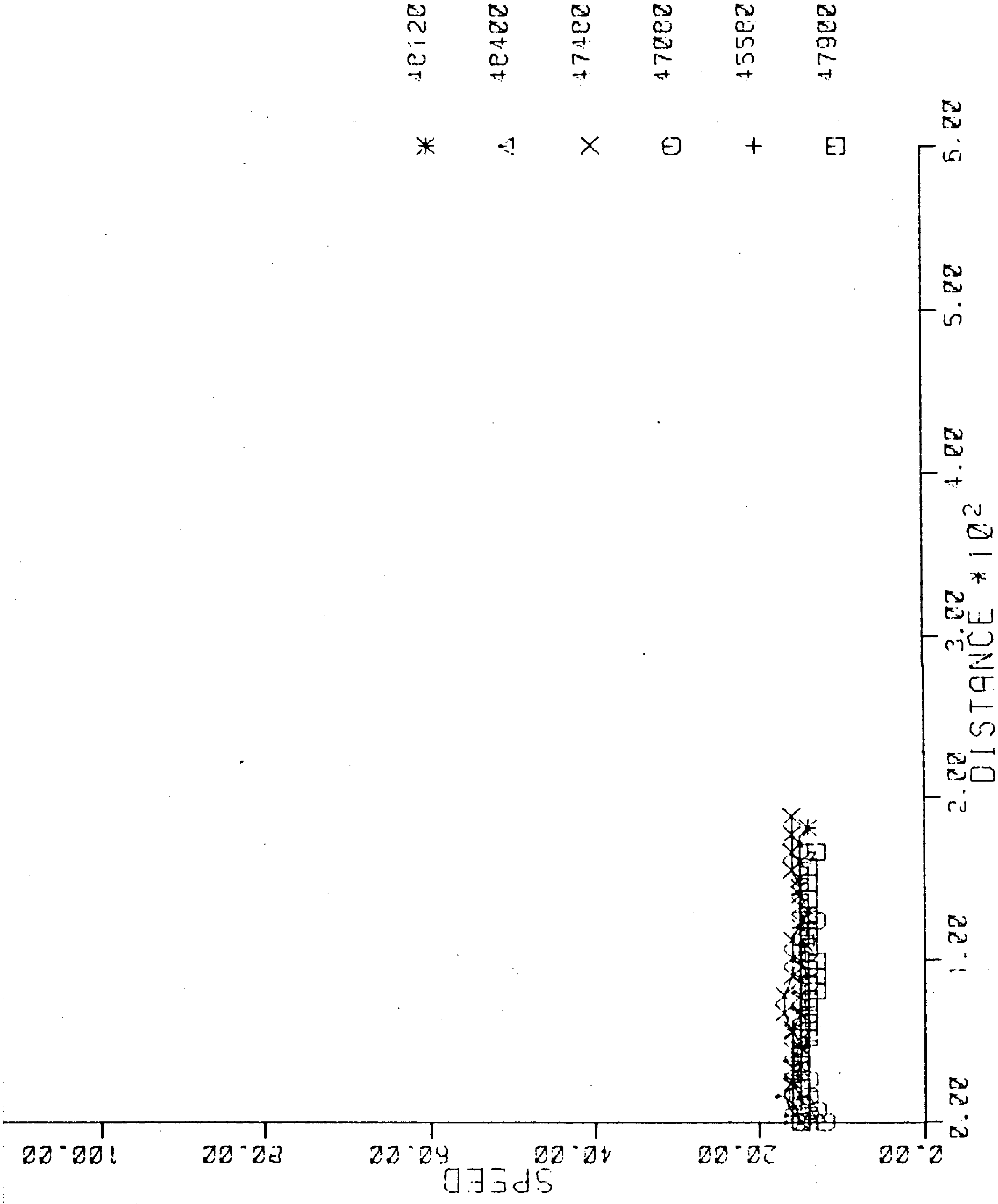
It is the responsibility of the driver of a vehicle to ensure that his load is within the permissible total cubic metres depending upon the number of axles, the extreme axle spacing and the type of timber being carried.

The above concessions apply where the logs are being hauled from the forest to a dump ONLY, and is not intended for the carriage of logs over long distances on main roads.

If you have any doubts on the operation of the system, please contact the Weight of Loads Officer, Department of Main Roads, 309 Castlereagh Street, Sydney, 2000, by letter of telephone (2-0933).

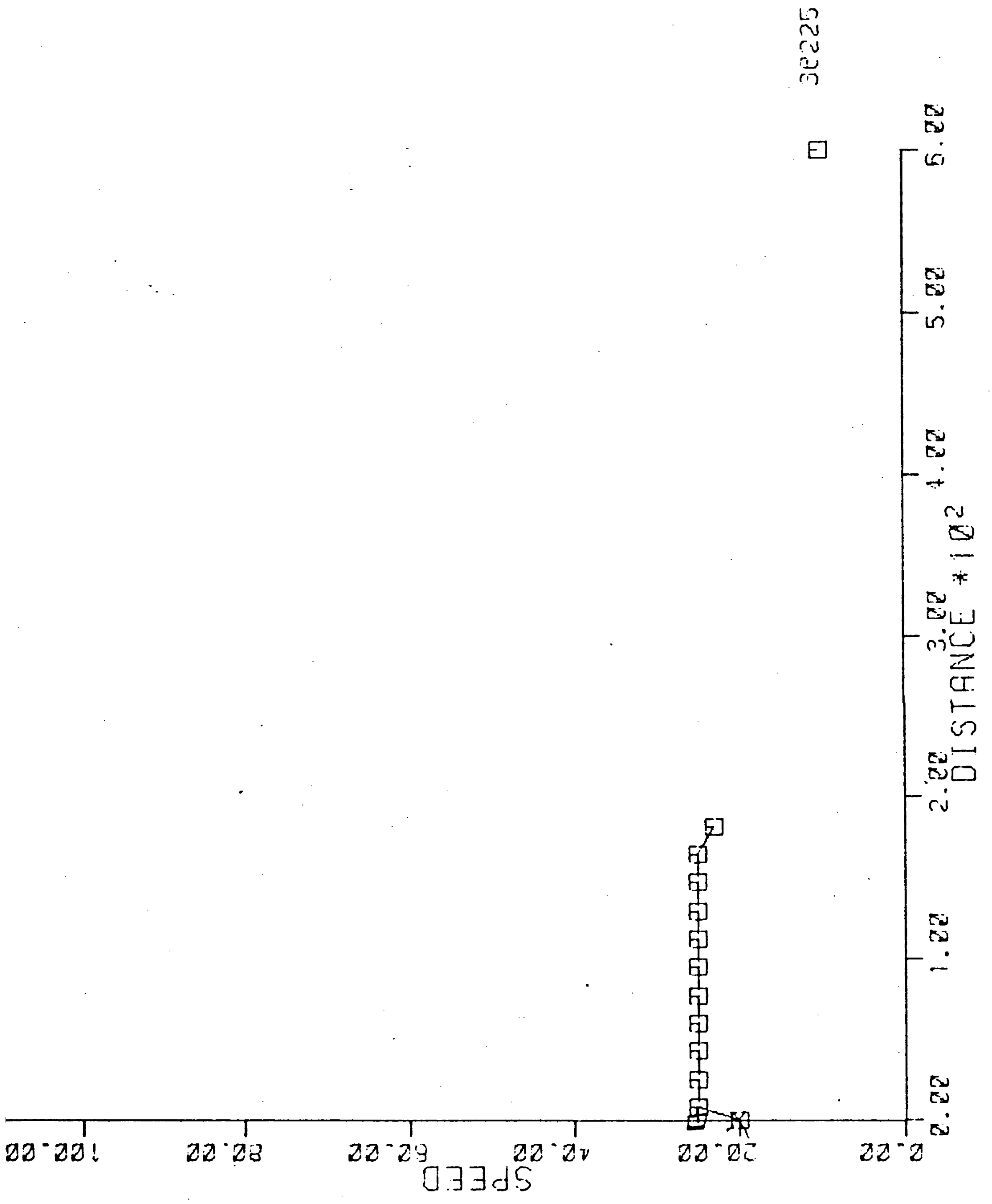
(C.W. Mansfield)
Secretary

Appendix 3.1.1



Speed - Distance Diagram
Truck No. YAH268
Six trips at Site 4

Appendix 3.1.2



Speed - Distance Diagram
Truck No. YAH268
Site 4

Appendix 3.2

```
SPEED - DISTANCE FOR EACH SITE

SITE    1 TRUCK FR0838 DIRECTION +
GROSS WEIGHT = 14340
SPEED    DISTANCE
45.0          .0
49.0        19.6
51.0        54.3
52.0        90.1
52.0       126.2
46.0       160.2
39.0       189.7
35.0       215.4
31.0       238.3
31.0       259.9
30.0       281.0
29.0       301.5

SITE    1 TRUCK FR0838 DIRECTION -
GROSS WEIGHT = 33675
SPEED    DISTANCE
57.0          .0
59.0        40.3
60.0        81.6
60.0       123.3
60.0       164.9
60.0       206.6
61.0       248.6
61.0       291.0
61.0       333.3
60.0       375.3
59.0       416.7
56.0       456.6

SITE    1 TRUCK FRS229 DIRECTION +
GROSS WEIGHT = 10850
SPEED    DISTANCE
69.0          .0
76.0        50.3
81.0       104.9
84.0       162.2
84.0       220.5
82.0       278.1
79.0       334.0
76.0       387.8
```

```
SITE    1 TRUCK FRW121 DIRECTION -
GROSS WEIGHT = 33350
SPEED    DISTANCE
62.0          .0
65.0        44.1
67.0        89.9
68.0       136.8
68.0       184.0
68.0       231.2
68.0       278.5
68.0       325.7
67.0       372.6
63.0       417.7
58.0       459.7

SITE    1 TRUCK FRW128 DIRECTION +
GROSS WEIGHT =  5460
SPEED    DISTANCE
60.0          .0
62.0        21.2
63.0        64.6
63.0       108.3
64.0       152.4
63.0       196.5
60.0       239.2
60.0       280.9
58.0       321.9
57.0       361.8
56.0       401.0

SITE    1 TRUCK YAH268 DIRECTION +
GROSS WEIGHT = 13420
SPEED    DISTANCE
65.0          .0
70.0        37.5
72.0        86.8
73.0       137.2
71.0       187.2
70.0       236.1
69.0       284.4
66.0       331.2
65.0       376.7
65.0       421.9
```

Computer Tabulation of Speed - Distance Information

```
PAGE  0001          FTN4 COMPILER: HP24177  (MARCH 1976)

FTN4,L
      PROGRAM STT
      DIMENSION X(200,3),DEV(200)
      NC = 12
      N = 102
      READ(5,10)((X(I,J),J=1,3),I=1,N)
   10 FORMAT(F6.2,3X,F7.4,14X,F2.0)
      DO 20 I = 1,N
      DEV(I)=X(I,3)-(90.391669/X(I,1)+2.7263105*X(I,2)-10.573968)
   20 CONTINUE
      T1=0.0
      T2=0.0
      DO 100 I = 1,N
      T1 = T1+DEV(I)*DEV(I)
      IF(I.EQ.1)GO TO 100
      T2 = T2 + (DEV(I)-DEV(I-1))*(DEV(I)-DEV(I-1))
  100 CONTINUE
      D = T2/T1
      WRITE(6,50)D
   50 FORMAT("1 D EQUALS ",F8.4)
      SD = 0
      SD2 = 0
      SD3 = 0
      SD4 = 0
      DO 110 I = 1,N
      SD = SD + DEV(I)
      SD2 = SD2 + DEV(I)*DEV(I)
      SD3 = SD3 + DEV(I)*DEV(I)*DEV(I)
      SD4 = SD4 + DEV(I)*DEV(I)*DEV(I)*DEV(I)
  110 CONTINUE
      WRITE(6,60)SD,SD2,SD3,SD4
   60 FORMAT("0 SUM DEVIATES SUM SQ DEV SUM CUBE DEVS SUM 4TH DEVS",/
     *1X,4X,F9.3,2X,F9.3,5X,F9.3,2X,F11.3)
      WRITE(6,70)
   70 FORMAT("1 GROUP  VARIANCE  (N-1)  CORR SS  1/(N-1)   LN  S*S  (N-
     *1)LN  S*S",/1X," -----  ---------  -----  --------  -------",
     *"  -------  ------------")
```

Statistical Analysis on Hewlett-Packard 2100 Programme Listing

```
0038          DO 300 K = 1,9
0039          T1 = 0.0
0040          T2 = 0.0
0041          DO 250 J = 1,NC
0042          ID = 12*(K-1) + J
0043          IF (ID.EQ.102)GO TO 251
0044          T1 = T1 + DEV(ID)
0045      250 T2 = T2 + DEV(ID)*DEV(ID)
0046          J = J - 1
0047      251 CONTINUE
0048          SS = T2 - T1*T1/J
0049          NM1 = J-1
0050          VAR = SS/NM1
0051          RNM1 = 1./NM1
0052          SLOG = ALOG(VAR)
0053          SNLOG = SLOG*NM1
0054          WRITE(6,71)K,VAR,NM1,SS,RNM1,SLOG,SNLOG
0055       71 FORMAT(1X,I5,2X,F8.2,2X,I5,2X,F8.2,2X,F7.4,1X,F9.6,2X,F12.6)
0056      300 CONTINUE
0057          WRITE(6,301)
0058      301 FORMAT(1H1)
0059          WRITE(6,303)((X(I,J),J=1,3),DEV(I),I=1,N)
0060      303 FORMAT(4F10.4)
0061          STOP
0062          END

STT    **  NO ERRORS**    PROGRAM = 02381      COMMON = 00000

0063          END$

D EQUALS     8800

SUM DEVIATES SUM SQ.DEV SUM CUBE DEVS SUM 4TH DEVS
     420.619   8551.211     178293.16  4862358.000

GROUP  VARIANCE  (N-1)  CORR. SS  1/(N-1)   LN  S*S  (N-1)LN  S*S
-----  --------  -----  --------  -------   -------  -----------
    1      3.92     11     43.16    .0909  1.367033    15.037357
    2      6.01     11     66.13    .0909  1.793755    19.731304
    3      4.66     11     51.24    .0909  1.538693    16.925629
    4      2.01     11     22.15    .0909   .699808     7.697893
    5     23.28     11    256.12    .0909  3.147734    34.625069
    6     41.22     11    453.46    .0909  3.719007    40.909081
    7     56.68     11    623.49    .0909  4.037441    44.411858
    8     93.87     11   1032.62    .0909  4.541963    49.961586
    9    193.44      5    967.22    .2000  5.264992    26.324959
```

The Relative Effect of an Increased Load on the Speed of Log Trucks on Flat and Steep Grades

The basis for the assumption was the observation that truck speeds on steep grades are low and a marginal increase in load did not make for a large absolute, as distinct from relative, decrease in speed. On the other hand trucks travelling at high speeds on flat grades seemed to have their speeds reduced considerably in absolute terms by increased loads.

This observation was supported by a very simple examination in relation to the rate at which the load is raised, that is the horsepower converted to potential energy.

If a loaded truck weighing W_1 is travelling up a grade of θ_1 degrees at speed S_1 then the rate of gain of potential energy is $W_1\ S_1 \text{ Sin } \theta_1$ energy units/unit time. Similarly on another grade $W_1\ S_2 \text{ Sin } \theta_2$. If the horsepower available to increase the potential energy was the same in both cases then

$$S_1 \text{ Sin } \theta_1 = S_2 \text{ Sin } \theta_2$$

Similarly if a marginal additional weight was placed on the truck say W^1 and the speeds become $S_1^{\ 1}$ and $S_2^{\ 1}$

$$S_1^{\ 1} \text{ Sin } \theta_1 = S_2^{\ 1} \text{ Sin } \theta_2$$

Hence
$$\frac{S_1^{\ 1}}{S_1} = \frac{S_2^{\ 1}}{S_2}$$

If the speed S_1 is on a steeper grade (θ_1) then S_1 would be less than S_2 and for the ratios to hold the change in speed from S_1 to $S_1^{\ 1}$ must be less than the change in speed from S_2 to $S_2^{\ 1}$.

```
@ELT,L LOGLOAD.MAIN
ELTOT7 RLIB70 U2/07-10:47:20-(26,)
000001          022    C A PROGRAM STORED IN ELEMENT MAIN OF FILE LOGLOAD,
000002          022    C WHICH USES DATA STORED IN LORRYTRIP., AND CALCULATES
000003          022    C FOR EACH TRUCK, THE NO. OF LOADS IN THE TWO MONTHLY
000004          022    C PERIOD,AVERAGE GROSS WEIGHT, AVERAGE NETT WEIGHT,
000005          022    C THE AVERAGE LOADS PER DAY,TOTAL PAYLOAD HAULED IN THE
000006          022    C PERIOD,NO. OF DAYS WORKED, AND THE NETT DAILY HAUL.
000007          023    C THE STANDARD DEVIATION OF THE GROSS & NETT LOADS
000008          023    C IS ALSO CALCULATED AND WRITTEN OUT.
000009          022    C PROGRAMMED 23.12.75, T.BEATH DEPT. FORESTRY.
000010          022            REAL N,NE,L
000011          022            INTEGER O,OV,DAY,D,T,TRUCK
000012          023            SDEV(X2,X1,N)=SQRT( ABS((X2-X1*X1/N)/(N-1)))
000013          022            AD=1.
000014          022            L=1.
000015          022    C
000016          022    C                                WRITE HEADING FOR PRINTOUT
000017          022    C
000018          022            WRITE(6,1)
000019          022          1 FORMAT('1 DATA FROM WEIGHT DOCKETS FROM A.C.T. FORESTS PERIOD FROM
000020          022          C 23.6.75 TO 30.8.75,REPRESENTING TWO MONTHLY ACCOUNTING PERIODS',/
000021          022          C1X,' TOTAL WEEKDAYS = 47, SATURDAYS = 10.')
000022          022    C
000023          022    C                                 WRITE DATA OUTPUT HEADINGS.
000024          022    C
000025          022            WRITE(6,2)
000026          022          2 FORMAT('0',
000027          022          C ' REGISTRATION',2X,'NO OF',2X,'AVERAGE',3X,'AVERAGE',4X,'AVERAGE',
000028          022          C4X,'TOTAL',2X,'NO OF',2X,'DAILY',6X,'STANDARD DEVIATIONS'
000029          022          C/1X,' NO OF TRUCK',
000030          022          C3X,'LOADS',2X,'GROSS WT',2X,'NETT WT',2X,'LOADS/DAY',
000031          022          C2X,'PAYLOAD',2X,'DAYS',3X,'HAUL',5X,'GROSS LOADS  NETT LOADS'
000032          022          C/'0 -------------',
000033          022          C2X,'------',2X,'---------',2X,'-------',2X,'----------',
000034          022          C2X,'--------',2X,'-----',2X,'-------',3X,'-----------  ----------')
```

Compilation of Load Data Programme Listing

Sheet 2

```
000035      022   C
000036      022   C                                    USE 10 TO REFERENCE DATA FILE.
000037      022   C
000038      022               READ(10,100)TRUCK,DAY,G,N,O
000039      022         9     CONTINUE
000040      023               SG2 = G*G
000041      023               SN2 = N*N
000042      024               SG = G
000043      024               SN = N
000044      024               NO = 1
000045      022        10  READ(10,100,END=999)T,D,GR,NE,OV
000046      022       100  FORMAT(A6,1X,I4,6X,F5.0,12X,F5.0,33X,A1)
000047      022               IF(TRUCK.NE.T)GO TO 30
000048      022               L = L + 1.
000049      022               NO = NO + 1
000050      023               SG2 = SG2 + GR*GR
000051      023               SN2 = SN2 + NE*NE
000052      023               SG = SG + GR
000053      023               SN = SN + NE
000054      022               IF(D.EQ.DAY)GO TO 20
000055      022               AD = AD + 1.
000056      022               DAY = D
000057      022
000058      022        20  IF(OV.NE.1HO)GO TO 10
000059      024               READ(10,100)T,D,G,N,OV
000060      024               SG2 = SG2 + G*G +2*G*GR
000061      024               SN2 = SN2+ N*N + 2*N*NE
000062      024               SG = SG + G
000063      024               SN = SN + N
000064      022               GO TO 10
000065      022   C                                    CALC AV. GROSS WT.
000066      023        30  AG = SG/L
000067      022   C                                    CALC. AV. NETT WT.
000068      023               AN = SN/L
000069      022   C                                    CALC.AV. NO. LOADS PER DAY
000070      022               ALPD = L/AD
```

Sheet 3

Appendix 4.1

```
000071     022   C                            CALC. AV. DAILY NETT HAUL
000072     022              DH = AN * ALPD
000073     C23              SDG = 0
000074     023              SDN = 0
000075     023              IF(NO.LE.1)GO TO 35
000076     022              SDG = SDEV(SG2,SG,NO)
000077     022              SDN = SDEV(SN2,SN,NO)
000078     025     35       WRITE(6,200)TRUCK,L,AG,AN,ALPD,SN,AD,DH,SDG,SDN
000079     022    200  FORMAT('0',4X,A6,5X,F5.0,3X,F6.0,3X,F6.0,4X,F6.2,2X,F9.0,
000080     022        C3X,F3.0,2X,F8.0,2X,F11.3,2X,F10.3)
000081     022              TRUCK=T
000082     022              DAY=D
000083     022              G=GR
000084     022              N=NE
000085     022              O=OV
000086     022              L=1.
000087     022          AD=1.
000088     022              GO TO 9
000089     023    999   AG= SG/L
000090     023              AN= SN/L
000091     022              ALPD=L/AD
000092     022              DH=AN*ALPD
000093     023              SDG = 0
000094     023              SDN = 0
000095     023              IF(NO.LE.1)GO TO 36
000096     022              SDG = SDEV(SG2,SG,NO)
000097     022              SDN = SDEV(SN2,SN,NO)
000098     026     36       WRITE(6,200)TRUCK,L,AG,AN,ALPD,SN,AD,DH,SDG,SDN
000099     022              STOP
000100     022              END

END ELT.



@END
@END IGNORED - IN CONTROL MODE


@RESUME,P PRI
```

Appendix 4.2

Australian Consumer Price Index
All Groups for Six State Capital Cities
Base 1966-67 = 100

End Quarter	Consumer Price Index						
	1969-70	1970-71	1971-72	1972-73	1973-74	1974-75	1975-76
September	107.8	119.9	119.4	126.2	139.6	162.0	181.6
December	108.7	114.0	122.2	127.7	144.6	168.1	191.7
March	109.8	115.2	123.4	130.4	148.1	174.1	197.4
June	112.2	117.2	124.5	134.7	154.1	180.2	
End Year	109.4	114.6	122.4	129.8	146.6	171.1	