TRUCKSIM - A Log Truck Performance Simulator

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ABSTRACT

Forestry transport expenditures in Australia include both the costs of owning and operating log trucks, and the costs of constructing and maintaining many kilometres of logging roads. Therefore, improving transport efficiency requires consideration of both road and truck related factors. However, analysis of these factors involves many complex interacting variables. A computer simulation model, TRUCKSIM, has been developed to assist in these analyses by predicting the effects of both road and alternative vehicle specification on transport performance. A description of the model and it's supporting programs is presented, together with a discussion of it's limitations and examples of it's use in evaluating alternative truck and road specifications.

INTRODUCTION

Log transport costs form a significant portion of the total cost of logs at the mill gate. Several factors related to truck and road specification have a direct impact on these costs. Selection of the most effective truck specification is perhaps the most important, through it's impact on travel speed, fuel consumption and operating cost [7]. Road construction and maintenance costs also form a significant part of overall transport expenditure, because, unlike the general transport sector which utilizes the public highway network exclusively, the forest industry is committed to the construction and maintenance of a substantial private road network. The trip from forest to mill involves a number of very different road types. These range from unprepared native soil landing access tracks through to the highest standard public highways.

The wide variation in road standards experienced in one trip makes truck specification difficult. Truck owners perceive a need to operate robust powerful trucks capable of negotiating the lowest standard of road successfully, while a lighter, often more fuel efficient truck might be most suited to operation on the public road network. Truck fleet managers have to select trucks to cope with the best and worst sections of today's road network. However, the specifications of both today's and tomorrow's truck fleets are limited by road design decisions because of the long service life expected from most roads.

Efficient transportation systems consider feasible changes in both truck components and road designs and of their interaction. The development of computer programs which model the critical aspects of truck response to road sections can be of assistance in understanding these complex interactions.

Truck Simulation Programs

Truck simulation programs predict the performance of specified vehicles over particular road sections. The CUMMINS VMS model [8] and the ICES ROADS package [6], each in use for more than 20 years, provide two important examples. The VMS model, a proprietary CUMMINS company model used primarily as a sales engineering tool, is oriented toward detailed consideration of truck and engine performance. It allows the transport manager to obtain comparable performance predictions for alternative vehicle configurations under the same fixed road and operator conditions. Smith [9] used the VMS package to compare potential performance of 5, 6 and 7 axle log trucks on a particular haul route. The older ICES Roads package is a civil engineering design package which allows evaluation of predicted vehicle response to detailed road design alternatives. The range of test vehicle configurations is relatively limited.

Lack of ready user access has been a major factor limiting the application of these, or similar packages, to evaluation of Australian forest transport problems. Lack of ready user access to the programs has been the major impediment. In general, the packages are either large (ICES) or large and company proprietary (CUMMINS VMS) and requiring mainframe computer access. Knowledge of how to operate the programs and the effort needed to satisfy detailed user input data requirements are other impediments. Since the major focus of these programs is on highway opera-

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tion, they are also less readily applied to the wide range of road section standards and vehicle alternatives of particular interest to loggers.

There is, however, a considerable body of knowledge available on which to base simpler versions of such programs. The framework provided by the SAE J688 Truck Ability Prediction Procedure [11], the expanded review provided by Smith [10], McNally [5] and the detailed work by Ljubic [1-3] provide a broad base for model development and parameter selection. Recent advances in micro computer technology have made it possible to develop and operate complex models such as dynamic vehicle simulations on desktop computers simplifying the issues of access and usage. The TRUCKSIM modelling system, developed for mini/micro computer application, is designed to allow managers to develop insights into the relative effects of both differences in truck specification and differences in road standard on performance.

The Trucksim Modelling System

Development of a satisfactory environment for the consideration of the response of proposed log trucks to forest roads involves more than just implementing a truck simulation program. Forestry users are interested in a range of truck specifications and a number of different roads sections. Therefore an integrated system of programs is required to manipulate and store for reuse the base data on these many roads sections, truck components, vehicle specifications and drivers. The TRUCKSIM system comprises a suite of programs (currently 11), written in the highly standardized FORTRAN77 language, to complete these tasks.

Truck Performance Prediction Model

The core model simulates mechanical performance of a "truck" with specified engine performance, transmission, rear end ratio, tyre size and driver capability as it traverses a road section described in vertical profile and subject to speed constraint. The model considers the vehicle's dynamics at user specified intervals (usually 0.1 - 1.0 seconds). At the start of each interval the model computes:

1/ Current position in the section and the grade for the segment predicted to be covered in the next interval.

2/ External forces acting on the vehicle (air resistance, road rolling resistance and grade resistance or assistance).

3/ Net tractive force available from the engine at the wheel - road interface, considering engine accessory loss, overall gear reduction and driveline losses.

From these, the net force available to accelerate the vehicle is determined, and if user applied speed restrictions permit, an acceleration, a new terminal velocity and the distance covered for the simulation interval are calculated. Trucks operate under three distinct operational conditions, 1/ power limited, 2/ downgrade braking, or precautionary speed limited and 3/ normal cruising. Power limited operations include all periods when the engine is operating at it's full power potential for the specific engine rpm, generally up more than light grades, at high road speeds and accelerating after braking or stopping. Loaded log trucks, which usually have weight/power ratios of 100 - 150 kg per kw can spend a considerable proportion of operating time at the full power level [4]. Downgrade or precautionary braking operations are all times when the driver's foot would be off the accelerator, ie. all times when the net engine power is at idle level or less. This normally covers steeper downgrades and periods of deceleration preceding areas of restricted speed (corners, traffic signs). Cruise mode operations cover the remaining periods when a real- world driver would be supplying some intermediate level of throttle with corresponding engine power input. Such periods normally cover sections of road of slight positive or negative grade where less than full power is needed to maintain the desired road speed.

Truck drivers enjoy and exercise considerable autonomy in the choice of operating pattern within these modes and transitions between them. Truck simulations need a detailed control logic to emulate the more important aspects of this highly discretionary driver behaviour. Two of the most important functions are gearshifting and precautionary braking.

In the TRUCKSIM model, the need for a gear shift is evaluated during each simulation interval, and in general, an UPSHIFT (DOWNSHIFT) is initiated whenever engine RPM climbs (falls) to a user-defined limit. However, a number of detailed tests are needed to prevent unnecessary gearshifts (e.g. cycling) and to calculate the correct moment and target gear for a needed shift. Rapid increases in grade require either early precautionary shifting to ensure the lower gear can be adequately engaged, or a downshift of two or more gears. Selection of gearshifting points involves considerable skill and judgement by truck drivers who use both engine performance clues, and a " through the windshield " perception of upcoming road conditions. Simulation of this behaviour as a set of rules (as in TRUCKSIM) cannot fully capture this diversity. While computer programs can make more accurate use of engine performance data for gearshifting than can real-world drivers, they have no access to the "through the windshield" clues. Therefore, simulation programs can be expected to be most reliable in the power limited mode (loaded, up hill, high speed, better roads), where the usefulness of visual clues available to the driver is generally least.

Conversely, simulation of truck performance is most difficult in the downhill and cruise modes, where driver choice and use of visual and other perceptual clues as well as route knowledge or experience is at a high level. TRUCKSIM approaches this problem by requiring the simulation user to describe a speed envelope (analogous to the road surface vertical profile) which specifies the preferred driver speed for each part of the road section. Thus areas where the driver is expected to explicitly limit speed, (eg. for highway speed limits, stop signs, sharp or limited sight distance corners) are emulated in the input speed profile. During simulation, the model attempts to accelerate the truck to and subsequently maintain the preferred speed for the current and successive locations in the section.

Data Input and Management

Data input and manipulation programs are provided for four classes of inputs: 1/ Truck component performance, 2/ Truck specification, 3/ Road geometry and speed profile, and 4/ Overall run control.

Individual engine and transmission component data are maintained in separate permanent files. These data are entered into storage by users as they become available or are needed. Engine data includes the full power torque curve and the full power fuel usage curve. Truck specification files are subsequently built up using index references to the engine and transmission data files of choice in addition to data on truck weight, frontal area, rear axle ratio and tyre size. Completed truck specification files are stored in the same manner as the engine and transmission files.

Individual driver data relating to gearshift pattern, shift rpm (up and down for each gear) and shift times are considered and stored separately. At least one separate driver response file is required for each unique engine / transmission combination. Many more than one could be generated where users are interested in response to changed rpm shift points (eg. progressive shifting) or changed driver ability (shift times). A graphical program provides a plot of engine RPM against road-speed for each gear and facilitates selection of gearchange RPM. Road data are described in two parts, a road geometry description and a maximum permitted (preferred) speed profile. Road geometry descriptions consist of distance, gradient and road surface information. Primary data can come from either user survey information or as output from a road design package. In either case input road data are transformed to a regular grid basis by interpolation for input to the simulation program. The user supplied preferred speed profile permits specification of areas of legal speed restriction (ie. stop signs, speed limits) as well as points where speed is restricted due to alignment or sight distance. A facility is also included in the speed profile for a downgrade brake warning which can be used by the model to select the appropriate gear for lengthy descent, analogous to the warning signs erected by major highways and the route knowledge accumulated by experienced drivers.

An individual run of the simulation program is controlled by a run control file which details the truck, driver and road segment. It also allows the user to specify segment starting speed and gear.

Limitations of the Program

Simulation programs seldom provide completely accurate predictions of future real-world behaviour. This is particulary true of vehicle simulation models where it is difficult to accurately describe all facets of the real world problem environment (ie. the user's trucks, drivers, roads, weather conditions). Therefore simulation results are unlikely to exactly predict real world performance. Users of simulation techniques need to recognise that their models provide a predicted response to a simplified, abstracted problem. One crucial aspect of simulation model development is the achievement of a balance between the effort expended in expanding the model and meeting the additional data requirements and the potential benefits of improved fidelity.

The TRUCKSIM core simulation program was designed to rely, where possible, on readily available input information. Therefore, the program is based on a simple representation of the dynamics of a moving truck and of engine and driveline performance. Users are required to supply the critical operation assumptions and basic data including engine torque and fuel efficiency curves, engine and driveline loss factors and road geometry and surface resistance. The computer program provides a dynamic calculation framework and the accuracy of it's predictions depend on the accuracy of user input.

There are several important design simplifications arising from the concept of using only readily available or collectable data. The two significant restrictions are:

1/ the use of only vertical alignment data for road sections, and

2/ the use of full power fuel efficiency.

Meaningful representation of horizontal alignment would require direction, superelevation and road surface condition data which are difficult for users to obtain in detail. The primary usefulness of these data are to permit prediction of cornering speed, although consideration of power loss through tyre friction and of weight transfer and traction are also important under specific conditions. However, the overall corner speed problem is often further compounded by variation in sight distance, the poor surface conditions on low standard roads and a tendency for log truck drivers to use the full width of the pavement where traffic is low, or radio contact has ensured a clear road. The result is that cornering speeds on low standard roads are often unpredictable from engineering data, even where it is available. Therefore, horizontal alignment data are not considered, and the user is required to enter cornering speed data directly through the speed profile. Some field data collection might be required.

Calculation of fuel usage in the model is usually based on the full power consumption efficiency curve, since part load power level - engine rpm-consumption relationships (often referred to as engine or fuel maps) are seldom available to truck users. Actual consumption efficiency levels at part load differ from the full load usage rates in a characteristic manner dependent on the engine design, air and fuel induction system and level of fuel input. Two factors help offset potential inaccuracy. Firstly, while fuel efficiency decreases and the level of engine load diminishes, the absolute quantity of fuel involved is also diminishing rapidly, thus the absolute level of inaccuracy is smaller. Secondly, engines spend the bulk of time at either full or no load. In a recent study of log trucks operating in the southern United States [4], the author found that diesel log truck engines spend between 60 - 70 percent of time either at or near full power or at idle fuel flow. The period of time at part load (cruise mode) where the consumption predictions will be inaccurate was small. The level of inaccuracy induced by this simplification will often be smaller than the variation induced by lack of accurate knowledge about such factors as road roughness and stiffness, engine accessory loads or driveline losses. These latter data are also difficult for users to determine and reliance is usually on published "typical" values.

Use of the Model

The two main uses projected for this type of model are:

1/ A generalized comparison of alternative truck specifications against a standardized set of road and driver characteristics, and

2/ A comparison of road design alternatives against a standardized set of truck specifications and driver characteristics.

Four examples developed to demonstrate application of the model are presented below. The first two compare truck characteristics using two standard routes, the last two use a standard truck specification to compare road design alternatives generated from a computer based road design package.

Table 1. Truck Specifications

Truck	6x4 Conv. Cab
Trailer	2 axle semi
Drive Axle	3.7
G.V.M.	38,000 kg

Simulation 1

Two alternative engine power levels are considered, 224 kw (300HP) and 298 kw (400 HP). Identical chassis, trailer, transmission, rear axles and gross load are assumed for each case (Table 1).

Two route specifications (grade and cornering speed) were developed from 25 and 68 km sections of the highway from Scottsdale to Launceston in Tasmania, Australia. The route involves a long sustained uphill pull, then a more level and finally descending roadway. The first section isolates the initial uphill component to capture full power limited performance. The longer test route includes both the initial uphill (Route 1) and the subsequent downhill to better capture overall trip performance.

The simulation results (Table 2) for the power limited uphill Route 1 predict a considerable increase in speed (41 to 47 km/h, >15%) and decrease in gear changing at the expense of about a 7% increase in fuel consumption (106 - 113 l/100km) for the larger engine. A reduction of the climbing time from about 37 to 32 minutes (five minutes) could be expected. Results for the longer test route which incorporated both the climb and the subsequent descent indicate a reduced advantage to the more powerful engine. The difference in total trip time was predicted to be only about seven minutes (83 minutes as compared to 90 minutes) indicating that after the initial climb was completed, the simulated truck with the larger engine only gained about one minute on the rest of the trip. A potential truck purchaser would weigh the value of the predicted speed increase against the projected additional fuel usage as part of his decision process.

Table 2. Comparison of 224 kw and 298 kw engines

	224 kw engine	296 kw engine
25 kilometre Test Route		
Average Speed (km/h)	40.7	47.4
Fuel Consumption	105.6	112.9
Number of Gear Shifts	72	57
Average RPM	1715	1743
Average Revs per km	2530	2206
Average Power Level (%)	74	68
68 kilometre Test Route		
Average Speed (km/h)	45.3	49.1
Fuel Consumption (L/100 km)	98.0	102.9
Number of Gear Shifts	142	120
Average RPM	1730	1725
Average Revs per km	2290	2106
Average Power Level (%)	42	34

Simulation 2

The second comparison considered two transmission alternatives, a traditional 15 speed and a one of the increasingly popular 9 speed units (Table 3). The simulated truck shared the same specifications as the larger engine truck used in Simulation 1. Comparison of the effectiveness of transmissions depends critically on the torque band capability of the engine and the demands of the route. Simulation results for the uphill section (Route 1) indicate speed, fuel consumption levels and shifting requirements were similar. Adoption of the lighter, simpler 9 speed transmission would be indicated for this engine on this route.

Table 3. Comparison of Transmissions

25 Kilometre Test Route	9 speed	15 speed
Average Speed (km/h)	47.3	47.5
Fuel Consumption	111.2	112.9
Number of Gear Shifts	54	57

Simulation 3

This test involved the comparison of four road design alternatives for a climb over a 20 m ridge with an initial ground slope of 7.5%. The four earthwork alternatives involve increasing depths of cut and subsequent fill. In the first three cases the final maximum grade remains the same. In the fourth, the volume produced by the cut was sufficient to reduce overall maximum grade when fill was placed at the toe of the slope. Road design data were obtained from the New Zealand Forest Research Institute Roading Package and results (Table 4) describe simulated truck performance over a one kilometre section. Considerable improvement in both fuel consumption and travel speed result. Such data provide an indication of the value of simulation evaluation in economic analysis of road design alternatives.

Table 4. Vertical Alignment Comparison of Earthwork, Speed and Fuel Consumption

Profile Number	Cutting Depth (m)	Max Grade (%)	Earthwork Volumes Cut/Fill m³	Speed (km/h)	Fuel (L/100km)
1	1.0	7.5	400/3500	30.5	173
2	4.0	7.5	3700/3500	31.0	160
3	6.1	7.5	8000/7000	31.3	151
4	8.2	4.5	16000/14000	37.5	125

Simulation 4

This test explores the likely economics of improving one corner on a compartment access road. The simulated route included a gravelled, right angle turn with a corner speed of 30 km/h. Proposed road improvement was a superelevated larger radius curve allowing a speed of 50 km/h. Entry and exit sections were straight with truck entry speed exceeding 50 km/h. The effects of the proposed change were simulated over the full 7 km access road. While the results for an individual trip are small at 0.2 L and 0.2 mins, (Table 5) a low cost of modification and a high traffic level could justify upgrading.

Table 5. Comparison of Alternative Corner Designs

Route Length — 8 km	Existing 30 km/h corner	Improved 50 km/h corner
Average Speed (km/h)	50.6	51.5
Fuel Consumption (L/100 km)	85.5	82.6
Number of Gearshifts	29	22
Average RPM	1745	1657
Average Revs per km	2068	1927
Average Power Level (%)	72	69
Fuel Saving (L)		0.2
Time Saving (min)		0.2

DISCUSSION AND CONCLUSION

The TRUCKSIM modelling system provides a method for exploring likely consequences of changes in truck specification and road design for truck performance, and ultimately transport costs. The model user is responsible for the input data for all critical parameters affecting the simulation. Therefore a simple design was required for the core simulation program, restricted to readily available user inputs. Even at this level, data for some important aspects of the simulation environment are difficult to collect or change seasonally (ie. driver response to sight distance and road surface condition). The greatest utility for these models comes in limited direct comparisons where expected shortcomings are minimised.

Examples of potential application for the model included comparisons of engine and transmission specification, and of alternative road designs. The primary performance predications produced by the model were expected truck speed and fuel consumption.

Application of models of this type depend on ease of use (collection and manipulation of input data). Initial design emphasis was placed on a capability to maintain and expand libraries of truck component and route data. Forest transport managers often enjoy several important advantages not shared by other transport sectors. Product delivery points are often stable in the long term (pulp and sawmill locations) and the operating entities often have long term responsibility for significant parts of the transport network. Under these circumstances, road data such as physical and speed profiles which changes only slowly, have longer term strategic value. Developments in data collection technology and of the intensity of management of transport systems favour the development of these data bases and allow application of dependent modelling systems.

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