TRUCK PERFORMANCE AND PREDICTION

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CSIRO.

SUMMARY

Truck simulation, coupled to a convenient way of specifying road shapes, offers great potential to road transport planners and roading engineers allowing detailed research into truck road interaction as well as vehicle specification alternatives.

ACKNOWLEDGEMENTS

The support of both my employer, CSIRO and of FRI is gratefully acknowledged. The Simlog program and the Transmission and Engine summary programs were written by Brian Clement of the FRI Harvest Planning Group. Other programs of the TRUCK-SIM system were written by the author.

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INTRODUCTION

The work described here originated in the CSIRO Harvesting Research Group's program of the late 1970's to develop a better, more systematic understanding of the operational and economic aspects of wood transport from stump to mill and has been continued in New Zealand under a co-operative arrangement with FRI.

The original project envisaged the development of computer-based data logging equipment for detailed performance measurement of both "in forest" transport (i.e. skidders, and more in the Australian context, forwarders) and trucking, envisaged as both primary road haulage and perhaps secondary, in forest off-highway, or specialised tractors. The development of simulation models of machine transport performance based on detailed engineering characteristics of machine and terrain (i.e. engine power, skidding resistance, ground slope, trail or road roughness data) was to follow. A family of these models could then provide the basis for detailed economic evaluation of transport alternatives, particularly the choice of landing, skid trail and road location subject to the local terrain and forest conditions. The road transport model was selected as the first target.

Important phases in this project were :

(1) Construction of a Harsh Environment Data Logger, a microprocessor based data logging system. Its general capabilities include the monitoring, recording and display of 10 channels of input data at intervals as short as 1.5th second and the recording of the data on computer compatible cassette tape. Specialised construction techniques produced a very robust unit capable of standing up to the harsh environments found on logging and trucking machinery.

(2) Road mapping and Vehicle Sensors. To provide the input to the data logger, sensors have been developed, modified or purchased, with varying degrees of success for road speed, engine rpm, throttle position, fuel flow rate, road grade and superelevation and braking.

(3) Data Analysis and Reporting programs to process, analyse and report on the large masses of data generated. About 6-9 man months were expended in this phase.

(4) Truck Studies. Installation of the data logger requires fitting to the truck (several man days).

(5) Truck Simulation programs were developed in parallel with the truck study. The structure of the model is dealt with in more detail following.

A representation of the projects structure is presented in Figure 1. The host minicomputer is required in each phase of the project. The data logger has two separate uses - truck study and road mapping. Truck performance data is required to check and correct the operation of the simulation model. Some form of road mapping to produce computer files of road shape information is required to run the simulation model. Two approaches have been followed.

Initially the data logging equipment was attached to sensitive slope and direction sensors and a specially equipped vehicle driven over the target road. A variety of low cost experimental sensors have been developed, based on hand built and aircraft surplus equipment. The pendulum based slope sensor has provied reliable. Contacts with other groups working to the same objective indicates that considerably more expensive measurement instruments are required. The British Columbia Forest Service and the Australian Road Research Board have both developed road mapping vehicles based on Aircraft grade Gyroscopes and Accelerometers. A recent joint project with DSIR, successfully developed and tested a prototype slope measurement system incorporating a high grade accelerometer and specially developed correction circuitry to correct for vehicle acceleration.

A second approach to road mapping is the use of data from direct survey or contour maps. In both cases computer processing is required to generate the road files. The Roading Planning package under development by Paul Richardson and others at FRI has provided these facilities with a little modification.

The integration of these two tools, road planning and truck simulation forms a fundamental element in this projects development strategy. One of the major uses of truck simulation is in the study of road vehicle interaction and this requires the close coupling of the truck simulation with a roading system capable of generating the manipulating alternative road shapes. This allows the road designer the opportunity of exploring the likely effects of design change on transport performance.

FRI Roading Design Package

The input programs for the Roading Package are structured to define a "design corridor" based on either field survey or contour map data. The design corridor consists of a field of ground surface points, in cross sections at intervals along the corridor (Figure 2). the designer then chooses particular horizontal (Figure 3) and vertical (Figure 4) alignments and the computer calculates the design road co-ordinates and the required earth work volumes. The cycle continues until a satisfactory design is obtained. The design road output file can be fed directly to the truck simulation.

(1) TRUCK-SIM The CSIRO-FRI Truck Simulation Programs

The form of the model was drawn from SAE J688 and McNally (1)*. The model works by calculating the forces acting on the truck at a particular instant and derives the net power surplus or deficit. If the simulated vehicle is under no particular speed restriction the net power is applied to the vehicles mass and the simulated truck is allowed to accelerate for an interval, after which the cycle is repeated. The simulation moves along the grades input from the road profile file. The basic factors considered by the simulation are shown in Figure 5. Force available at the wheel is derived from the total engine power available at that rpm, less estimated losses from cooling fan, engine accessories and friction in the gearbox and drive train. Other forces considered (all retarding in this case) include grade resistance due to the weight of the truck, air resistance and the resistance due to the road surface (termed rolling resistance). In this example, net power is positive so the vehicle could accelerate.

1.1 Truck Specification Files

Three specification files are required as input to the Simulation system, Truck configuration, Engine and Transmission Files. These files may be drawn from computer file libraries. (Input specifications are attached to Appendix A).

1.2 Road Files

Road input comes from a Road File. Important components of this data (illustrated in Figure 6) include the road horizontal curvature, vertical curvature and superelevation. Two additional factors are important, speed limitations due to other factors (i.e. sight distance, traffic signals) and road roughness. In the operation of the simulation system, the first three factors (horizontal and vertical curvature and superelevation) are stored as the basic road description. Speed restriction is described as a notional "speed envelope"

(1)* The form of the model is similiar to that presented by John Galbraith in his earlier paper to the workshop which prescribes the maximum allowed speed at any point. The idea is that this "envelope" is largely independent of a particular vehicle and represents factors under control of the road designer. It is an extension of the idea of design speed, joined with sight distance and traffic control limitations. Using computer data storage permits expression of this more complicated data as a curve or "envelope".

The roading engineer could, by changing the road, or clearing a corner, change the envelope for all trucks. A control file describing the speed envelope is maintained as part of the road data.

Similarly, road roughness is a factor under some control by the road engineer, and will vary along the length of a road. The factor used in this simulation is that of Grade Equivalent, as drawn from McNally. It is a factor that users of the simulation will likely vary experimentally.

1.3 Simulation Output

Appendix A provides an example of some of the output reports and graphs produced by the system. Of these, the Simulation Log File is perhaps the more important where hard numbers on particular road features or vehicle changes are required. The Log produces a summary of simulated performance over particular segments requested by the user. Route summary and gear change tables are also produced. The Simulation Analysis graph includes traces of speed, engine rpm, gear and power usage. Engine torque curve and Transmission gear ratio charts can also be produced. Finally, a road profile analysis provides both long section and point slope data.

(2) SIMULATION APPLICATIONS

Three examples of the use of the truck simulation model were generated to demonstrate potential applications. These were :-

(i) levels of variation in cutting depth on a hill top

(ii) variations of the level of road improvement on an existing forest secondary road, and

(iii) three alternative in grade selection to climb up a long slope

2.1 Hilltop Cutting Example

An experimental road profile comprising a climb over a 20 metre ridge with five depths of cutting were prepared using the roading package. The final road section was 1 km long and the grade was about 7.5%. Depths of cutting tested ranged from 1 m to over 8 m. In the last case, large quantities of material were moved (16000 cubic metres) and the cutting merged into the fill at the bottom of the ridge resulting in a substantial reduction in the maximum grade (4.5%). Figures 7 and 8 give examples of the road profile data.

Both starting and terminal speed were controlled as was down grade speed to allow strict comparison between tests. Truck configuration was 50 tonne gross, 320 hp, 15 speed Transmission, with 2 axle pole jinker, similar to that detailed in Appendix A. Increasing levels of cut provided both fuel saving and speed increase. Profile 5, with substantial earthworks, yielded considerable improvement, due primarily to the substantial reduction in maximum grade.

2.2 Secondary Compartment Access Road

In this case a 7 km section of metalled compartment access road was used. The road section, including the road profile analysis is that presented in Appendix A. In the base line case, a road roughness grade equivalent of 1.5 was assumed (Trial 2). A grade equivalent of 1.0 (sealed surface - McNally) resulted in a travel speed increase of 11% and a fuel reduction of 12%. In general terms, higher travel speed requires greater fuel consumption so the two results are essentially additive.

In another test, the effects of a specific speed restriction were investigated. During a period of detailed truck study on this route a speed restriction of 28 kph was identified on a particular corner. Imposing this restriction resulted in a time loss of 0.4 min. and a 0.151 increase in fuel consumption. Since this particular corner, and as speed restrictions do exist on the road, the results can be used to indicate likely returns from improving the corner. A final test on this segment indicates the effect on performance of a major increase in gross vehicle weight. Assuming that net payload has increased from 32 tone to 48 tonne, then fuel per tonne km has improved from 0.051 l/tonne km to 0.044 l/tonne km (14% reduction) and truck transport efficiency from 1068 tonne km/hour to 1155 tonne km/hour (8% improvement).

2.3 Grade Change

For truck drivers, road design is an important consideration since steep section in a long grade can force a truck into a low gear from which it cannot accelerate even as the grade moderates. As an experiment, three alternative grade configurations for a 1 km route were generated using the road planning package. These were an even 5% grade, an equivalent total climb comprising a section of 3% finished with a section of 7% (steep last) and a third profile with the grade order reversed (steep first). Again, entry and exit speeds were regulated to facilitate comparison. The even grade section allowed the fastest travel time while the greatest reduction in speed was caused by the section with the steep grade first.

2.4 Summary of Trials

These three set of trials provide some indication of the use to which a detailed truck/road simulation model can be put. It is unlikely that we will ever have the resources to develop precise predictors for individual truck models, of the Cummins VMS type. However, it is equally unlikely that the users of these models will have detailed data on the roads of interest to us. Much can be learned by forest transport planners and researchers, I believe, by using simpler models of the type described above with a well integrated road design or road recording system, particularly if used in comparative tests. Such models as the CSIRO-FRI Truck-Sim program described above also provide the platform, through program modification, for more detailed measurement and investigation of vehicle performance. However, it is important not to loose sight of the over-riding importance of real measurement and experiment with operational trucks and local roads, just as one example, real local values are required for road roughness.

(3) FUTURE DIRECTIONS

Technologies associated with research and development, primarily those based around the microchip suggest the following possibilities :

(i) Robust, reliable, commercially available Data Recording Equipment within 2-3 years at prices of $1-5000. Here, the emphasis is on robustness and reliability. Several factors need to be considered. First the data recorders need sensors to provide the data to record, which poses additional problems. Secondly, such data collection and analysis usually becomes computer intensive, and trained staff and computer resources are needed.

(ii) Specially assembled Road Mapping Systems priced at $20000-$50000 in the next 2-4 years. In forestry where many roads are not mapped at construction, road mapping could become an important element in the understanding of our transport systems. Certainly, it is a prerequisite to the extensive use of vehicle simulation for wider management purposes. Currently, civilian road mapping systems are expensive, and apparently, a little delicate. Military technology is reportedly much more advanced although civilian spinoff occurs all the time. For example gyros suitable for these applications are now almost "mass produced" for missile and aeroplane guidance and control systems at fractions of the cost five years ago. However, it is difficult to identify a large market that will spur commercial development of the fully developed system, so equipment will likely continue to be specially built.

(iii) Reliable and Accessible Heavy Vehicle Simulation Programs, available now for the researcher but access unknown for the general user. A variety of research or "large computer" models are already available. However, close integration with road map data systems is essential for detailed use in investigating road/vehicle interaction. This suggests the need to run the joint models in the user's own computer facility.

(iv) Accessible, Integrated Roading/Logging Planning Packages are available now, from a number of sources priced from $20000 upward including the computer. Decisions to road, or choose a particular transport system depend crticially on the associated planning of the logging operation. Planners need to be able to consider both during the development phase of the plans. Adoption of computer-based planning tools paves the way for later, more detailed usage of tools such as those outlined above.

(4) REFERENCES

CUMMINS ENGINE COMPANY, 1982. VMS-Vehicle Mission Simulation. Bulletin 3382633. Cummins engine Company Inc., Columbus, Indiana, U.S.A.

McNALLY, J.A., 1975. Trucks and Trailers and their Application to Logging Operations, University of New Brunswick, Canada

SOCIETY OF AUTOMOTIVE ENGINEERS, 1958. Truck Ability Prediction Procedure - SAE J688. Report of Transportation and Maintenance Committee (Revised 1958). Society of Automotive Engineers, Inc., New York, U.S.A.

FIGURE 1

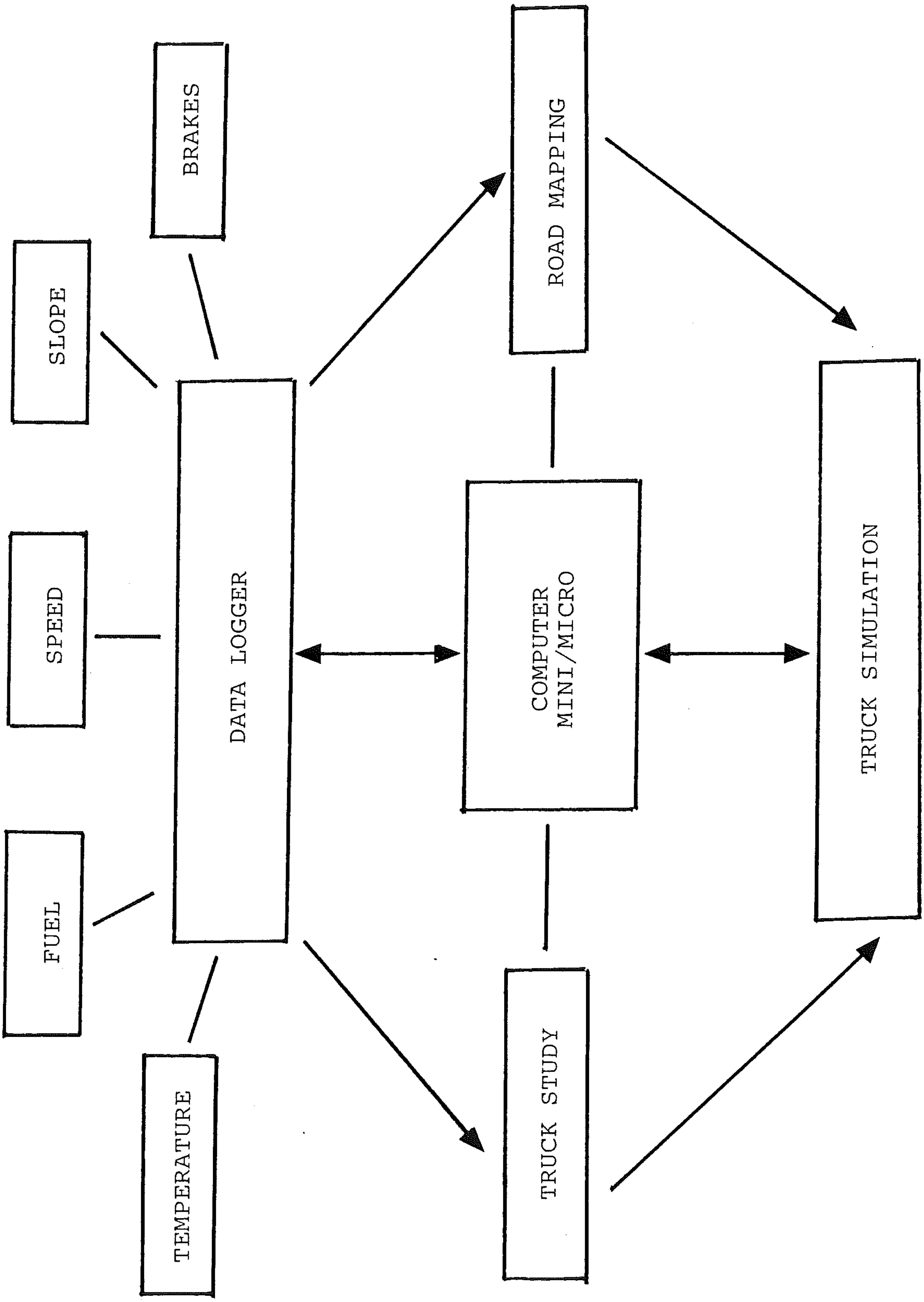
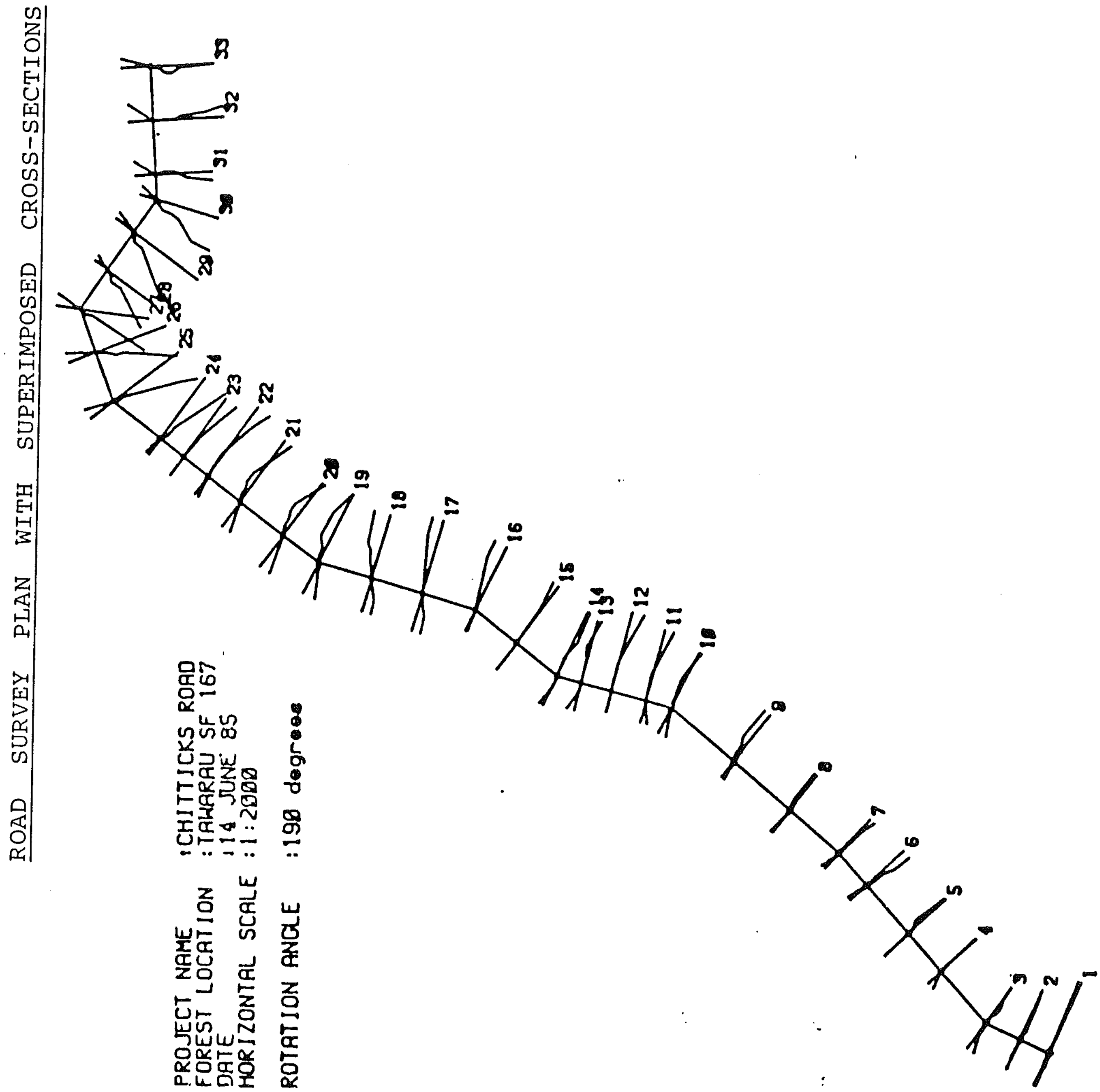

BRAKES
SLOPE
SPEED
FUEL
TEMPERATURE
DATA LOGGER
ROAD MAPPING
COMPUTER
MINI/MICRO
TRUCK STUDY
TRUCK SIMULATION

FIGURE 2


ROAD SURVEY PLAN WITH SUPERIMPOSED CROSS-SECTIONS
PROJECT NAME :CHITTICKS ROAD
FOREST LOCATION :TAWARAU SF 167
DATE :14 JUNE 85
HORIZONTAL SCALE :1:2000
ROTATION ANGLE :190 degrees
1
2
3
4
5
6
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32
33

FIGURE 3

DESIGN HORIZONTAL ALIGNMENT

PROJECT NAME	:ANAURA UPGRADING P1 TO P15
FOREST LOCATION	:MOHAKA SF (WELLINGTON CNSY)
DATE	:5 JUNE 85
HORIZONTAL SCALE	:1:2000
ROTATION ANGLE	:60 degrees
ROAD LENGTH	:1360 metres
HORIZ. PLAN REF.	:1

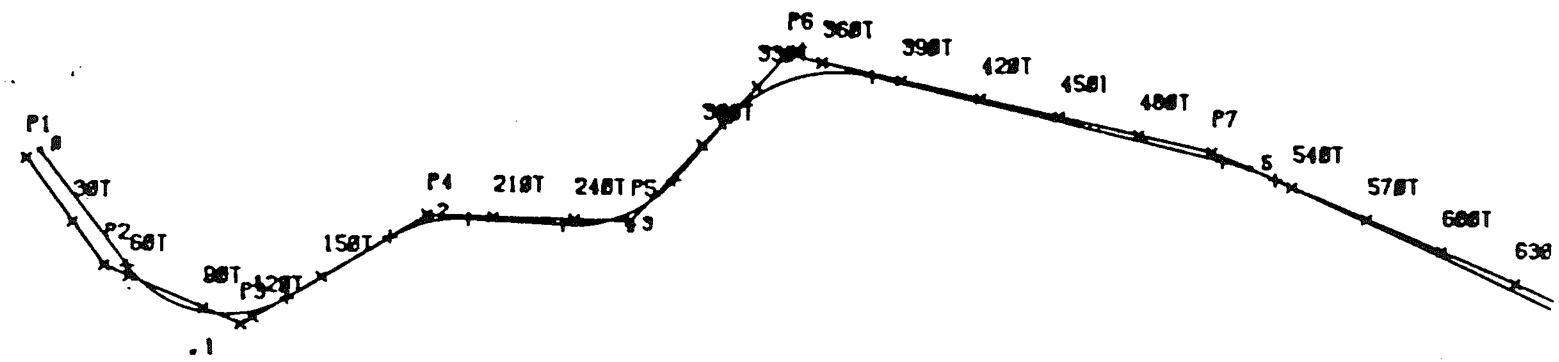
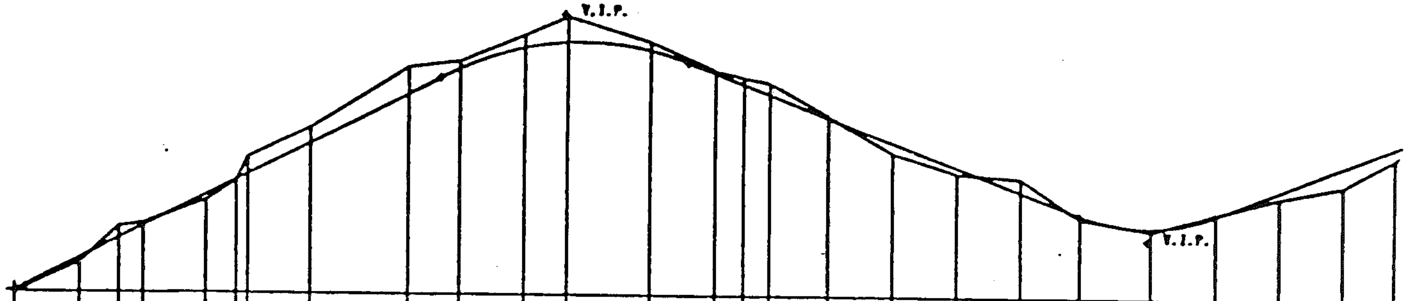


FIGURE 4

DESIGN VERTICAL ALIGNMENT

PROJECT NAME : ANAURA UPGRADING P1 TO P15
FOREST LOCATION : MOHAKA SF (WELLINGTON CNSY)
DATE : 5 JUNE 85
HORIZONTAL SCALE : 1:2500
VERTICAL SCALE : 1:500



PEG IDENTIFIER	P1	30T	P2	60T	90T	P3	120T	150T	P4	210T	240T	P5	300T
CUT (metres)			1.2	.4		0.0	1.8	1.7	2.7	.9	1.3	2.5	1.0
FILL (metres)	0.0	.4			.5								
GRADE LEVEL	428.5	431.7	433.6	434.9	437.9	439.3	[illegible]	442.8	447.6	450.1	452.1	452.7	451.9
GROUND LEVEL	428.5	431.3	434.8	435.1	437.4	439.3	441.6	444.5	450.4	451.0	453.5	455.2	452.9
DISTANCE	0.0	30.0	40.2	59.4	88.3	[illegible]	[illegible]	135.9	181.2	204.0	234.9	254.9	283.5

PEG IDENTIFIER	330T	P6	360T	390T	420T	450T	480T	P7	540T	570T	600T	630T	P8
CUT (metres)	.4	.8	1.2	.3			1.5			.3			
FILL (metres)					.9	.5		.2	.2		.6	1.8	.9
GRADE LEVEL	449.8	448.7	447.8	445.6	443.2	440.9	438.5	436.3	435.2	436.5	438.9	441.3	443.3
GROUND LEVEL	450.2	449.5	449.0	445.9	442.3	440.4	440.0	436.1	435.0	436.8	438.3	439.6	442.3
DISTANCE	323.7	337.0	349.1	377.2	407.2	437.2	467.1	494.6	527.1	557.1	587.1	617.2	641.2

FIGURE 5

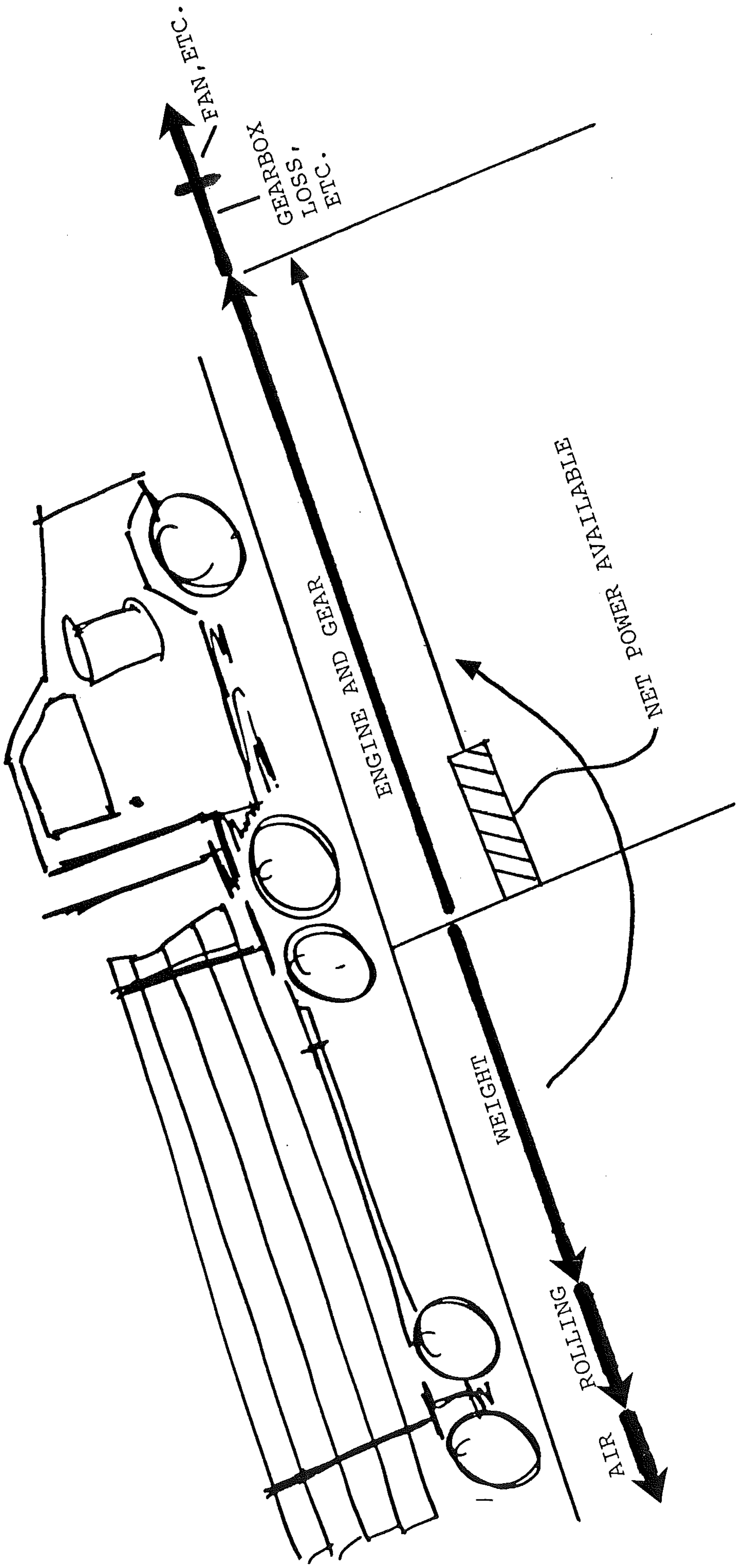
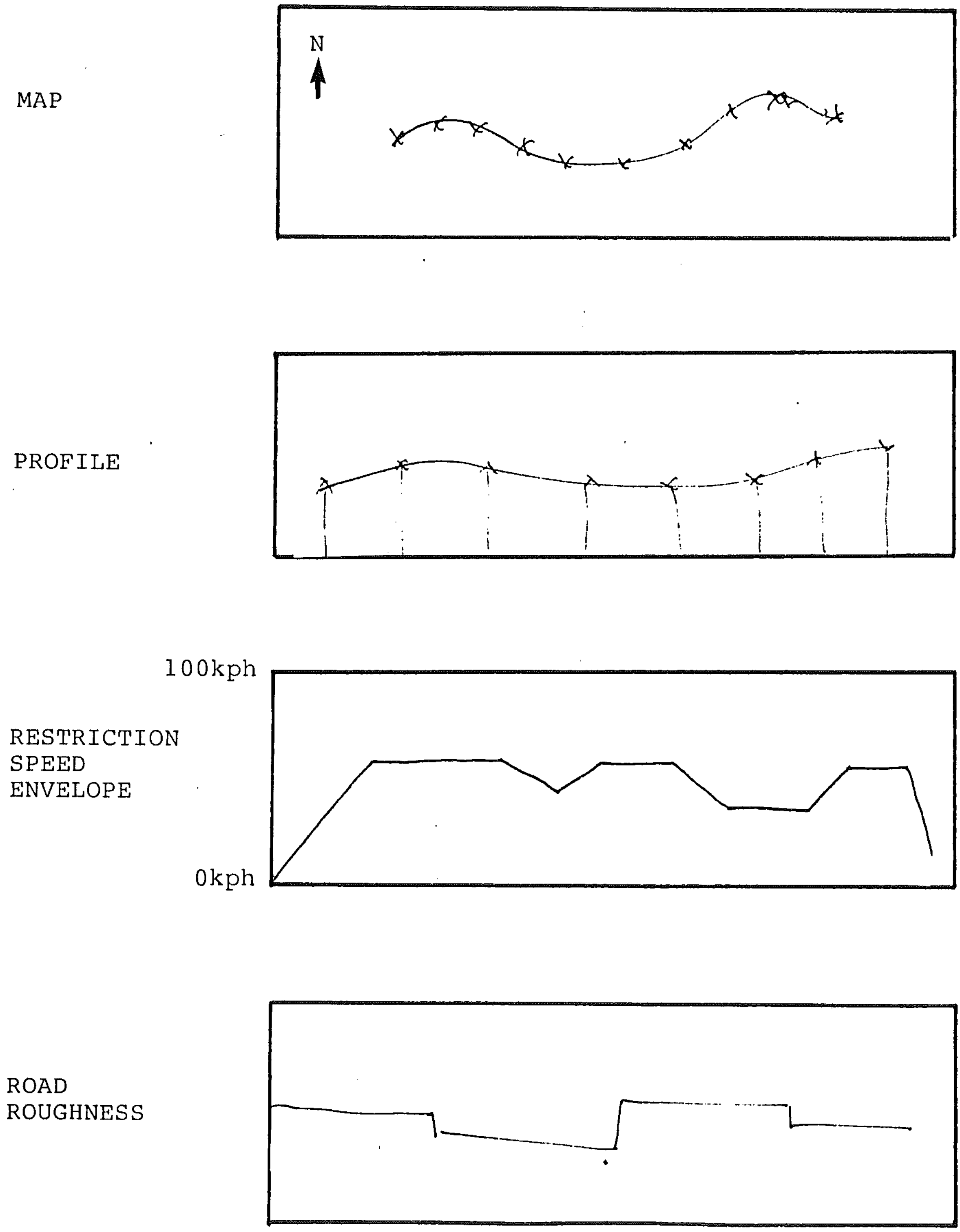

FAN, ETC.
GEARBOX LOSS, ETC.
ENGINE AND GEAR
NET POWER AVAILABLE
WEIGHT
ROLLING
AIR

FIGURE 6

ROAD DESCRIPTION FILES



APPENDIX A

TRUCK PERFORMANCE MEASUREMENT AND SIMULATION

Presentation Notes

1. SIMULATION output Example

2. Performance Examples

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*********************************************************************************************
*                                                                                           *
*  CSIRO - FRI      LOG TRUCK PERFORMANCE ANALYSIS PROJECT                                  *
*  ----------------------------------------------------------                               *
*  @@@@@ @@@@  @   @  @@@@ @   @      @@@  @@@ @   @                         Page  1        *
*    @   @   @ @   @ @      @ @       @      @ @@ @@                                        *
*    @   @@@@  @   @ @      @@@   @@@ @@@    @ @ @ @                       21-JUL-85        *
*    @   @  @  @   @ @      @ @          @   @ @   @                        22:47:31        *
*    @   @   @  @@@   @@@@ @   @      @@@  @@@ @   @                                        *
*                                                                                           *
*-USER-: Bob MCCORMACK - FRI :-ROAD---: SECTION 6 NZFP      :-RUN--: 100000                  *
*-TRUCK:  PACIFIC  JINKER    :-ENGINE-: CUMMINS NTC 320     :-GVW--: 50.80tonne              *
*-TRANS:  Fuller RTO-915     :-DIFF---:  Rockwell 6.38      :-TYRE-:  1100:22               *
*                                                                                           *
*********************************************************************************************
```

Journey Log

ID	Segment Time min	Segment Dist m	Total Dist m	Segment Speed km/hr	Segment RPM	Segment Fuel l	Fuel Rate l/100km	
1	0.90	403.4	403.4	26.89	1787	0.72	179.29	First Corner
2	1.55	1203.8	1607.2	46.60	1823	1.52	126.37	Bend
3	1.62	1405.7	3012.9	52.17	1825	1.59	112.80	End Flat
4	0.95	792.9	3805.8	50.08	1783	0.91	115.02	Post Yard corner
5	2.23	1247.7	5053.5	33.52	1855	2.17	174.11	Start steep pinch
6	1.70	450.6	5504.1	15.90	1986	1.30	288.95	End steepest pinch
7	1.32	800.5	6304.6	36.48	1814	1.25	155.55	Start last flat
7	0.75	619.0	6923.6	49.52	1868	0.63	102.54	<<< End of data >>>

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*******************************************************************************************
*                                                                                         *
*  CSIRO - FRI      LOG TRUCK PERFORMANCE ANALYSIS PROJECT                                *
*  ----------------------------------------------------                                   *
*  @@@@@ @@@@  @    @  @@@@ @   @      @@@  @@@ @   @                        Page  2      *
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*    @   @@@@  @    @ @     @@@   @@@  @@@    @ @ @ @                        21-JUL-85    *
*    @   @  @  @    @ @     @  @         @  @ @   @                          22:47:31     *
*    @   @   @  @@@  @@@@ @   @      @@@  @@@ @   @                                       *
*                                                                                         *
*-USER-: Bob MCCORMACK - FRI :-ROAD---: SECTION 6 NZFP       :-RUN--: 100000              *
*-TRUCK:  PACIFIC  JINKER    :-ENGINE-: CUMMINS NTC 320     :-GVW--: 50.00tonne           *
*-TRANS:  Fuller RTO-915     :-DIFF---:  Rockwell 6.38      :-TYRE-:  1100:22             *
*                                                                                         *
*******************************************************************************************
```

Journey Summary
==============

Total Distance	:	6923.60	metres
Total time	:	11.02	mins
Total number of gear changes	:	29	
Average Speed	:	37.71	km/hr
Total fuel used	:	10.10	litres

```
***************************************************************************************************
*                                                                                                 *
*  CSIRO - FRI      LOG TRUCK PERFORMANCE ANALYSIS PROJECT                                        *
*  ---------------------------------------------------                                            *
*  @@@@@ @@@@  @    @  @@@@ @    @      @@@  @@@ @    @                       Page  3             *
*    @   @   @ @    @ @      @  @       @      @ @@ @@                                            *
*    @   @@@@  @    @ @      @@@    @@@  @@@   @ @ @ @                        21-JUL-85           *
*    @   @  @  @    @ @      @  @          @   @ @   @                        22:47:31            *
*    @   @   @  @@@   @@@@ @    @       @@@  @@@ @   @                                            *
*                                                                                                 *
*-USER-: Bob MCCORMACK - FRI :-ROAD---: SECTION 6 NZFP      :-RUN--: 100000                       *
*-TRUCK:  PACIFIC  JINKER    :-ENGINE-: CUMMINS NTC 320     :-GVW--: 50.00tonne                   *
*-TRANS:  Fuller RTO-915     :-DIFF---:  Rockwell 6.38      :-TYRE-:  1100:22                     *
*                                                                                                 *
***************************************************************************************************
```

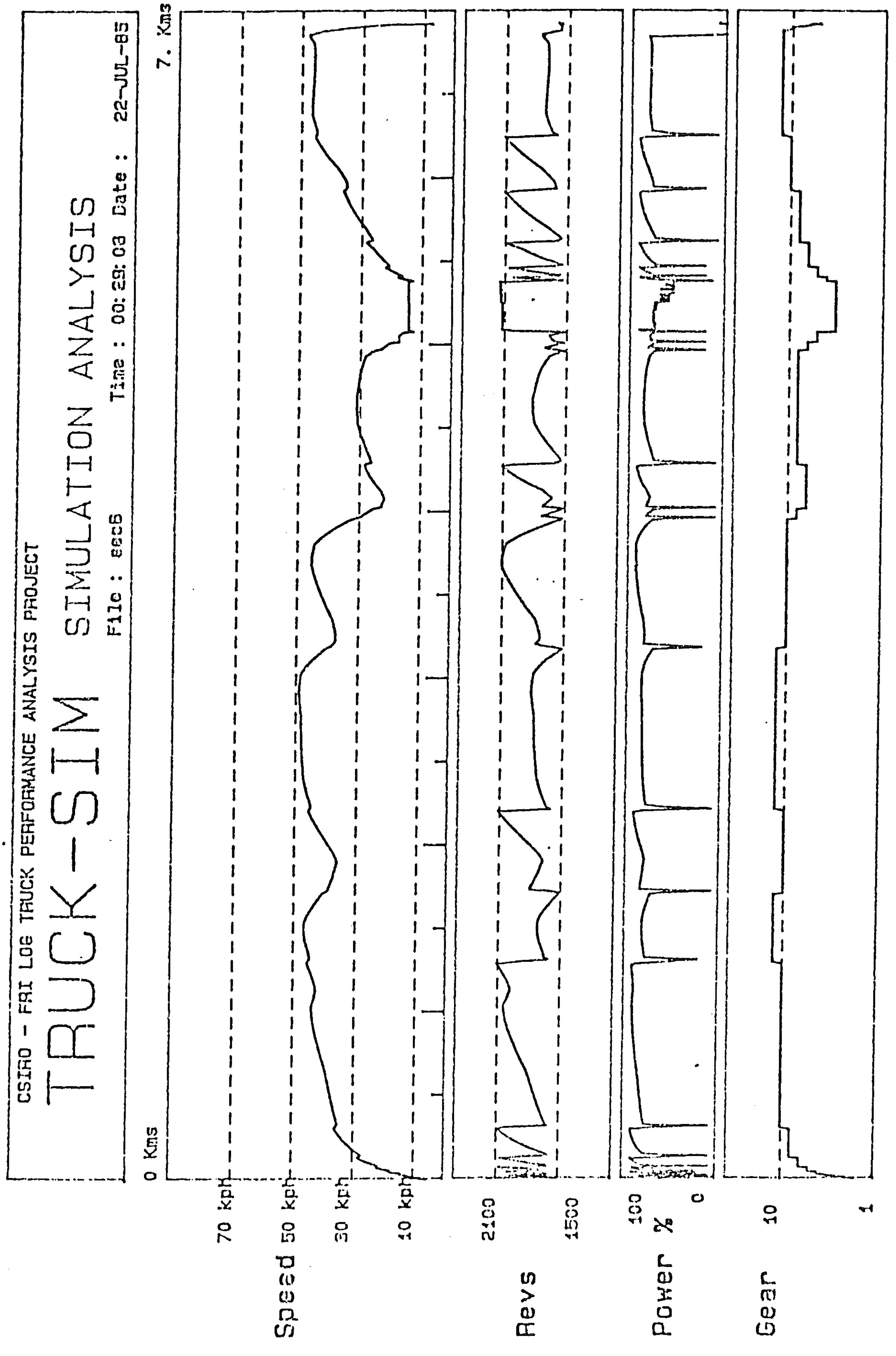
Percent time in each Gear

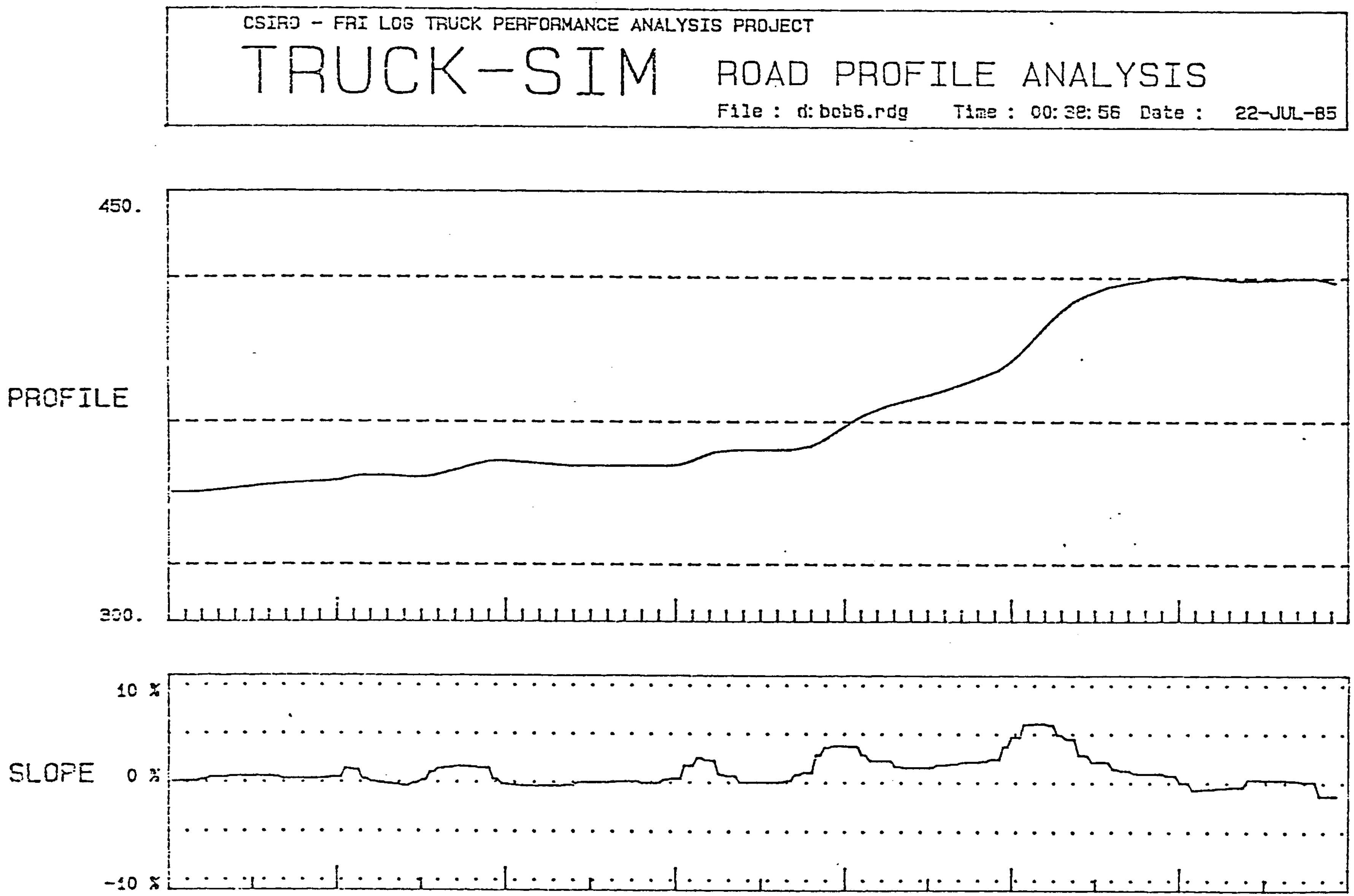
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.0	0.2	0.5	0.3	10.7	1.4	3.2	4.5	23.3	12.6	38.3	5.1	0.0	0.0	0.0

Gear Change Table

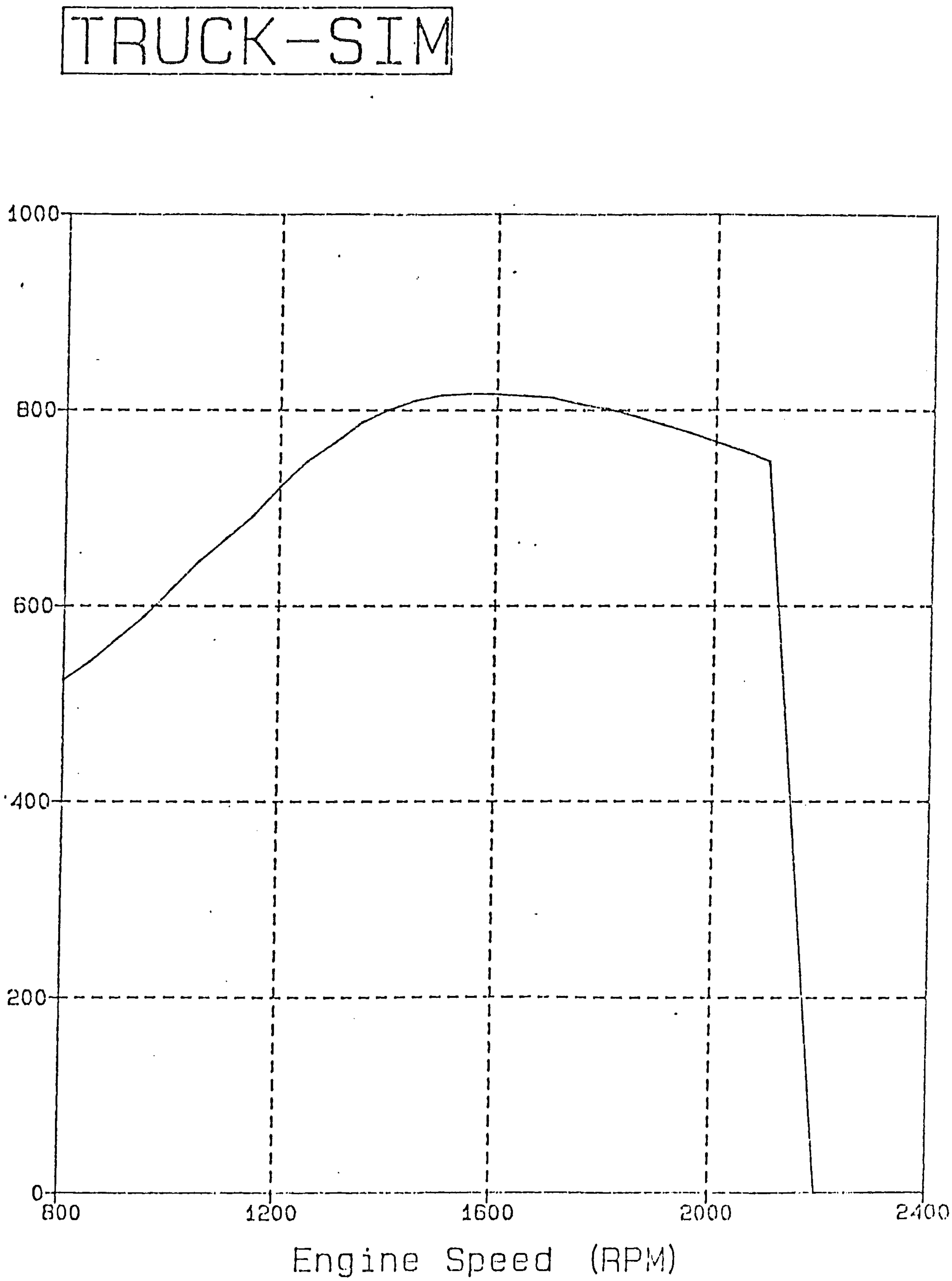
(Gear changed to)

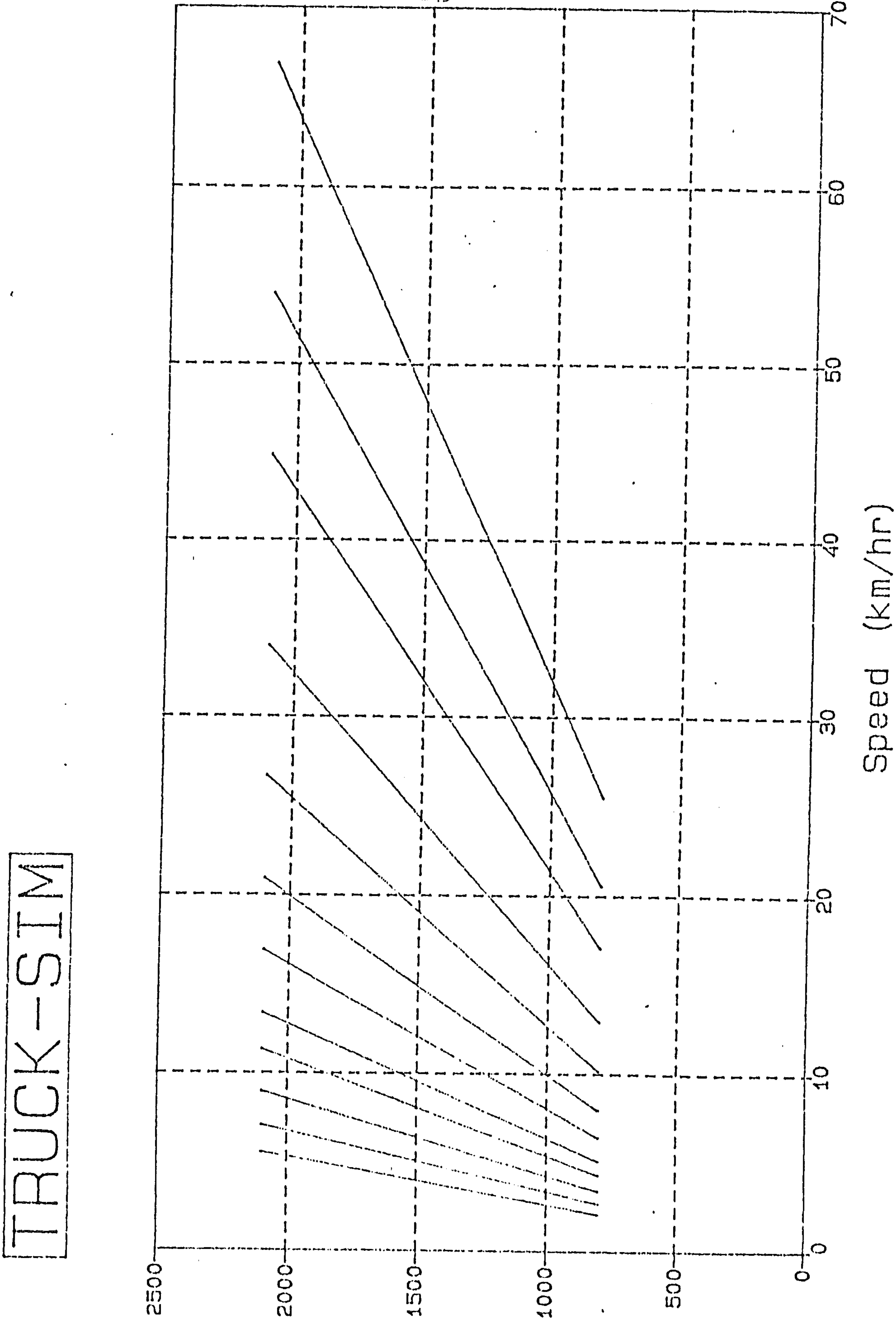
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	*	1													
2		*	1												
3			*	1											
4				*	1										
5					*	2									
6						*	2								
7					1		*	2							
8							2	*	2						
9								2	*	2					
10									2	*	2				
11										2	*	2			
12											2	*			
13													*		
14														*	
15															*


CSIRO - FRI LOG TRUCK PERFORMANCE ANALYSIS PROJECT
TRUCK-SIM
SIMULATION ANALYSIS
File : esc6
Time : 00:29:03 Date : 22-JUL-85
0 Kms
7. Kms
Speed
70 kph
50 kph
30 kph
10 kph
Revs
2100
1500
Power %
100
0
Gear
10
1



CSIRO - FRI LOG TRUCK PERFORMANCE ANALYSIS PROJECT
TRUCK-SIM ROAD PROFILE ANALYSIS
File : d:bob6.rdg Time : 00:38:56 Date : 22-JUL-85
450.
PROFILE
330.
10 %
SLOPE 0 %
-10 %


TRUCK-SIM
1000
800
600
400
200
0
800
1200
1600
2000
2400
Engine Speed (RPM)


TRUCK-SIM
Speed (km/hr)
0
10
20
30
40
50
60
70
0
500
1000
1500
2000
2500

TRUCK PERFORMANCE EXAMPLES

CUTTING DEPTH

PROFILE Number	Speed kph	Fuel (l)	Maxm Grade	Cutting Depth	Cut/Fill Vols m**3
1	30.5	1.39	7.6	1 m	400/3500
2	31.0	1.28	7.6	4 m	3700/3500
3	31.3	1.22	7.6	5.6m	7000/6000
4	31.3	1.21	7.6	6.1	8000/7000
5	37.5	1.14	4.5	8.2	16000/14000

COMPARTMENT ACCESS ROAD EXAMPLE (6.9km)

Time	Limitation	Weight	Fuel
11.0	assume good seal Grade equiv 1.0	50.8t	10.10l (145 l/100k)
12.4	pummice surface Grade equiv 1.5	50.8t	11.35l (163 l/100k)
12.8	28 kph corner Grade equiv 1.5	50.8t	11.50l (166 l/100k)
17.2	trailer Grade equiv 1.5	70.0t	14.48l (193 l/100k)

GRADE POSITION EXAMPLE

Slope type	Speed	Fuel
Even (5%)	23.5	2.27l/km
Steep last 4% , 7%	22.6	2.15l/km
Steep first 7% 4%	21.4	2.26l/km