Mainline Upgrading: Evaluation of a Range of Options for the Melbourne - Sydney Rail Link

Report

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BUREAU OF TRANSPORT ECONOMICS

MAINLINE UPGRADING - EVALUATION OF A RANGE OF OPTIONS FOR THE MELBOURNE-SYDNEY RAIL LINK

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FOREWORD

The majority of Australia's intercapital railway lines are single track and they all experience some degree of congestion. Various combinations of capital investment options and improved operating practices are evaluated in this report, with a view to eliminating the growing congestion on the Melbourne-Sydney rail link. A separate report is published by the BTE regarding investment in the Victorian portion of the Melbourne-Adelaide rail link.

The study was carried out by an interdisciplinary team but is largely the work of the Operations Research Branch. The team was led by A.F. Walker, and her principal assistants were A.M. Currie and A.J. Green. The forecasts were provided by A.B. Smith and the single track simulator was developed by A.J. Storry. The road congestion costs form part of the work of A.E. Fitzpatrick.

The methodology used in the study was developed under the direction of J.C.M. Jones.

The BTE acknowledges the assistance received from the Public Transport Commission of New South Wales, Victorian Railways and the Commonwealth Bureau of Roads.

J.H.E. Taplin
Director

Bureau of Transport Economics,
Canberra,
November 1975.

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SUMMARY

This study forms part of the general assessment of railway freight operations being carried out by the Bureau of Transport Economics at the request of the Australian Transport Advisory Council (ATAC). As requested by ATAC, this study examines:

- the effect of variations in the average weight of interstate freight trains on the efficient utilisation of existing resources; and

- the effect of investment in railway tracks and signalling on mainline capacity.

The growing congestion problem on the single track portion of the Melbourne-Sydney rail link between Junee and Melbourne is quantified and a range of upgrading options are evaluated. These options include: regrading, centralised traffic control, selective line doubling and the addition of crossing loops on stretches where the existing loops are widely spaced.

Main line upgrading is evaluated from two viewpoints: firstly from the railway's point of view as a commercial concern and secondly from the point of view of the optimum allocation of resources within

the transport sector. It turns out in this particular study that the upgrading options best meeting both criteria are identical.

For New South Wales, all present crossing loops should be extended immediately to 915 metres, allowing the use of heavier and therefore fewer trains. At the same time the present signalling system should be improved with the introduction of centralised traffic control. The cost of the preferred upgrading scheme is $2.4 million in 1973 prices and the calculated rate of return is in excess of 30%.

For Victoria, the most effective way to reduce congestion delays and increase the capacity of the track is to build six new crossing loops some time between 1977 and 1982. The cost of the upgrading is estimated at $1.52 million in 1973 prices and again the calculated rate of return on investment exceeds 30%.

The social benefit-to-cost ratio of upgrading the Sydney-Melbourne rail link - ignoring likely congestion effects on the Hume Highway if the rail is left in its present state - is expected to be in the range 1.7 to 5.2 depending on discount rate and traffic growth.

CHAPTER 1 INTRODUCTION

The traffic carried on the Melbourne-Sydney railway is the heaviest in the Australian State and National system. The greatest movement is on the double track portion between Goulburn and Moss Vale, but the most serious congestion problems are experienced on the single track section between Albury and Junee. The signalling system on the latter section is based on mechanical operation and exchange of tokens between crossing trains. Interstate freight traffic, presently comprising 10 northbound and 12 southbound trains daily, with a projected 1990 estimate of 19 and 18 respectively, is the traffic most sensitive to congestion delays.

This study forms part of the general assessment of railway freight operations being carried out by the Bureau of Transport Economics (BTE). It was initiated at the request of the Australian Transport Advisory Council (ATAC) in July 1973. As requested by ATAC, this study examines:

- the effect of variations in the average weight of interstate freight trains on the efficient utilisation of existing resources; and the effect of investment in railway tracks and signalling on mainline capacity.

The study examines a comprehensive range of upgrading options including regrading, centralised traffic control (CTC), and selective line doubling.

Early examination of the Melbourne-Sydney line indicated that the standard gauge link from Albury to Melbourne would also become congested during the study period. This single track line with CTC carries interstate traffic only, and runs parallel to a broad gauge line of the Victorian system. The relatively small number of crossing loops on the standard gauge line are a consequence of the low traffic volumes at the time it was designed. Options involving additional crossing loops were consequently embodied in the study.

Loading and unloading of trains is an essential process in carrying interstate freight by rail and it is conceivable that present terminals may become inadequate within the study period. The Public Transport Commission of N.S.W. (NSWPTC) is currently planning a new terminal at Enfield based on containers and on the concept of unit trains, whilst freight forwarders already operate similar facilities in Sydney and Melbourne. The whole question of freight wagon utilisation and terminal performance is under study by the BTE and the upgrading of major interstate freight terminals will be one of the first aspects to be evaluated. This report therefore ignores the implications of traffic growth to terminal upgrading. However, the conclusions arising from this report should be viewed in an overall manner; for instance, there is no point in upgrading the main line if this action simply shifts the bottleneck to the terminals.

Main line upgrading is evaluated firstly from the railway's point of view as a commercial concern and secondly, from the point of view of the optimum allocation of resources within the transport sector. In the former case the evaluation is basically a trade-off between the cost of upgrading on the one hand, and the resultant savings and additional revenues on the other. In the latter case we are concerned with the effect, in resource cost[1] terms, of carrying more or less by rail, road or sea, as a function of the capacity of the railway. These two points of view are not

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(1) Resource cost is defined as the total cost of carrying the projected rail interstate freight traffic, including the cost of delays inflicted on other traffic. The increase in interstate freight traffic is carried by rail until rail capacity is reached; a further increase in general goods traffic is carried by road and an increase in steel traffic by sea.

necessarily compatible, but in this particular case it turns out that the optimal upgrading options satisfying both criteria are identical.

This report is written in six chapters. The second chapter presents the quantity of interstate freight expected to move by rail between Sydney and Melbourne during the study period 1972/73 to 1991/92. The third chapter describes the upgrading options suggested by NSWPTC and Victorian Railways to accomodate the expected growth in traffic. A description of the method and principal assumptions used are detailed in the fourth chapter. Chapters five and six present the results of the evaluations and the conclusions.

CHAPTER 2 RAIL FREIGHT PROJECTIONS, 1972-1991

The services offered by the Sydney-Melbourne rail link can be classified into two groups.

Firstly, the broad gauge line between Melbourne and Albury carries mainly intrastate passengers and freight, and acts as a link for the Victorian branch lines. This service does not influence the study and will not be considered further in this analysis.

The second group relates to the standard gauge line linking Sydney with Melbourne, which is duplicated from Junee to Sydney. This line provides four services:

- interstate freight (for both steel and general goods traffic)
- intrastate freight (N.S.W.),
- interstate passenger, and
- intrastate passenger (N.S.W.).

This chapter is concerned with forecasting the demands for each of these rail services over the period 1972-1991.

Prediction of any economic activity over a long period of time is a hazardous business and this is particularly true of long distance rail transportation. Examination of historical data over the short period for which it is available, for purposes of predicting over a long period, is complicated by the dominance of cyclical and transient movements which tend to obscure long run trends.

Generally our approach will utilise expected growth in production as a basis for growth in transportation. The important interstate freight component involves an examination of both total freight growth rates and the road/rail split. The substantial competition and consequent scope for substitution between road and rail must be considered in order to ensure consistent forecasts for individual modes and total flows.

2.1 INTERSTATE FREIGHT

2.1.1 Expected Future Growth of Interstate Freight

Growth in interstate general freight traffic depends on growth in production and trends in industrial location patterns. As discussed in the Outlook Papers[1]

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(1) Bureau of Transport Economics , Outlook Papers (Transport Outlook Conference, Canberra, July 1975).

the impact of the latter is very difficult to predict, and we are forced back on projections of past trends. Trends presented in the freight transport Outlook paper suggest a prediction for the growth rate in interstate general freight of about 4% compound p.a. This rate is expected to fall slightly beyond a ten year horizon because of a predicted slackening of growth in population.

Historically, the populations of Sydney and Melbourne have grown faster than the total Australian population. Growth in the Sydney-Melbourne corridor is expected to be faster than the national average. We shall therefore settle on a compound growth of 5% p.a. for general freight in the Sydney-Melbourne corridor for the period to 1984/85, falling away slightly to about 4.8% p.a. in the following 10 years.

Little if anything is gained by attempting projection of individual commodities unless specific information for an important commodity can be introduced. Steel is extremely important in terms of weight carried, the great majority of it being transported by rail and sea in the N.S.W. to Victoria direction. There are several factors which cause considerable uncertainty about the growth of rail freight of steel in the Sydney-Melbourne Corridor:

(a) increased use of sea transport with the introduction by BHP and John Lysaghts (with ANL) of integrated roll-on roll-off systems, and

(b) location of major steel plants in areas outside N.S.W. (with the new mills at Westernport Bay, Victoria, being of particular relevance in the short term).

We shall therefore use a separate growth rate of 2% compound p.a. for projecting steel rail freight.

2.1.2 Mode Split of General Traffic Flows

The growth of interstate rail and road freight along the Sydney-Melbourne Corridor over the past ten to fifteen years has fluctuated widely due to a variety of interdependent factors. The impact of these factors can be separated into five components:

(a) trend in total traffic,

(b) cycles in total traffic occuring because of business cycles,

(c) switching between modes because of changes in relative modal performance,

(d) short term switches between modes with a change of attitudes to modal choice over the business cycle, and

(e) other random or unexplainable changes.

Cyclical fluctuations and random changes (Categories (b), (d) and (e)) may be ignored when predicting future freight flows over a long period.

We have already discussed the trend in total traffic. The available time series information for road and rail freight between N.S.W. and Victoria was examined. Although it was very difficult to separate the trend component from cyclical fluctuations, there is no strong evidence for rejecting a 5% p.a. compound growth rate for general freight.

We turn now to road/rail competition and changes in modal shares (Category (c) above). In the early sixties both road and rail freight traffic in the Sydney-Melbourne Corridor grew rapidly because of the rapid recovery in general economic conditions after the 1961 recession. The rate of growth in rail traffic, however, was considerably greater than in road traffic due largely to rail standardisation and the resultant relative improvement in rail performance. In the early seventies the introduction of unit trains carrying containers between Sydney and Melbourne also improved the competitive position of rail.

Furthermore, a study by Fitzpatrick and Taplin[1] found a significant causal relationship between relative prices of road and rail freight and the quantity of road freight carried. Cross price elasticities of demand of about 2 were estimated. We therefore assume that there is scope for substitution between road and rail freight.

There are two factors which could operate over the forecast period to improve the competitive position of interstate rail freight. Because rail is less energy intensive than road an increase in the price of fuel gives it a cost advantage. But fuel is only a small proportion of total operating costs for both road and rail and it has been estimated that a 30% rise in fuel price would only result in an increase of about 2% in rail freight at the expense of road[2].

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(1) M.D. Fitzpatrick & J.H.E. Taplin, 'A Model to Estimate the Price Elasticity of Demand for Transport of Goods by Road', Australian Road Research Board Proceedings, 6, 2 (1972), pp 252-265.

(2) J.H.E. Taplin, 'Energy and Transport in an Island Continent' Transportation Research, 8 (1974), pp 259-265.

A potentially more important factor is the improvement in the terminal operations of rail freight coinciding with the increased use of containers and unit trains. This would result in decreased handling and shunting costs. It could also improve rail's competitiveness with regard to overall transit time and reliability.

We shall assume that both road and rail grow at 5% compound p.a. until 1984/85, thus maintaining the present modal split. For the remainder of the forecasting period the factors discussed above will assert themselves, but because of their uncertain nature we conservatively predict rail freight to grow at 5.5% compound p.a. and road freight to grow at 4.5% compound p.a.

It is necessary to see whether this assumed change in modal split implies a price change in rail which is inconsistent with the assumption made later of constant revenue per tonne-kilometre measured in real terms. The demand for rail increases over the latter half of the study period by about 7% above what it would have been with no change in the modal split. Even if this were due entirely to a reduction in the real price of rail, an elasticity of 2 means that the price would only drop by 3.5% or an average of just over

0.3% compound p.a. But both the change in relative price of rail with respect to road and the change in the relative service provided by rail contribute to the modal switch. Furthermore a fall in the rail/road price ratio can be consistent with a falling, stationary or rising real rail price, depending on the relationship of the productivity growths of rail and road freight to the average economy wide growth. Thus a constant real rail freight rate seems a reasonable assumption.

These projections are of course sensitive to the policies for upgrading the line haul components of the modes. Thus a factor invalidating the projections would be capacity restrictions, but this is accounted for in the various evaluations.

2.1.3 Forecasts for Interstate Rail Freight

Table 2.1 summarises the growth rates and the 1972/73 bases from which projections were made. The base figures for general rail freight are influenced by the actual figures for 1972/73 and several immediately preceding years. The base for steel is well below the actual 1972/73 figure because of the expected initial impact of the ro-ro systems early in the forecast period.

TABLE 2.1 - BASE FREIGHT FLOWS AND GROWTH RATES: SYDNEY-MELBOURNE CORRIDOR

Traffic Type	Forecast								
	Low			Expected			High		
	Base freight flow	Growth rate to 1984-85	Growth rate after 1984-85	Base freight flow	Growth rate to 1984-85	Growth rate after 1984-85	Base freight flow	Growth rate to 1984-85	Growth rate after 1984-85
	'000 tonnes	%	%	'000 tonnes	%	%	'000 tonnes	%	%
Rail									
Steel freight N.S.W. to Vic.	551	0	0	580	2	2	609	4	4
Other freight N.S.W. to Vic.	713	4	4.5	750	5	5.5	788	6	6.5
Vic. to N.S.W.	855	4	4.5	900	5	5.5	945	6	6.5
Road									
All freight		4	3.5		5	4.5		6	5.5

Three sets of forecast flows were calculated. The expected set comes from the bases and growth rates given in Table 2.1. The high estimates come from bases 5% above the expected level and growth rates 2% above the expected for steel and 1% above for all other freight; the low estimates result from 5%, 2% and 1% below the expected values respectively. The forecasts are shown in Table 2.2.

2.2 INTRASTATE FREIGHT IN N.S.W.

There have been no significant developments in intrastate rail freight transport in the past decade. However some changes may be imminent due to the introduction of regional freight centres. Already two such centres are being planned, one in Tamworth in N.S.W. and one at Horsham in Victoria. Although they will have no effect on the operation of the Melbourne-Sydney line, the introduction of additional regional freight centres is likely to depend on the success of these two initial trial centres. Only limited information is presently available on the operation of regional freight centres, but it seems likely that the present frequency of intrastate freight services will be maintained on the main lines.

TABLE 2.2 - PROJECTED RAIL FREIGHT FLOWS: SYDNEY-MELBOURNE CORRIDOR

('000 tonnes)

Year	Forecast								
	Low			Expected			High		
	Steel freight	Other freight		Steel freight	Other freight		Steel freight	Other freight	
	NSW to Vic	NSW to Vic	Vic to NSW	NSW to Vic	NSW to Vic	Vic to NSW	NSW to Vic	NSW to Vic	Vic to NSW
1972/73	551	713	855	580	750	900	609	788	945
74	551	742	889	592	788	945	633	835	1002
75	551	771	925	603	827	992	659	885	1062
76	551	802	962	616	868	1042	685	939	1120
77	551	834	1000	629	912	1094	712	995	1193
78	551	867	1040	640	957	1149	741	1055	1265
79	551	902	1082	653	1005	1206	777	1118	1343
1979/80	551	938	1125	666	1055	1266	801	1185	1421
81	551	976	1170	680	1108	1330	833	1256	1506
82	551	1015	1215	693	1163	1396	867	1331	1597
83	551	1055	1266	707	1222	1466	901	1411	1692
84	551	1098	1316	721	1283	1539	938	1496	1794
85	551	1142	1369	736	1347	1616	975	1586	1902
86	551	1193	1431	750	1421	1705	1014	1689	2026
87	551	1247	1495	765	1499	1799	1055	1799	2157
88	551	1303	1562	781	1582	1898	1097	1916	2298
89	551	1362	1633	796	1669	2002	1141	2040	2447
1989/90	551	1423	1706	818	1760	2112	1186	2173	2606
91	551	1487	1783	828	1857	2228	1234	2314	2775
92	551	1554	1863	845	1959	2351	1283	2465	2956
93	551	1624	1947	862	2067	2480	1334	2625	3148
94	551	1697	2034	879	2181	2616	1388	2795	3352
1994/95	551	1773	2126	897	2301	2760	1443	2977	3570

Another factor which may influence the demand for intrastate rail freight is the lifting of the road/rail regulation in N.S.W. allowing competition between the two modes. The regulation has only been lifted recently and its effect is not clear as yet, but it is thought that because of the long line-haul distances involved, there will be little impact on the demand for intrastate rail freight.

Information provided by the NSWPTC estimated Sydney bound rail freight tonnages for 1972/73, originating in the Albury-Junee area, as 256,700 tonnes, 97% of which was wheat. Most of the wheat is believed to have been for export.

In a recent publication the Bureau of Agricultural Economics[1] estimated a growth rate in the world wheat trade of approximately 2% p.a. compound, and it was considered that Australia's share of this trade would not significantly increase above current levels. Since the 1969/70 season, when wheat quotas were initially imposed, N.S.W. wheat production has declined at least partially due to the diversification of rural production activities (e.g. beef and fat lamb production) and adverse conditions and prices. However,

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(1) Bureau of Agricultural Economics, 'Agricultural Supply Projection, Australia 1978-79' (Canberra, 1974).

this is viewed as a temporary aberration and a growth rate equal to the world rate was projected for wheat transported from the Albury-Junee region. No significant reduction is expected by an easing of the permit system for the carriage of wheat by road, due to the existence of associated infrastructure for handling of bulk wheat at rail heads, and the long distances separating these areas from the main export ports. Future decisions as to which ports will accept wheat for export from the Riverina area, may however influence the direction of the flow of wheat.

The low growth in the volume of wheat transported by rail is expected to have a negligible effect on an average busy day's traffic because of the seasonal pattern of demand which results in transient peaks for grain trains. These peaks are mainly associated with ship arrival times because the peak due to harvesting is dampened by the availability of wheat silos.

Manufactured products and building materials totalling approximately 210,000 tonnes(1) are the major freight components transported by rail to the Albury-Junee area from Sydney. There are no historical

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(1) NSWPTC estimate for the year ended 30 June 1973.

data available and no information on the precise destinations of such products. In another study by BTE[1], rail freight of a similar kind from Melbourne to the Western Districts was forecast to decline slowly. It is suggested that this could happen to a considerable proportion of the total Sydney to Albury-Junee rail freight but the component to Albury will grow as the Government's plans for the Albury-Wodonga growth centre get under way.

Two factors make the growth centre a minor consideration for this study. The first is that substantial growth will probably not become a reality until well into the study period. The second is that the closer proximity of the growth centre to Melbourne could mean that much of the growth in demand for goods will be satisfied from Melbourne rather than Sydney.

On balance, slow growth in Sydney to Albury-Junee rail freight is expected but there will be a negligible effect on the number of trains over the study period.

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(1) Bureau of Transport Economics, 'Mainline upgrading - evaluation of a range of options for the Melbourne-Serviceton rail link' (Canberra, November 1975).

Freight generated from the Albury-Junee area and transported by rail to Melbourne is presently less than 5000 tonnes per annum[1].

The only factors that could foreseeably affect this estimate significantly could be the diversion of Melbourne bound agricultural products presently using road transport to rail, and/or the diversion of wheat by rail for export from ports in N.S.W. to ports in Victoria. It was assumed that no substantial changes would occur, so that little or no growth in rail traffic on this route could be expected.

Freight from Melbourne transported by rail to the Albury-Junee area was also less than 5000 tonnes in 1973. As discussed above, this could be expected to significantly increase during the development of the Albury/Wodonga area, but little growth in freight could be expected to areas outside the growth area.

2.3 PASSENGER MOVEMENTS

Monthly rail passenger movements from Melbourne to Sydney and from Sydney to Melbourne were provided by the Victorian Railways for the years 1968 to 1974

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(1) NSWPTC estimate for year ended 30 June 1973.

inclusive. Inspection of these data revealed that there has been an irregular cyclical pattern of passenger movements with peaks in 1968 and 1974, and a trough during 1972. This pattern was also evident for demand during the seasonal peak months of January, August and December.

A linear trend was fitted to the data and the result indicated that a very slight downward trend in demand for passenger trips in both directions had occurred over the period 1968 to 1974.

Few changes have occurred in the technology of transporting passengers over the last 10 years. There is a possibility of a high speed rail link being introduced between Sydney and Melbourne; however work carried out within the BTE indicated that such a link was unlikely within the next 20 years.

It was felt that while interstate rail passenger volumes may continue to fluctuate about a long term declining trend, the demand variation will not be sufficient to affect the number of trains which is therefore expected to remain constant over the study period.

Intrastate rail passenger movements are generally declining. However it will be assumed that the growth of the Albury-Wodonga region will be sufficient to hold intra-state rail passenger movements on the Albury-Sydney line approximately constant.

CHAPTER 3 UPGRADING OPTIONS

For the purposes of this report, the railway between Melbourne and Sydney has been considered in three sections: Melbourne-Albury, Albury-Junee and Junee-Sydney. A detailed description of the existing sections is given in Annex A. The main limitations on these sections are seen to be:

- Melbourne-Albury: insufficient crossing loops on the single track standard gauge;

- Albury-Junee: congestion due to slow mechanical signalling procedures based on manual electric staff working and insufficient number and length of crossing loops;

- Junee-Sydney: a succession of steep grades, excessive headway on some parts of the double track line, and insufficient loops available for overtaking purposes.

One means of increasing the traffic capacity of the line is to increase the train weight. Although heavier trains would require lengthened crossing loops and in some cases a new type or more powerful locomotive to be fully effective, we consider this capacity increasing measure as an operational improvement rather than line upgrading. The evaluation will therefore be based on examining each line upgrading proposal over a range of train weights.

Descriptions of the proposed upgradings of the sections of the Melbourne-Sydney line follow and Table 3.1 summarizes the corresponding capital costs. All costs quoted are in 1973 prices.

3.1 MELBOURNE-ALBURY

3.1.1 Additional Crossing Loops

The single track section between Albury and Melbourne is already operating under Centralised Traffic Control and the capacity of this portion can be easily increased by the addition of extra crossing loops, at a capital cost of $230,000 per 915 metre loop. Although these loops can be installed one at a time, to produce a practical number of alternatives for detailed study they have been introduced in multiples as follows:

- 6 new loops (at locations A in Figure 3.1),

TABLE 3.1 - COSTS OF PROPOSED UPGRADINGS

($ million, 1973 prices)

Proposed Upgrading	Cost
MELBOURNE-ALBURY	
Additional crossing loops	
6 new loops	1.5
10 new loops	3.1
18 new loops	5.1
Selective line doubling	
Somerton-Broadford	6.1
Seymour-Wallan	6.1
Grade easement	
1 in 75 average grade	1.2
Jacana flyover	3.0
ALBURY-JUNEE	
Centralised traffic control	
CTC1	2.4
CTC2	5.1
Selective line doubling	
Scheme A (includes CTC1)	36
Scheme B (includes CTC1)	36
ALBURY-SYDNEY	
Grade easement	
1 in 75 average grade (includes replacement of the Wagga viaduct)	24-40

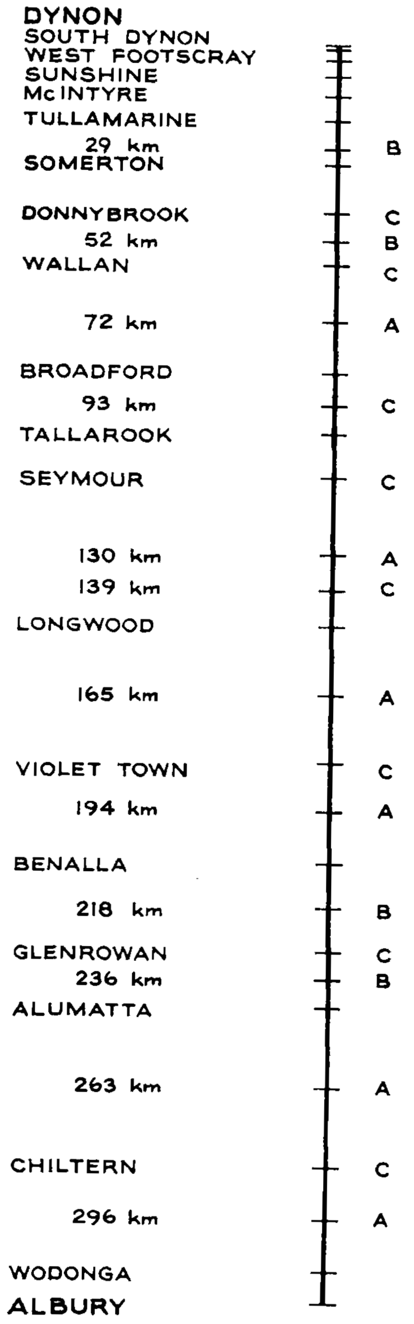

FIGURE 3.1

NEW LOOP LOCATIONS

FOR MELBOURNE - ALBURY

- 10 new loops (at locations A and B in Figure 3.1), and

- 18 new loops (at locations A, B and C in Figure 3.1).

Springhurst was proposed by Victorian Railways as the most desirable location for a new loop and this proposal has been included in the first alternative. Subsequent locations were chosen on sections which had the largest delays during simulations of the previous track configuration. The utilisation of new loops in subsequent simulations indicated the relative importance of each new loop. Results show that indeed Springhurst is the most important location for a new loop.

The criterion used for deciding on the number of new loops to be added as a single upgrading was that the Melbourne-Albury and Albury-Junee sections should have comparable delay characteristics. Plots of the ratio, Average Delay per Train/Base Average Transit Time per Train in Figure 3.2 show that the existing line on the N.S.W. side has quite different characteristics from the existing line on the Victorian side. Introduction of the first complementary upgrading measures, CTC1 (Figure 3.3) and 6 loops, not only resolves these differences, but also achieves a considerable reduction in the average delays. Introduction of the next complementary measures, CTC2

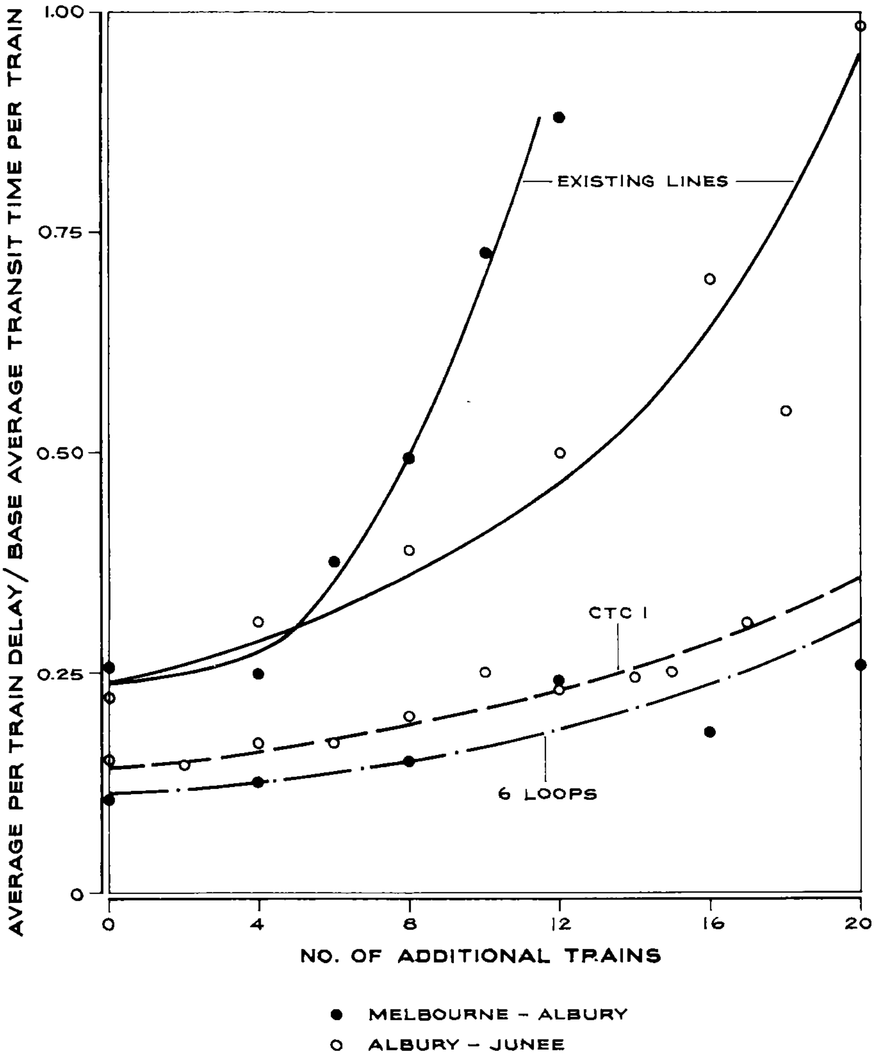

FIGURE 3.2

DELAY CHARACTERISTICS FOR 800 TONNE TRAINS

AVERAGES ARE OVER ALL TRAIN CLASSES

BASE AVERAGE TRANSIT TIMES :

MELBOURNE – ALBURY 298 MINUTES

ALBURY – JUNEE 152 MINUTES

(Figure 3.4) and 10 loops, produces a further improvement in delays which only become significant towards the end of the study period in the case of the high forecast.

Although in principle it would have been possible to study loop additions one at a time, and hence determine the best time sequenced introduction for all loops, the capital cost per loop is insufficient to justify such detailed analysis.

3.1.2 Selective Line Doubling

Introduction of double line in some sections in conjunction with additional crossing loops was seen as a long term capacity increasing measure. The doubling scheme involves the duplication of 52 km of track between Wallan and Seymour at a cost of about $6.1 million.

3.1.3 Grade Easement

The regrading options in Victoria, costing about $4.2 million, are as follows:

- regrading of the track to an average grade of 1 in 75 at a total cost of $1.2 million, and

. regrading of the Jacana flyover at a cost of $3 million.

3.2 ALBURY-JUNEE

3.2.1 Centralised Traffic Control (CTC)

The single track portion between Junee and Albury is characterised by evenly spaced, relatively short and mechanically controlled crossing loops (Annex A). The longer freight trains cannot fit into many of these loops at present and the capacity of this section can be considerably increased by lengthening all existing loops between Bomen and Table Top to 915 metres (1). However, since loops of this length can no longer be controlled mechanically, introduction of power signalling becomes essential (2). Furthermore, for little extra cost the power controlled signals and points can be

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(1) Crossing loop lengths of 915 metres are indicated here for the purpose of conforming to the present loop lengths between Albury and Melbourne on the Victorian side. However, as far as the economic analysis is concerned, the actual length of the improved crossing facilities is of no great importance - provided that they exceed the length of the longest trains considered in the study (of the order of 680 metres) - because the increment in cost of extending to 915 metres is small.

(2) It is possible to install a motor only for the operation of the extended loops, and although this solution is somewhat cheaper than CTC, it has no benefits such as reductions in crossing delay and in workforce requirements.

operated from a central point (CTC) thus reducing workforce requirements at most stations. In summary then, the simplest way of upgrading the Albury-Junee portion of the line is to extend all shorter crossing loops and introduce CTC.

The introduction of CTC has three further advantages. Firstly, it results in a reduction of crossing delays from an average of four minutes necessary for the manual exchange of staff (Annex A) to about one minute. On densely trafficked lines these crossing delay reductions are reflected in measurable increases in physical capacity. Secondly, considerable savings in the workforce are now possible because stations no longer need to be attended for signalling purposes. Some time may elapse between the introduction of CTC and the full realisation of these savings, however due to lack of information on duration of retraining schemes and staff turnaround within the railways, the delay in the realisation of savings will not be accounted for in this study. Thirdly, centralised control may lead to more effective train control by considerably facilitating the train Controller's task especially on such heavily trafficked lines as the Sydney-Melbourne link. However, this effect, again difficult to quantify, is not taken into consideration in the study.

Two CTC schemes are evaluated, CTC1 having a minimum number of power signalled loops, and CTC2 including a large number of new loops in addition to the extended existing loops. Each complete scheme can be introduced in its own right, however CTC2 can be considered as an improvement on CTC1 and can be introduced at some later date after CTC1.

<u>CTC1 (Figure 3.3)</u>

This scheme is based on a minimum number of power signalled loops. All existing loops (a total of 10) between Bomen and Table Top are extended to 915 metres and power signalled at a total cost of about $2.4 million with an annual operating saving of $180,000 (Annex C). The details of CTC1 are as follows:

- 1 existing loop connected to CTC at Harefield;
- 10 extended loops at Bomen, Wagga Wagga, Kapooka, Uranquinty, The Rock, Yerong Creek, Henty, Culcairn, Gerogery, and Table Top;
- 161 km of conductors, pole line reconstruction for 65 km and 10 switchlocks.

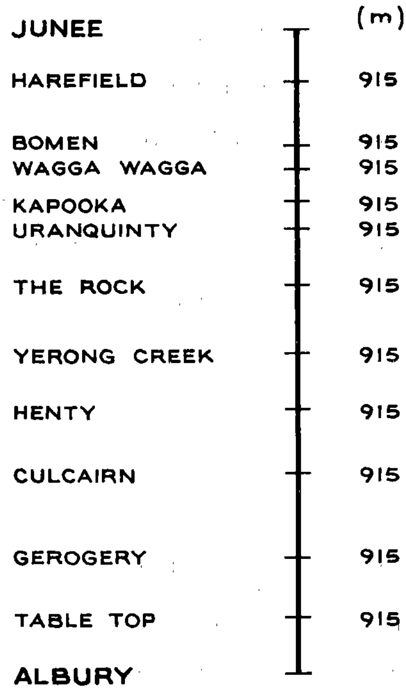

FIGURE 3.3

POSITION AND LENGTH OF LOOPS

CTC1 SCHEME

CTC2 (Figure 3.4)

This scheme includes all the features of CTC1 with the addition of eleven new loops; it can therefore be considered as an extension of CTC1.

The details of CTC2, costing around $5.1 million, with an annual operating saving of $180,000 are as follows:

- 1 existing loop connected to CTC at Harefield;

- 10 extended loops at Bomen, Wagga Wagga, Kapooka, Uranquinty, The Rock, Yerong Creek, Henty, Culcairn, Gerogery, and Table Top;

- 11 new loops, two at Shepherds, one at 543 km from Sydney, one at The Rock, one at Yerong Creek, one each at 575, 586, and 607 km from Sydney, one at Gerogery and two at Kinloss;

- 161 km of conductors, pole line reconstruction for 65 km and 10 switchlocks.

The Rock and Gerogery facilities are proposed as one 1830 metre loop but can also be used as two 915 metre loops. Since the longest trains considered in this

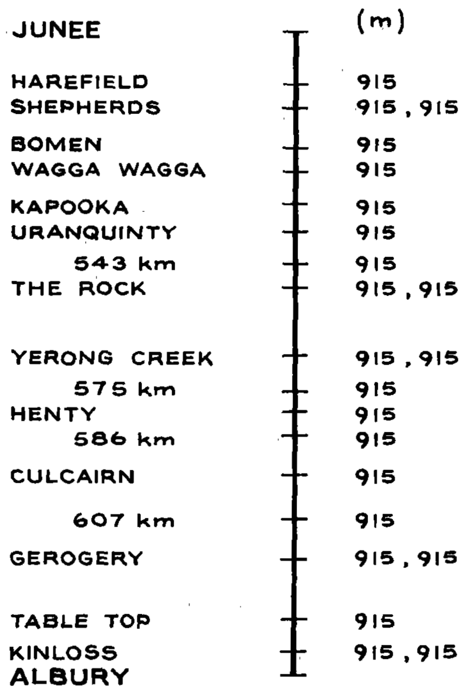

FIGURE 3.4

POSITION AND LENGTH OF LOOPS

CTC 2 SCHEME

report are less than 915 metres long (of the order of 680 metres for 1800 gross tonne trains), only the latter configuration will be studied.

The original proposal by the NSWPTC included a 3.2 km double line section at Yerong Creek with crossover facility in the centre which can also be used as two 915 metre loops. The double line configuration could save some crossing delays if the opposing trains happened to arrive simultaneously at each end of the double line section. An examination of train diagrams representing present and projected traffic, however, showed that such situations only occur rarely, and that the proposed Yerong Creek facility can be simplified to the case of two 915 metre crossing loops for the purposes of this study.

3.2.2 Phased Line Doubling

Two line doubling proposals are considered. Both schemes, preceded by CTC1, are introduced in four stages, and attempt to improve the most congested sections first. Scheme A however proposes in its second stage doubling of every alternate section, while Scheme B doubles groups of adjacent sections.

Scheme A (Figure 3.5)

This scheme proposes a four stage duplication of the 161 km section between Albury-Junee at a total capital cost of about $36 million together with a 75% increase in track maintenance cost above that of a single line (Annex C). The scheme includes the following:

- CTC1 (Section 3.2.1);

- Two double line sections between Junee-Bomen and Table Top-Albury (45 km), Stage 1;

- Four double line sections between Kapooka-Uranquinty, The Rock-Yerong Creek, 575 km from Sydney - Culcairn and 607 km from Sydney - Gerogery (55 km), Stage 2;

- Duplication of the four remaining sections between Uranquinty and Table Top (48 km), Stage 3; and

- Duplication between Bomen and Kapooka including new Wagga Viaduct (13 km), Stage 4.

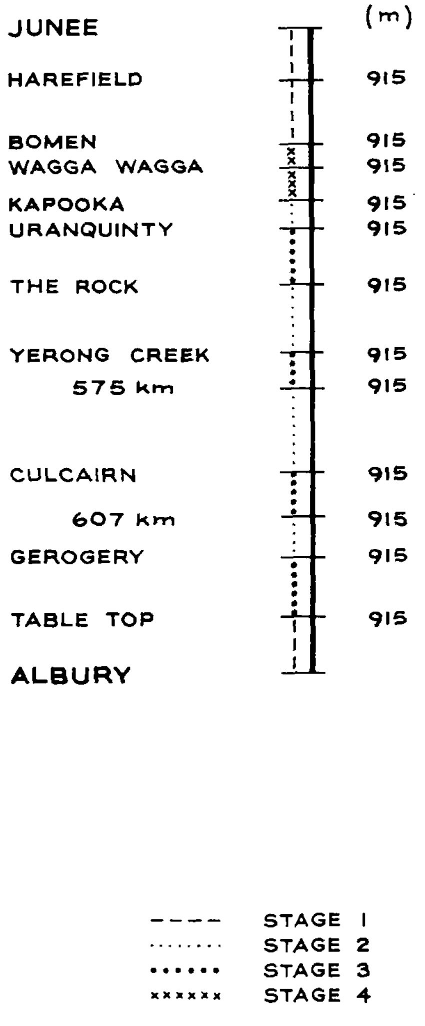

FIGURE 3.5

POSITION AND LENGTH OF LOOPS
AND POSITION OF DOUBLE SECTIONS
DOUBLING SCHEME A

The original scheme proposed CTC controlled automatic signalling for bi-directional train working. This feature is unlikely to be effective with this particular line configuration[1] and is not studied here. For such a feature to be effective for overtaking purposes the sum of transit times of the faster train over the bi-directional double line section plus its transit times over the two adjacent single sections should be less than the transit time of the slower train over the bi-directional double line section. Such overtakings would only occur once or twice/day on only one of the proposed double sections under present conditions and may occur even less often in the future if a policy of reducing the differences in train speed classes is introduced. Bi-directional signalling is used by some European railways to minimise delays during permanent way maintenance sessions. These railways however, carry traffic levels well above the maximum projected traffic on the Albury-Junee line.

Scheme B (Figure 3.6)

This scheme proposes a four stage duplication of the 161 km section between Albury and Junee; however, it avoids alternating short single and double line sections. Although both schemes have the same total

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(1) N.S.W. Public Transport Commission Report,'Proposed upgrading of main line, Albury-Junee' (August 1972, p3, unpublished).

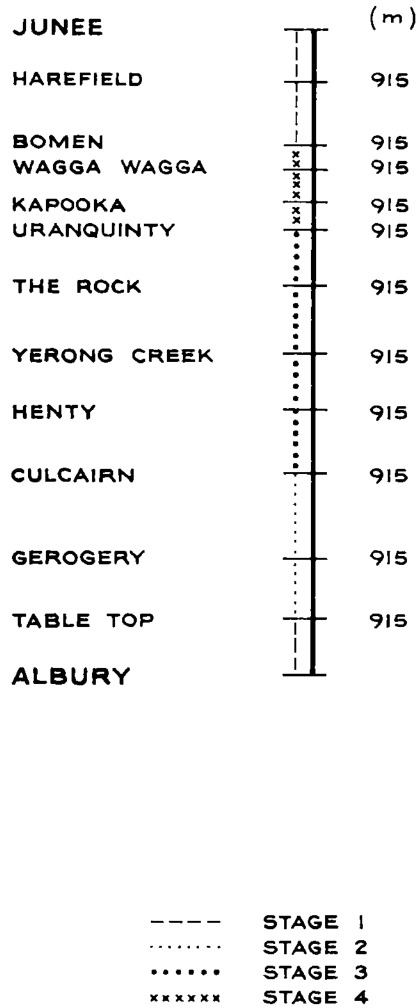

FIGURE 3.6

POSITION AND LENGTH OF LOOPS AND POSITION OF DOUBLE SECTIONS DOUBLING SCHEME B cost, the line configuration, the delay patterns, the phasing and the discounted cashflows will be different. Apart from a total capital cost of $36 million, the scheme also incurs a 75% increase in track maintenance costs above that of a single line (Annex C), and includes the following:

- CTC1 (Section 3.2.1);
- Two double track sections between Junee-Bomen and Table Top-Albury (45 km), Stage 1 (same as for Scheme A);
- Duplication between Culcairn and Table Top (35 km), Stage 2;
- Duplication between Uranquinty and Culcairn (61 km), Stage 3; and
- Duplication between Bomen and Uranquinty (21 km), Stage 4.

3.3 JUNEE-SYDNEY

The double line between Junee and Sydney has a mixture of automatic signalling and telegraph block working, with 60% of the installations being over 50 years old. There is also a shortage of adequate refuge loops, the existing ones being too short and mainly of the set back type. Consultations with NSWPTC staff indicated that an integrated loop/signal improvement scheme would take some time to prepare and we decided at this stage to concentrate our efforts on the analysis of the single track portions of the line, bearing in mind that the Junee-Sydney section will need further consideration at a later date. For the purposes of this study delays to local trains caused by the increased number of interstate freight trains using the existing Junee-Sydney link were also taken into account. Inspection of train diagrams indicated that trains using the Goulburn-Junee section would be unlikely to suffer increased average delays greater than 10 minutes. However, on the twice as heavily trafficked Goulburn-Moss Vale section, average additional delays to local traffic were estimated to vary linearly from 0 to 30 minutes over the study period.

3.4 ALBURY-SYDNEY GRADE EASEMENT

Grade easement to 1 in 75 is proposed at numerous locations including replacement of the Wagga Viaduct. The total cost is likely to be between $24 million and $40 million. The benefits of easement, mainly motive power savings, only accrue if the regrading is introduced in toto i.e., the whole line is within the 1 in 75 standard. For this reason it was thought unlikely that regrading would be economically justified and no detailed cost estimates were made.

CHAPTER 4 METHOD AND ASSUMPTIONS

The question of how and when to upgrade a railway line is not a simple one. Given a traffic forecast, the problem is essentially one of trading off the reductions in transport cost resulting from the upgrading against the cost of introducing the upgrading. Like any other production facility, railway lines exhibit an increasing cost characteristic as output is increased beyond a certain point. The main source of additional cost is congestion, reflected as increased train crew costs and motive power and rolling stock investment. An ultimate point is reached beyond which the railway can no longer carry any further increase in traffic and further growth in freight movement is therefore diverted to alternative transport modes which generally incur higher costs. This suggests two points of view for economic evaluation of railway line upgrading; firstly, the commercial viewpoint which in essence is a profit maximising exercise, and secondly, the resource viewpoint (defined in Chapter 1) which takes into account the additional cost of having to divert to another mode.

The analysis of the upgradings from the commercial viewpoint requires not only an estimate of the direct and indirect costs of carrying the growth in interstate freight traffic but also an estimate of the revenue generated by that traffic. Rail revenue could be considered a variable during the study period because it would be rational for the railway to increase its price as congestion costs rise, leading to a new supply/demand equilibrium as the demand curve shifts in response to growth. In practice, however, competition for railway services is far from perfect. Interstate rail freight is dominated by contract arrangements between the railways and a small number of freight forwarders. The range of pricing strategies available to the railway therefore tends to be attenuated by the averaging process inherent in "lumpy" contracts. For similar reasons, freight rates are not expected to fall appreciably in the latter part of the study period, as explained in Section 2.1.2. Thus our approach to the commercial evaluation of upgrading is based on constant revenue per unit from the growing traffic over the study period. The assumed revenue rate in the present studies must involve some judgement because the railways do not publish this kind of commercial information; we have reason to believe however, that the present revenue rate lies between 0.62 and 0.81 cents per tonne km. These two values will be used to test the sensitivity of the results to variations in the value of the revenue rate.

In estimating the resource costs of diverting general freight to another mode when rail can no longer accept further traffic, we have concentrated on the road alternative. An estimate of the costs of shipping general freight (Annex C) has indicated that the cost of sea transport between Melbourne and Sydney would be somewhat higher than rail. Other operational disadvantages of the sea alternative are the lower frequency and longer transit time. It is for these reasons that general freight tends to favour land modes. In matching transport resources and capability to shippers' requirements, the freight forwarder's operation is geared to high frequency and readily interchangeable land modes.

The rail-sea choice for the transport of steel from Newcastle and Port Kembla to Melbourne offers feasible alternatives as manifested by the use of both modes by steel manufacturers. Again, drawing on previous work[1] and unpublished information, we have assumed that steel carried by sea incurs a resource cost of 1.24¢/tonne km[2] (Annex C, Section C.3.2).

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(1) Bureau of Transport Economics 'An Assessment of Tasmania's Interstate Transport Problems' (Canberra, March 1973).

(2) The basis of this assumption does not do justice to the complexity of rail/sea competition for steel traffic but a more firmly based analysis was beyond the effort available to this study. The resource cost allocated to diverted steel traffic turned out to be only 10-15% of the total resource cost in the most favourable case of the high projections, indicating the non-critical nature of this parameter.

In this chapter, the step by step evaluation procedure is described. Starting from the freight forecast for each year, the average number of trains in each direction is calculated for an "average busy day"; each year's traffic is then exercised on a single track simulation of those sections of the line subject to congestion delays for both the present line and for proposed upgraded configurations. The estimated delay characteristics are then translated into delay costs and incorporated into an annual net revenue variation as traffic grows. This leads to the idea of line capacity from both commercial and resource viewpoints, which then become the basis for the selection and timing of upgradings.

4.1 TRAINS REQUIRED TO MEET PROJECTED DEMAND AND THEIR TIMETABLING

Because interstate general goods traffic and steel are the only traffics expected to grow during the study period, all other traffics are assumed to operate indefinitely to the present timetable. In practice, the timetable would be adjusted periodically to take account of operational and demand changes, but it is assumed that in terms of the trend of growing congestion delays, the effect of these adjustments can be ignored.

The present interstate general goods trains have an average gross weight of 800 tonnes in N.S.W. and 900 tonnes in Victoria, whereas the steel trains, running from Newcastle and Port Kembla to Melbourne average 1500 gross tonnes. From data supplied by both NSWPTC and Victorian Railways for 1971/72, the following ratios of gross tonnage to load carried were calculated.

Traffic	Gross train weight/load carried
General goods (Sydney to Melbourne)	2.24
General goods (Melbourne to Sydney)	2.28
Steel (Sydney to Melbourne)	1.50

These ratio values were assumed to remain constant during the study period[1].

The use of heavier interstate general goods trains can be beneficial provided that the corresponding

(1) More recent information obtained on completion of the study suggests that, ultimately, unit freight trains could achieve a ratio of gross train weight to load carried of about 1.8. The achieved ratio will depend on both engineering and operational factors not experienced to date. It was therefore assumed that the present ratios would remain constant during the study period.

increase in train length can be accommodated in the existing goods yards and crossing loops and provided that the corresponding reduction in train frequency does not adversely affect rail's market. Heavier but fewer trains can increase the tonnage capacity of the line, reduce train crew costs and may lead to reduction in the size of the locomotive fleet, if more powerful locomotives can be introduced.

In the particular case of the Albury-Sydney section where many of the existing crossing loops are relatively short, increases in the tonnage capacity of the line as a result of the use of heavier trains are not likely until the introduction of an upgrading measure which involves crossing loop extensions. Furthermore, the steep grades between Goulburn and Sydney make heavy demands on motive power. By contrast, the Victorian section, Albury-Melbourne, is relatively flat and the crossing loops on the standard gauge are sufficiently long to hold general goods trains in excess of 1400 tonnes gross weight. At present there seems to be no agreed standard weight for interstate freight trains between N.S.W. and Victoria(1), and as a consequence a number of these trains are broken up and remarshalled at Albury. For the purposes of this study however,

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(1) Victoria and N.S.W. are at present jointly considering this question for operational purposes.

agreement was reached between NSWPTC and Victorian Railway officers regarding three common train weights for interstate freight trains. Table 4.1 summarises the agreed range of average train weight and corresponding motive power requirements assumed for this study. Table 4.2 lists the assumed motive power requirements corresponding to the regrading options[(1)].

In calculating the number of trains per day, given a freight forecast and train weight, it would clearly be unrealistic to assume that the traffic would be distributed uniformly across 365 days a year. Examination of current railway timetables indicates that steel trains run on the average five days per week and interstate general goods trains run on the average seven days per week, but with fewer trains on Saturdays and Sundays; we have estimated that the week-end traffic is roughly equivalent to half a day's week-day traffic. Thus, for the steel traffic, the average busy day's traffic is calculated on a basis of 260 days per year and that for general goods on a basis of 286 days per year. It should be noted here that line capacity could be increased by running all trains 365 days a year.

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(1) The possibility of through running the trains from Melbourne to Junee has also been considered; however this proposal is only worth further study once the Wagga Viaduct is rebuilt and all 1/40 grades are eliminated on this section of the line.

TABLE 4.1 - MOTIVE POWER REQUIREMENTS: EXISTING GRADES

Average gross weight of interstate freight trains (tonnes)	Motive power requirements (kW)
SYDNEY-ALBURY	
800	2 x 1491
1100	2 x 2237
1400	3 x 1491
ALBURY-MELBOURNE	
800	1 x 1491
1100	1 x 2237
1400	2 x 1491

NOTE: The average train weights were chosen as suitable for through running between Sydney and Melbourne. On the relatively gradient free Vic. sections the transit times are more or less insensitive to the range of train weight and motive power. On the N.S.W. side, however, this no longer holds and some allowance was therefore made for varying transit times corresponding to different combinations of motive power and train weight.

TABLE 4.2 - MOTIVE POWER REQUIREMENTS: REGRADING OPTIONS

Average gross weight of interstate freight trains (tonnes)	Motive power requirements (kW)
SYDNEY-ALBURY	
800	1 x 1491
1100	1 x 2237
1400	2 x 2237
ALBURY-MELBOURNE	
800	1 x 1491
1100	1 x 1491
1400	1 x 2237

However, the study of such a proposal may require lengthy experimentation to determine the day to day variation of demand throughout the year, and to define other operating constraints.

Given the postulated range of train weight, the present ratios of gross train weight to load carried, the three levels of freight transport demand derived in Chapter 2 and the definitions of average busy day given above, the daily traffics given in Table 4.3 can be calculated.

It is now necessary to postulate a timetable for these new trains before we are able to quantify the likely congestion delays. Timetables for the projected interstate freight trains were prepared according to the following guidelines.

(a) During the early part of the study period trains were timetabled to depart during normal working hours in order to defer for as long as possible the introduction of multiple shifts, although some overtime may be introduced.

(b) By about 1980 it is likely - according to some freight forwarders - that city congestion or legislation will force most

TABLE 4.3 - PROJECTED NUMBER OF INTERSTATE FREIGHT TRAINS PER "BUSY DAY"

Freight type	Average train weight (gross tonnes)	Forecast	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Steel																						
Sydney to Melbourne[(a)]	1500	Low	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		Expected	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4
		High	3	3	3	3	3	3	3	4	4	4	4	4	4	4	5	5	5	5	5	5
General goods																						
Sydney to Melbourne[(b)]	800	Low	7	8	8	8	9	9	9	10	10	10	11	11	12	12	13	13	14	14	15	16
		Expected	8	8	9	9	9	10	10	11	11	12	12	13	14	14	15	16	17	18	19	20
		High	8	9	9	10	10	11	11	12	13	14	14	15	16	17	18	19	20	22	23	25
	1100	Low	6	6	6	6	6	7	7	7	7	8	8	8	9	9	9	10	10	11	11	12
		Expected	6	6	6	7	7	7	8	8	8	9	9	10	10	11	11	12	12	13	14	14
		High	6	6	7	7	8	8	8	9	9	10	11	11	12	13	13	14	15	16	17	18
	1400	Low	4	5	5	5	5	5	6	6	6	6	6	7	7	7	7	8	8	8	9	9
		Expected	5	5	5	5	6	6	6	6	7	7	7	8	8	8	9	9	10	10	11	11
		High	5	5	5	6	6	6	7	7	8	8	8	9	9	10	11	11	12	13	13	14
Melbourne to Sydney[(c)]	800	Low	9	9	10	10	10	11	11	12	12	13	13	14	14	15	15	16	17	17	18	19
		Expected	9	10	10	11	11	12	13	13	14	14	15	16	17	17	18	19	20	22	23	24
		High	10	10	11	12	12	13	14	15	15	16	17	18	19	21	22	23	25	26	28	30
	1100	Low	7	7	7	7	8	8	8	9	9	9	10	10	10	11	11	12	12	13	13	14
		Expected	7	7	8	8	8	9	9	10	10	11	11	12	12	13	14	14	15	16	17	18
		High	7	8	8	9	9	10	10	11	11	12	13	13	14	15	16	17	18	19	21	22
	1400	Low	5	6	6	6	6	6	7	7	7	7	8	8	8	9	9	9	10	10	11	11
		Expected	6	6	6	6	7	7	7	8	8	8	9	9	10	10	11	11	12	13	13	14
		High	6	6	7	7	7	8	8	9	9	10	10	11	11	12	13	14	14	15	16	17

(a) Gross train weight/Freight load = 1.5, 260 "busy days" per year

(b) Gross train weight/Freight load = 2.24, 286 "busy days" per year

(c) Gross train weight/Frieght load = 2.28, 286 "busy days" per year

NOTE: Fractional numbers of trains have been rounded upwards.

freight to be delivered at night. It is therefore probable that train departure times between 10 pm and 6 am would then be introduced. Thus existing loading and unloading facilities would be more fully utilised and the traffic on the line would be more evenly spread by making use of what now amounts to an "off peak" period.

The timetables prepared along these lines were considered acceptable by NSWPTC and Victorian Railways' officials.

4.2 CONGESTION DELAYS AND CAPACITY

4.2.1 Congestion Delays

Various attempts have been made to obtain estimates of delays analytically on a single track railway line[(1)(2)]. All of these models either neglect realistic line configuration constrains such as restrictions arising from limitations on the length

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(1) N.S.W. Public Transport Commission Report 'Proposed upgrading of main line, Albury-Junee' (August 1972, unpublished).

(2) E.R. Petersen, 'Over the road transit time for a single track railway', Transportation Science, 8, 1 (1974), pp 65-74.

or number of crossing loops or do not account for the interaction between one section of the line and another (Annex B). A more general approach, capable of analysing all options of interest which involves simulation of single or double track portions of various track configurations was selected. Such an approach is embodied in the Single Track Railway Simulation (STS) model jointly developed by the BTE and IBM Systems Development Institute[1]. The model allows for the input of departure times, sectional transit time data per train class, track configuration data and train priority weighting factors; a unique feature of the model allows for crossing conflicts to be resolved using a weighted delay criterion. The model generates synthesised timetables and delay statistics by train class.

Delays produced by STS compare very favourably with delays computed from an actual train diagram of the already congested Albury-Junee section (Annex B), while several previously developed single track simulators could not cope with processing the data derived from the same train diagram. It seems then reasonable to assume that STS will give realistic estimates of delays caused by high traffic levels in the region of track capacity.

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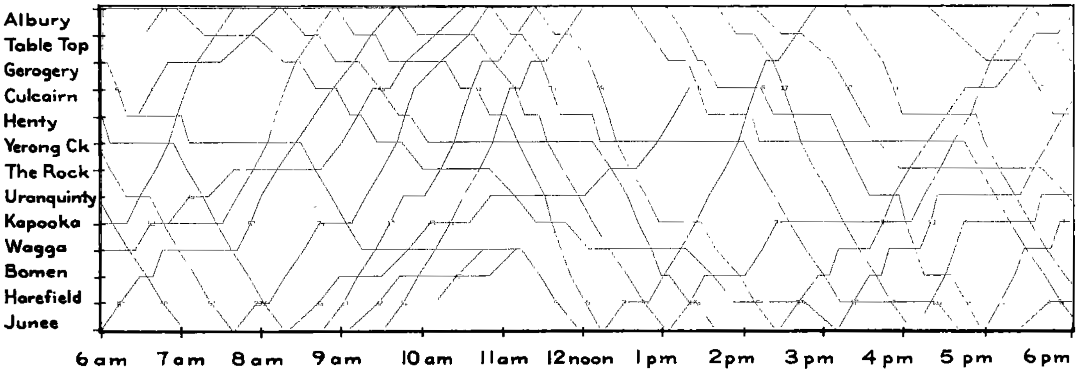
(1) D.A. Rudd, & A.J. Storry, 'Single Track Railway Simulation - Documentation' IBM Systems Development Institute Canberra, SDI0057, (December 1974).

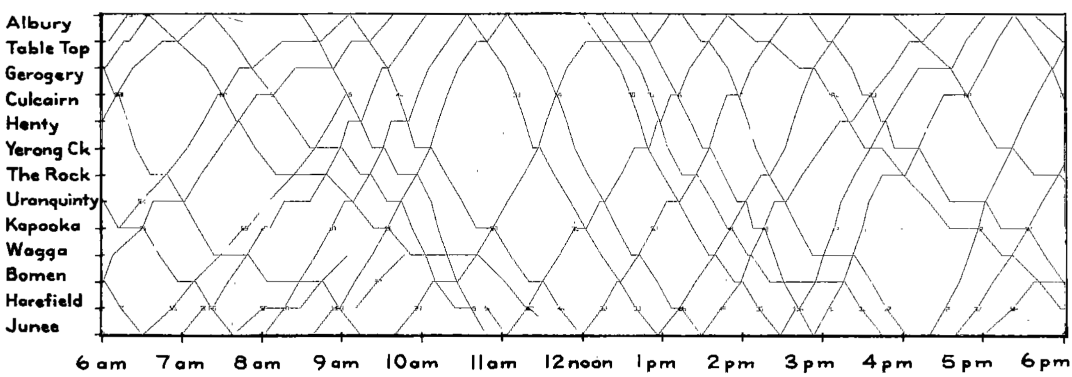
The performance of the line under each configuration is simulated with various traffic levels and the corresponding delay characteristic obtained. Physical capacity is reached when the next additional train cannot complete its journey within 24 hours. Figure 4.1 shows simulated train diagrams corresponding to near capacity situations. In practice, it would probably be impossible to sustain the highest traffic levels synthesised by STS because of non-traffic delays such as late departures and speed restrictions imposed by track maintenance. Annex B details the results of an analysis of the effect of late departure times on the delay pattern and in principle, the model could simulate the effect of other disturbances. However, the additional computational effort required was not thought justified. In fact, the expected upgradings are generally optimally scheduled before physical capacity is reached, and the capacity definition only affects the magnitude of the benefit to cost ratios in the case of the resource cost calculations. It follows from this discussion that these ratios represent a lower limit.

4.2.2 Commercial and Resource Capacity

The approach to deriving the traffic capacity of a railway line is based on that proposed by Jones and



(a) EXISTING LINE , 55 TRAINS OF AN AVERAGE WEIGHT OF 800 GROSS TONNES



(b) CTC I , 64 TRAINS OF AN AVERAGE WEIGHT OF 800 GROSS TONNES

FIGURE 4.1

SIMULATED TRAIN DIAGRAMS

Walker[1], also detailed in Annex D. Briefly, the annual net revenue P from a particular class of traffic can be expressed in the following form:

$$P = x\{R - C_1(1 + D) - C_2\} - C_3 \qquad (4.1)$$

where: x is the traffic volume expressed in number of single trips per year

R is the gross revenue per train trip per year in a given class

C_1 is the total cost affected by delay e.g. crew, motive power and rolling stock inventory[2]

C_2 is the total cost unaffected by delay e.g. fuel, track maintenance

C_3 is the annual fixed cost e.g. capitalisation of upgrading

D is the congestion delay factor, being the ratio of delay to undelayed transit time per train.

As additional trains are scheduled, the revenue will be increasingly eroded by the increase in the congestion

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(1) J.C.M. Jones, & A.E.G. Walker, 'Scheduling Investment in Main Railway Lines' (paper delivered to Australian Transport Research Forum, Sydney, 1975).

(2) The effect of delay on the cost of inventory in transit and on passenger time costs is negligible (Annex D, Section D.1.2).

delay cost until a point is reached at which the net revenue from the next additional train is zero i.e. marginal revenue equals marginal cost. At this point, as a commercial operator, the railway would decline further traffic. This we call commercial capacity. Subsequent growth would spill over, or divert, on to the next preferred mode. From a resource point of view, the railway should continue to accept this additional traffic until the *marginal* resource cost by rail equals the marginal resource cost by the alternative mode. This point we call resource capacity. It would be expected to be somewhere between commercial capacity and physical capacity, as previously defined (Section 4.2.1).

It is shown in Annex D that the cost components detailed in the above formulation include all long run marginal costs except those associated with signalling, earthworks, tunnels and bridges, other than those introduced as an upgrading during the study period. New signalling and other items introduced during the study period would be included(1) under C_3 in our formulation.

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(1) Capital expenditures are included as an annuity at a given discount rate. The annuity on capital outlay of C, of life n, and at a discount rate i is given by:

$$C\, i(1 + i)^n / \{(1 + i)^n - 1\}$$

Administrative overhead is ignored[1]. Our approach is illustrated by Figure 4.2.

4.3 SELECTION AND TIMING OF UPGRADING

Determining the optimal timing of an upgrading is a more or less complex process depending on whether this point occurs before or after commercial capacity. If the best upgrading measures are optimally timed before commercial capacity occurs, then it will be shown in the following section that, this optimal timing is independent of the selection criterion and the gross revenue rate. This simplification however does not hold in cases where upgrading is only justifiable following the occurrence of the capacity constraint.

4.3.1 Upgradings Justifiable before the Capacity Constraint Occurs

We can extend the formulation of Section 4.2.2 to determine whether or not an upgrading should be considered from the commercial viewpoint. Using the

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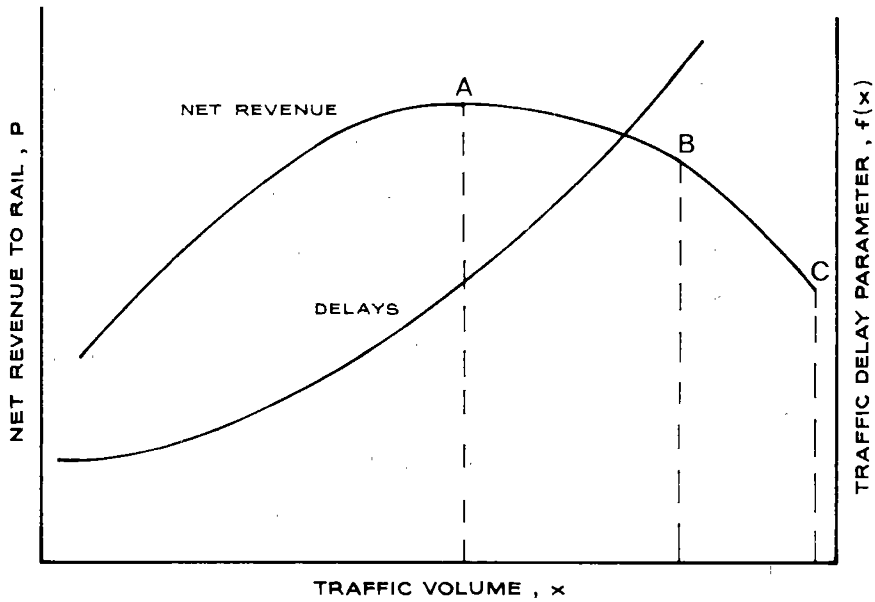
(1) Strictly speaking, some administrative costs which vary with traffic should be allocated to growth traffic.



A : COMMERCIAL CAPACITY
B : RESOURCE CAPACITY
C : PHYSICAL CAPACITY

NOTE : B MAY LIE ANYWHERE BETWEEN A AND C

FIGURE 4.2

VARIATION OF NET REVENUE TO RAIL AND DELAYS WITH TRAFFIC VOLUME same nomenclature as before, it is evident that upgrading is justified when:

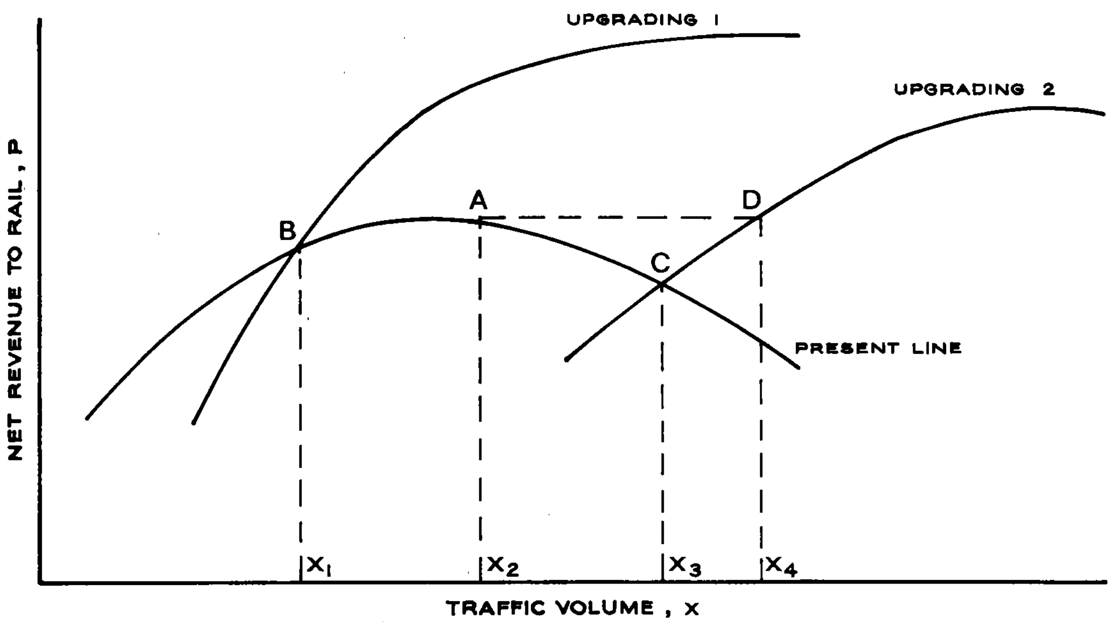
$$x\{R - C_1'(1 + D') - C_2'\} - C_3' \geq x\{R - C_1(1 + D) - C_2\} - C_3$$

where the primes refer to the upgraded condition. The revenue term is common to both sides of the inequality and may therefore be removed, giving as the upgrading decision criterion:

$$x\{C_1'(1 + D') + C_2'\} + C_3' \leq x\{C_1(1 + D) + C_2\} + C_3 \qquad (4.2)$$

Under these circumstances the optimal year of introduction of an upgrading is independent of gross revenue and the best upgrading measures are selected by a simple cost minimising process. The net present value will however, always remain a function of gross revenue. The above formulation is illustrated on Figure 4.3 where Upgrading 1 becomes desirable at traffic volumes greater than x_1.

From a resource viewpoint the decision criterion is unchanged except that the overflow costs are added to the cost of carrying the capacity traffic on the existing



A, X_2	:	COMMERCIAL CAPACITY
B, X_1	:	POINT TO INTRODUCE UPGRADING 1
C, X_3	:	POINT TO INTRODUCE UPGRADING 2, PROVIDING RESOURCE CAPACITY IS GREATER THAN V_3, FROM A RESOURCE POINT OF VIEW
D, X_4	:	POINT TO INTRODUCE UPGRADING 2, FROM A COMMERCIAL POINT OF VIEW. THE RAILWAY WOULD ONLY CARRY V_2 BETWEEN POINTS A AND D

FIGURE 4.3

INTRODUCTION OF UPGRADING FROM COMMERCIAL AND RESOURCE POINTS OF VIEW line. Overflow costs would start occuring as soon as the resource capacity constraint applies. Clearly, such manipulation does not alter the crossing point of the "present line" and "Upgrading 1" curves at x_1, indicating that the optimal timing of the upgrading in this case is independent of the criterion chosen.

4.3.2 Upgradings Justifiable after the Capacity Constraint Occurs

Figure 4.3 also depicts the situation corresponding to an upgrading which only becomes effective after commercial capacity is reached (Upgrading 2). Annex D describes the general equations and derivatives corresponding to the capacity situation. In the case of Upgrading 2 the gross revenue term R can no longer be eliminated (Section 4.3.1) and the optimal timing of the upgrading from the commercial viewpoint is dependent on the value of the net revenue (P) at which commercial capacity is reached (1) (point A on Figure 4.3, at traffic volume x_2). Resource capacity would however occur at a different traffic volume (2).

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(1) Equation (D.3) indicates that the commercial capacity point is a function of the gross revenue per train R.

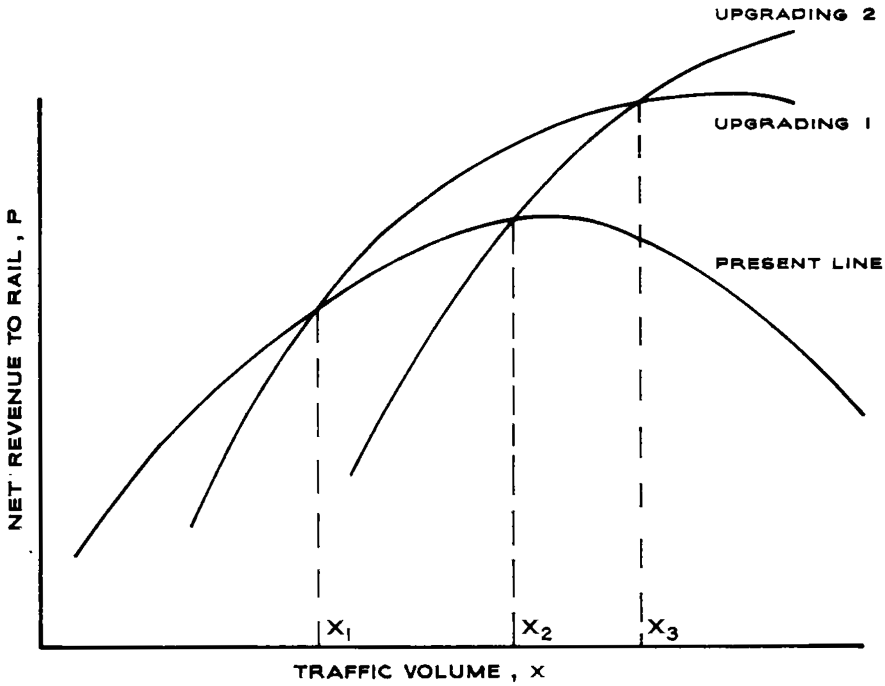
(2) Unless the gross revenue per train R happens to equal the marginal resource cost of carrying one train load by road - Equation (D.6).

4.3.3 Selection from a Large Number of Upgradings

Figure 4.3 shows the case of two upgradings, one becoming effective before commercial capacity, the other only afterwards.

If the choice between upgradings was indeed between 1 and 2 as indicated on the diagram, the decision would clearly be in favour of the former, given that we wish to maximise revenue. A less obvious situation is depicted on Figure 4.4; if upgradings 1 and 2 were mutually exclusive, the choice would need to be determined by comparing the present values of net revenue cash flows over the study period. Taken a step further, if there were several such mutually exclusive alternatives, possibly made up of sequences of incremental upgradings phased in time, then selection of the sequence giving maximum present value of the net revenue stream would require massive computing effort. For this reason a mathematical programming procedure was developed which led to computationally efficient procedures - see Annex B.

From a commercial point of view, the decision to upgrade is influenced by several criteria, including capital required and rate of return on capital. The capital requirement is subject to availability of funds



X_1 : TRAFFIC VOLUME AT WHICH UPGRADING 1 SHOULD BE INTRODUCED

X_2 : TRAFFIC VOLUME AT WHICH UPGRADING 2 SHOULD BE INTRODUCED , WITH NO PRIOR UPGRADING

X_3 : TRAFFIC VOLUME AT WHICH UPGRADING 2 SHOULD BE INTRODUCED , SUBSEQUENT TO UPGRADING 1

FIGURE 4.4

CHOICE BETWEEN UPGRADINGS, COMMERCIAL CRITERIA and the rate of return is an index of the effectiveness with which the capital is deployed. For the present study, constraints on capital availability have not been considered.

For convenience, we have compared upgrading alternatives on the basis of net present value over a range of discount rates, 7%, 10% and 12%. Those upgradings showing highest net present value were then re-evaluated over a wider range of discount rates bracketing the rate of return. Note that this approach does not necessarily identify the upgrading giving the highest rate of return. In the present study it turned out that the upgradings selected on a basis of net present value were also those having the lowest cost of introduction, and for this reason would be preferred under capital constraint.

4.4 RESOURCE COST OF TRANSPORTING THE INTERSTATE FREIGHT TRAFFIC

In this case, apart from rail cost, we also need to take road and sea spillover costs into consideration; such spillovers occur when rail reaches its resource capacity. Dealing first with interstate general freight, almost all this traffic is marketed by freight forwarders who consolidate less-than-container load consignments (LCL) into full unit loads (FCL). These unit loads are generally containerised or carried on special flats designed to fit on an articulated truck. The consolidated loads, together with similar unit loads assembled by consignors are loaded directly on to railway wagons with a gantry crane. So the railway's function is mainly that of a line haulier.

Discussions with the major freight forwarders have indicated that most of their rail traffic is LCL; the FCLs would tend to travel door to door by road directly from consignor to consignee. Figure 4.5, which is a diagram representing general freight movement between Melbourne and Sydney, is based on LCL traffic moving through consolidating depots, although in principle, the model suggested by the figure could also be applied to FCL traffic(1). We argue that, on the average, the road haul from the consolidating depot to the rail head is the same as it would be to the interstate highway access points (links 1, 3, 4 and 8 on the diagram). Thus, in comparing rail and road costs we need only be concerned with the line haul links 6 and 2 and the rail/road transfer stages 5 and 7. Note that the road line haul distance corresponds to the interstate highway distance, assumed as the city centre to centre distance less eighty kilometres.

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(1) Some account would need to be taken of the distribution of consignors of FCLs with respect to the rail head and the interstate highway access points.

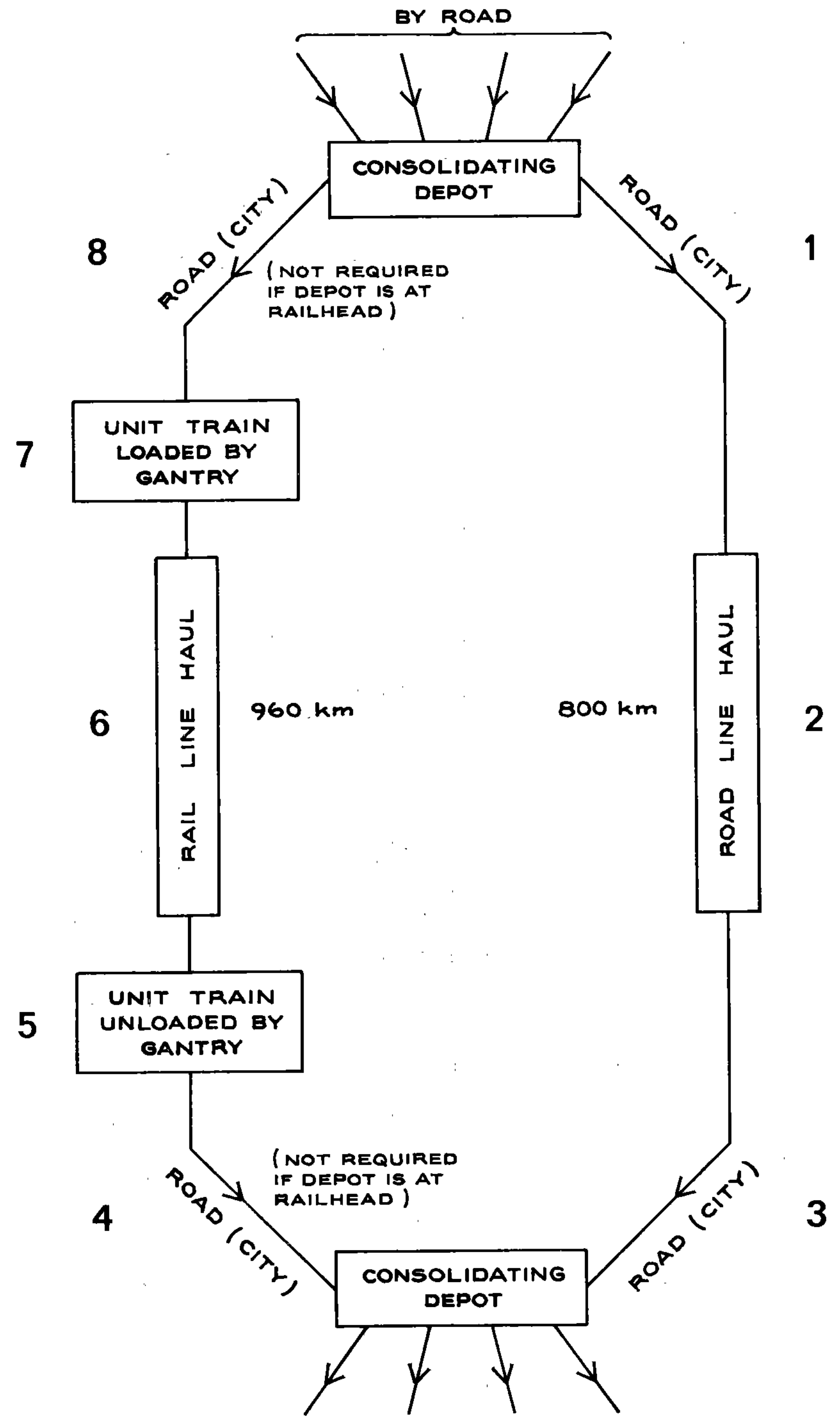

FIGURE 4.5

FLOW CHART FOR TRANSPORT OF GENERAL FREIGHT

4.4.1 Road Overflow

In estimating the cost of transporting the general freight diverted on to road, two categories of costs are distinguished:

- average operating cost of trucks based on the condition and congestion of the Hume Highway in 1973, and
- additional costs to the trucks carrying diverted traffic and to other road users due to the interaction between the diverted and other road traffic.

The average operating costs are based on present costs of operating a semi-trailer shuttle service between Sydney and Melbourne(1) (Annex C details these operating costs) and some attempt is made to take future congestion costs into account as a function of the state of the road. These additional costs were estimated with the aid of the Commonwealth Bureau of Roads (CBR) model RURAL(2), modified by the

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(1) Bureau of Transport Economics' report,'A study of intersystem railway rating practices with particular reference to the Riverina area of N.S.W.' (Canberra, to be published).

(2) G.J. Both, K.E. Thompson, & G.T. Lack,: 'The evaluation of rural road and bridge improvements', Australian Road Research Board Proceedings, 6,2 (1972), pp 145-171.

BTE for the purpose of this study. The interaction costs will clearly be affected by the state of the Hume Highway during the study period; three road states were taken into consideration, based on the CBR Hume Highway Study(1):

- Configuration 1: Hume Highway maintained and upgraded in such a way that average 1973 truck operating costs are held constant throughout the study period, irrespective of the diverted freight;

- Configuration 2: Hume Highway maintained in its 1973 configuration throughout the study period; and

- Configuration 3: Hume Highway upgraded to four lane standard by the 14th year of study period.

4.4.2 Sea Overflow

In comparison with road and rail costs, the ship costs used are rather rough. However, due to the slow growth of steel carried by rail, the effect of

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(1) Commonwealth Bureau of Roads and Department of Main Roads, N.S.W., 'National Highway Corridor Study -Hume Highway, Goulburn to Albury-Wodonga' (January 1975).

overflow to sea is insignificant except in the case of the high forecast where the sea overflow costs are around 10 to 15% of the total incremental cost. It is argued in the case of sea that, in the long run, present bulk prices (minimum of 15 tonnes) will reflect costs which amount to about 1.24¢/tonne km (first part of Chapter 4 and Annex C).

4.4.3 Resource Cost Calculations

The total resource cost of transporting rail's modal share of interstate freight can then be calculated as the sum of the following:

- total rail line haul cost, including that due to congestion, and rail/road transfer at the railheads;

- cost of rail upgrading, expressed as an annuity during the appropriate part of the study period(1), less savings directly attributable to the upgrading;

- average truck operating cost for diverted traffic, when applicable;

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(1) This automatically allows for residual value at the end of the study period.

- additional cost to diverted traffic and other road users when applicable; and

- cost of diverted steel traffic, when applicable.

The year by year total resource cost may then be discounted to a single net present value (NPV) at a specified discount rate.

The difference between the NPVs for the situation with and without rail upgrading can then be interpreted as the NPV of the resource benefit attributable to the upgrading.

CHAPTER 5 EVALUATION OF OPTIONS

The first section of this chapter briefly describes the preliminary screening process applied to all upgradings to identify those worthy of detailed examination. Before proceeding to the evaluation proper, the estimated physical and commercial capacities of the present line are presented for a range of freight projections and train weights. The results of the evaluations according to commercial and resource criteria are then discussed.

The outcome of the ranking procedure is tested with regard to variations in the following parameters:

- projections (low, expected and high),
- train weight (an average weight of 800, 1100 and 1400 gross tonnes),
- discount rate (7%, 10% and 12%),
- gross revenue earned from interstate general goods traffic (0.62 and 0.81 cents/tonne km).

Originally it was intended to vary the fuel price as part of the sensitivity testing process; however, a closer examination of the competitive position between long distance road and rail haulage has shown that fuel price will only have a moderate effect on the modal split (Section 2.1.2).

The freight projections were calculated from a base year of 1972/73, which was the most recent available. All costs are quoted in 1973 dollars. The study period is 1972/73 to 1991/92, all discounted net present values being based on the first year. For convenience, the years of the study period are designated 1 to 20.

5.1 FIRST SCREENING OF OPTIONS

5.1.1 Melbourne-Albury

Because the Victorian standard gauge only carries interstate traffic and present crossing loops are spaced relatively far apart, additional crossing loops effectively reduce delays to a negligible proportion of transit time and can provide adequate capacity throughout the study period. The additional benefits from line doubling are therefore small and consistently dominated by the higher capital cost of doubling. Doubling was therefore not considered further.

On the basis of annual net revenue, regrading is never justified if 800 tonne trains are used, but could be justified in the case of the high projections in the mid 1990s with 1100 tonne trains and in the early 1980s with 1400 tonne trains. Regrading of this section will not be considered further in this report because 1100 tonne trains were found to be preferred to 1400 tonne trains.

5.1.2 Albury-Sydney

Early results indicated that combinations of CTC and the first stage of selective doubling[1] dominated any scheme involving additional doubling. Doubling beyond the first stage is therefore not considered further.

Benefit from regrading is mainly manifested as a saving of motive power. Approximate calculations showed that, even with the high forecast, regrading does not become justified until the mid 1980s with 1100 tonne trains; with the expected forecast, the year of introduction would be in the early 1990s. The prospect of regrading in 10 to 15 years time, at a cost of $24 to $40 million would have no significance in relation to

(1) The first stage of doubling was common to both schemes A and B described in Chapter 3.

other upgrading options, costing $2.4 to $5.1 million, which could be justified in the immediate short term. So, for the purposes of this report, regrading was not considered further.

5.2 PHYSICAL AND COMMERCIAL CAPACITIES OF EXISTING LINE

5.2.1 Physical Capacities

Table 5.1 shows the years in which physical capacity is reached on the Victorian and N.S.W. sections of the Melbourne-Sydney link. The estimates were obtained with the aid of the Single Track Railway Simulation model (STS); note that these are theoretical estimates which in practice would be subject to degradation from delayed departures and other practical constraints not accounted for (Section 4.2.1). The main features of the table are:

- The use of heavier trains delays the onset of physical capacity. On the Victorian section this applies to the whole range of train weights considered. For N.S.W., increase of train weight beyond 1100 tonnes is ineffective because of the increasing effect of insufficiently long crossing loops.

TABLE 5.1 - YEARS IN WHICH PHYSICAL CAPACITIES ARE REACHED

Average weight of interstate freight trains (gross tonnes)	Section	Forecast		
		Low	Expected	High
800	Sydney - Albury	20	16	13
	Albury - Melbourne	15	11	8
1100	Sydney - Albury	20	19	16
	Albury - Melbourne	20	17	13
1400	Sydney - Albury	17	13	9
	Albury - Melbourne	20	20	17

NOTE: Capacities were estimated using the BTE Single Track Railway Simulator. No simulations were done beyond 1993.

- For gross train weights up to 1100 tonnes, the Victorian section would be expected to reach physical capacity first.

5.2.2 Commercial Capacity

In the formulation developed in Chapter 4, terms involving both revenue and capital commitment to motive power and rolling stock are involved in the development of the idea of commercial capacity. We would therefore expect both revenue and discount rate to affect a deduced level of commercial capacity. This is brought out in Tables 5.2 and 5.3 which summarise the estimates of commercial capacity for the Victorian and N.S.W. sections respectively. Reference to Equation (4.1) would suggest that commercial capacity would be expected to increase with freight revenue rate and decrease with discount rate. Also, previously quoted results of physical capacity would suggest that commercial capacity would be expected to increase with train weight, but only up to 1100 tonnes gross for the N.S.W. section. The results are consistent with these expectations.

The results corresponding to a revenue rate of 0.62 cents per tonne km were omitted from the tabulations for the N.S.W. section because, for most cases,

TABLE 5.2 - YEARS IN WHICH COMMERCIAL CAPACITIES ARE REACHED: EXISTING MELBOURNE-ALBURY SECTION

Average weight of interstate freight trains (gross tonnes)	Revenue (cents/tonne km)	Forecast								
		Low			Expected			High		
		Interest rate			Interest rate			Interest rate		
		7%	10%	12%	7%	10%	12%	7%	10%	12%
800	0.62	6	5	5	5	3	3	3	2	2
	0.81	11	10	8	8	7	7	8	6	4
1100	0.62	16	16	14	13	13	11	10	8	8
	0.81	18	18	18	17	17	14	12	12	12
1400	0.62	20	20	20	17	17	17	15	12	12
	0.81	20	20	20	19	19	18	15	15	15

TABLE 5.3 - YEARS IN WHICH COMMERCIAL CAPACITIES ARE REACHED: EXISTING SYDNEY -ALBURY SECTION

Average weight of interstate freight trains (gross tonnes)	Revenue (cents/tonne km)	Forecast								
		Low			Expected			High		
		Interest rate			Interest rate			Interest rate		
		7%	10%	12%	7%	10%	12%	7%	10%	12%
800	0.81	18	15	13	14	12	10	10	8	8
1100	0.81	20	20	20	19	19	18	16	16	16
1400	0.81	18	18	18	14	14	14	9	9	9

these indicated a continuously decreasing negative net revenue from the beginning of the study period. In that case commercial capacity is always exceeded and the traffic is carried at a loss, although upgrading would be still beneficial in the sense that losses would be minimised. The N.S.W. section, because of its steeper grades, requires about double the motive power required for Victoria, and its operating costs are therefore correspondingly higher. This demonstrates the fallacy of a simple allocation of interstate revenue by distance.

A general observation, applicable to both physical and commercial capacity results, is that, in the middle of the ranges of train weight and freight forecast, both capacities are virtually coincident. Thus, growth traffic would spill over from rail to road at the same time whether commercial or resource cost criteria are applied.

5.3 EVALUATION OF UPGRADINGS - COMMERCIAL CRITERIA

Following the initial screening process, seven upgrading options were evaluated in detail - see Table 5.4. Four were concerned with the Albury-Junee section and three with Melbourne-Albury. The results (Table 5.5 to 5.10) will be expressed in terms of Net Present Value

TABLE 5.4 - SYDNEY-MELBOURNE - UPGRADING SEQUENCES STUDIED IN DETAIL

Line Configuration Number	Description	Label
1	CTC1 only (Albury-Junee)	CTC1
2	CTC1 followed by CTC2 (Albury-Junee)	CTC1, CTC2
3	CTC1 followed by the first stage of doubling (Albury-Junee)	CTC1, A1
4	CTC1 and CTC2 introduced simultaneously (Albury-Junee)	CTC2
5	6 crossing loops added to existing line (Albury-Melbourne)	6 loops
6	A further 4 crossing loops added to line configuration 5 (Albury-Melbourne)	6 and 10 loops
7	A further 8 crossing loops added to line configuration 6 (Albury-Melbourne)	6, 10 and 18 loops

(NPV) of net revenue to the railway over a range of discount rates. The reasoning leading to the selection of this criterion is discussed in Section 4.3.

Tables 5.5 and 5.6 summarise the results for the Victorian section with the freight forecast at the "expected" level and the revenue rate set at 0.62 and 0.81 cents/tonne km respectively. The implications are:

- In all cases considered, 1100 tonne trains would be preferred to the other train weights. Although 1400 tonne trains have been shown to be superior in terms of freight carrying capacity of the line, Table 4.1 indicates that this train weight requires two locomotives in contrast to the lower weights which only need one. Thus, the reduced congestion with fewer 1400 tonne trains is offset by the greater total demand for motive power. It may be noted from the tables that increasing the average gross train weight from 800 tonnes to 1100 tonnes with the existing line, has an effect comparable to that from upgrading at the lower train weight. Thus, if all upgrading/train weight combinations were evaluated against a base of the existing line and present train weight

TABLE 5.5 - MELBOURNE-ALBURY COMMERCIAL RESULTS: EXPECTED FORECAST AND 0.62 CENTS/TONNE KM REVENUE

Average weight of interstate freight trains (gross tonnes)	Line Configuration	Interest rate					
		7%		10%		12%	
		Best year of introduction[a]	NPV of net revenue ($million)	Best year of introduction[a]	NPV of net revenue ($million)	Best year of introduction[a]	NPV of net revenue ($million)
800	Existing line	-	18.30	-	13.04	-	10.41
	6 loops	1	21.47	1	14.89	1	11.68
	6 & 10 loops	1, 15	21.64	1, 16	14.90	1, 19	11.70
	6 & 10 & 18 loops	1, 15, 19	21.62	1, 16, 19	14.89	1, 18, 19	11.65
1100	Existing line	-	23.38	-	16.58	-	13.41
	6 loops	6	25.06	6	17.63	6	14.04
	6 & 10 loops	6, 19	25.06	6, 19	17.63	6, 19	14.04
	6 & 10 & 18 loops	6, 18, 19	25.01	6, 18, 19	17.59	6, 18, 19	14.01
1400	Existing line	-	23.72	-	16.62	-	13.17
	6 loops	10	24.53	10	17.14	11	13.57
	6 & 10 loops	10, 19	24.51	10, 19	17.12	11, 19	13.56
	6 & 10 & 18 loops	10, 18, 19	24.45	10, 18, 19	17.08	11, 18, 19	13.52

(a) Year 1 is 1973

TABLE 5.6 - MELBOURNE-ALBURY COMMERCIAL RESULTS: EXPECTED FORECAST AND 0.81 CENTS/TONNE KM REVENUE

Average weight of interstate freight trains (gross tonnes)	Line Configuration	Interest rate					
		7%		10%		12%	
		Best year of introduction (a)	NPV of net revenue ($million)	Best year of introduction (a)	NPV of net revenue ($million)	Best year of introduction (a)	NPV of net revenue ($million)
800	Existing line	-	35.10	-	26.11	-	21.62
	6 loops	1	41.11	1	30.01	1	24.62
	6 & 10 loops	1, 15	41.28	1, 16	30.11	1, 16	24.69
	6 & 10 & 18 loops	1, 15, 19	41.26	1, 16, 19	30.09	1, 16, 19	24.67
1100	Existing line	-	41.68	-	30.79	-	25.90
	6 loops	6	44.70	6	32.83	6	27.08
	6 & 10 loops	6, 19	44.70	6, 19	32.83	6, 19	27.08
	6 & 10 & 18 loops	6, 18, 19	44.65	6, 18, 19	32.79	6, 18, 19	27.05
1400	Existing line	-	43.14	-	31.66	-	26.12
	6 loops	10	44.16	10	32.34	11	26.61
	6 & 10 loops	10, 19	44.15	10, 19	32.33	11, 19	26.60
	6 & 10 & 18 loops	10, 18, 19	44.08	10, 18, 19	32.28	11, 18, 19	26.56

(a) Year 1 is 1973

the results would express two major effects without distinguishing between them. So all upgrading comparisons are made at constant train weight.

- In all cases, minimum upgrading with six additional crossing loops led to the highest NPV of net revenue. In the case of 1100 tonne trains, the addition of ten crossing loops gave the same result as six crossing loops, however, the second stage of the sequence could not be timed until the end of the study period.

- The timing of introduction of the first six crossing loops is sensitive to train weight. With 800 tonne trains, the first crossing loops should have been introduced in 1972/73, with 1100 tonne trains in 1978/79 and with 1400 tonne trains in about 1983.

- The timing and ranking of the upgradings is insensitive to both discount rate over the range 7% to 12% and revenue rate over the range 0.62 to 0.81 cents/tonne km.

Table 5.7 summarises the corresponding results for the N.S.W. section for the single revenue rate of 0.81 cents/tonne km. As explained in section 5.2.2, the gross revenue figure of 0.62 cents/tonne km is not worth considering. The following implications can be drawn from Table 5.7:

- 1100 tonne trains again lead to the highest NPVs of net revenue for basically the same reason as applies to the Victorian section, except that in this case 1400 tonne trains require three locomotives compared to two for the other weights.

- With 1100 and 1400 tonne trains, the minimum upgrading CTC1 gives the best result, although the CTC1, CTC2 sequence gives virtually the same. However, the second stage of the sequence would not be timed until the end of the study period.

Tables 5.8 and 5.9 show the effect of freight forecast level on selection and timing of upgrading for 1100 tonne trains on the Victorian section at revenue rates 0.62 and 0.81 cents per tonne km respectively. The tables show that varying the rate of growth of freight transport demand merely affects

TABLE 5.7 - SYDNEY-ALBURY COMMERCIAL RESULTS: EXPECTED FORECAST AND 0.81 CENTS/TONNE KM REVENUE

Average weight of interstate freight trains (gross tonnes)	Line Configuration	Interest rate					
		7%		10%		12%	
		Best year of introduction(a)	NPV of net revenue ($million)	Best year of introduction(a)	NPV of net revenue ($million)	Best year of introduction(a)	NPV of net revenue ($million)
800	Existing line	-	33.79	-	21.50	-	15.65
	CTC1	1	36.44	1	22.84	1	16.44
	CTC1, CTC2	1, 17	36.52	1, 17	22.87	1, 19	16.39
	CTC1, A1	1, 19	36.38	1, 19	22.79	1, 19	16.33
	CTC2	6	35.29	8	21.86	13	15.69
1100	Existing line	-	42.15	-	27.20	-	20.12
	CTC1	1	46.16	1	30.05	1	22.28
	CTC1, CTC2	1, 19	46.14	1, 19	30.02	1, 19	22.26
	CTC1, A1	1, 19	46.03	1, 19	29.95	1, 19	22.20
	CTC2	5	44.37	7	28.48	9	20.90
1400	Existing line	-	42.04	-	27.27	-	20.10
	CTC1	1	45.85	1	29.92	1	22.23
	CTC1, CTC2	1, 19	45.81	1, 19	29.89	1, 19	22.20
	CTC1, A1	1, 19	45.70	1, 19	29.81	1, 19	22.14
	CTC2	1	43.75	4	27.91	7	20.38

(a) Year 1 is 1973

TABLE 5.8 - MELBOURNE-ALBURY COMMERCIAL RESULTS: 1100 GROSS TONNE TRAINS AND 0.62 CENTS/TONNE KM REVENUE

Forecast	Line Configuration	Interest rate					
		7%		10%		12%	
		Best year of introduction(a)	NPV of net revenue ($million)	Best year of introduction(a)	NPV of net revenue ($million)	Best year of introduction(a)	NPV of net revenue ($million)
Low	Existing line	-	19.93	-	14.09	-	11.30
	6 loops	9	20.65	9	14.54	9	11.57
	6 & 10 loops	9, 19	20.63	9, 19	14.53	9, 19	11.56
	6 & 10 & 18 loops	9, 18, 19	20.56	9, 18, 19	14.48	9, 18, 19	11.52
Expected	Existing line	-	23.38	-	16.58	-	13.41
	6 loops	6	25.06	6	17.63	6	14.04
	6 & 10 loops	6, 19	25.06	6, 19	17.63	6, 19	14.04
	6 & 10 & 18 loops	6, 18, 19	25.01	6, 18, 19	17.59	6, 18, 19	14.01
High	Existing line	-	26.13	-	18.72	-	15.08
	6 loops	4	29.84	4	20.90	5	16.62
	6 & 10 loops	4, 15	29.96	4, 16	20.97	5, 16	16.67
	6 & 10 & 18 loops	4, 15, 19	29.93	4, 16, 19	20.95	5, 16, 19	16.65

(a) Year 1 is 1973

TABLE 5.9 - MELBOURNE-ALBURY COMMERCIAL RESULTS: 1100 GROSS TONNE TRAINS AND 0.81 CENTS/TONNE KM REVENUE

Forecast	Line Configuration	Interest rate					
		7%		10%		12%	
		Best year of introduction[a]	NPV of net revenue ($million)	Best year of introduction[a]	NPV of net revenue ($million)	Best year of introduction[a]	NPV of net revenue ($million)
Low	Existing line	-	36.68	-	27.19	-	22.55
	6 loops	9	37.57	9	27.77	9	22.99
	6 & 10 loops	9, 19	37.55	9, 19	27.76	9, 19	22.98
	6 & 10 & 18 loops	9, 18, 19	37.48	9, 18, 19	27.71	9, 18, 19	22.94
Expected	Existing line	-	41.68	-	30.79	-	25.90
	6 loops	6	44.70	6	32.83	6	27.08
	6 & 10 loops	6, 19	44.70	6. 19	32.83	6. 19	27.08
	6 & 10 & 18 loops	6, 18, 19	44.65	6, 18, 19	32.79	6, 18, 19	27.05
High	Existing line	-	46.82	-	34.61	-	28.66
	6 loops	4	52.69	4	38.42	5	31.55
	6 & 10 loops	4, 15	52.81	4, 16	38.48	5, 16	31.59
	6 & 10 & 18 loops	4, 15, 19	52.78	4, 16, 19	38.46	5, 16, 19	31.57

(a) Year 1 is 1973

the timing of upgrading; the preferred first upgrading is unchanged. So six loops should be introduced in 1981/82, 1978/79 or 1976/77 depending on whether the forecast is "low", "expected" or "high". For the high forecast, a second upgrading giving a total of ten additional loops would be justified on a net present value basis eleven to twelve years after the first upgrading. There would not be any economic advantage in introducing the third upgrading, up to 18 crossing loops.

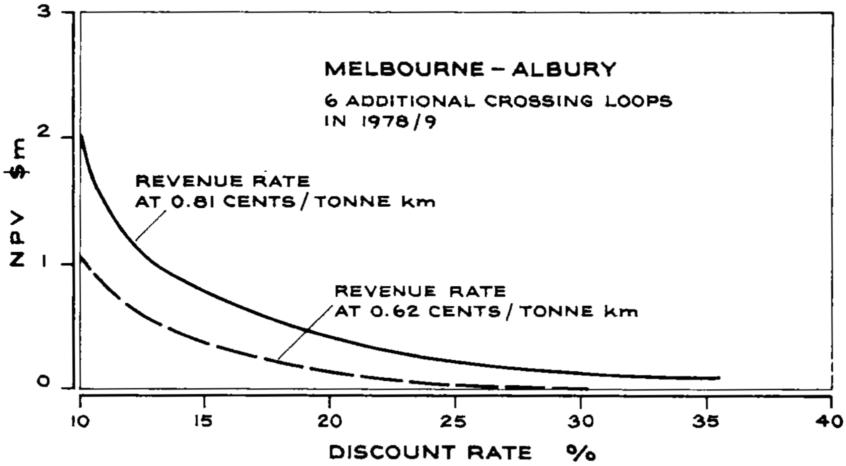
Table 5.10 shows the corresponding results for the N.S.W section at the three freight forecast levels and one revenue rate of 0.81 cents/tonne km. As explained in Section 5.2.2, the gross revenue figure of 0.62 cents per tonne km is not worth considering. The main conclusion arising from Table 5.10 is that CTC1 would have been justified by 1972/73 even with the "low" forecast. With the "high" forecast, a second upgrading corresponding to configuration CTC1, CTC2 would be justified towards the end of the study period. This sequence would be marginally superior to a sequence involving doubling e.g. CTC1, A1.

Figure 5.1 shows plots of the differences in NPVs of net revenue between the existing and upgraded lines for a range of discount rates. Using 1100 tonne trains on an upgraded line having 6 additional loops in

TABLE 5.10 - SYDNEY-ALBURY COMMERCIAL RESULTS: 1100 GROSS TONNE TRAINS AND 0.81 CENTS/TONNE KM REVENUE

Forecast	Line Configuration	Interest rate					
		7%		10%		12%	
		Best year of introduction[a]	NPV of net revenue ($million)	Best year of introduction[a]	NPV of net revenue ($million)	Best year of introduction[a]	NPV of net revenue ($million)
Low	Existing line	-	33.87	-	21.58	-	15.60
	CTC1	1	36.68	1	23.50	1	17.08
	CTC1, CTC2	1, 19	36.63	1, 19	23.46	1, 19	17.05
	CTC1, A1	1, 19	36.52	1, 19	23.38	1, 19	16.99
	CTC2	7	34.85	10	22.04	12	15.88
Expected	Existing line	-	42.15	-	27.20	-	20.12
	CTC1	1	46.16	1	30.05	1	22.28
	CTC1, CTC2	1, 19	46.14	1, 19	30.02	1, 19	22.26
	CTC1, A1	1, 19	46.03	1, 19	29,95	1, 19	22.20
	CTC2	5	44.37	7	28.48	9	20.90
High	Existing line	-	50.66	-	32.88	-	24.39
	CTC1	1	56.53	1	36.96	1	27.63
	CTC1, CTC2	1, 18	56.54	1, 19	36.97	1, 19	27.64
	CTC1, A1	1, 19	56.45	1, 19	36.90	1, 19	27.59
	CTC2	3	54.86	5	35.37	7	26.16

(a) Year 1 is 1973



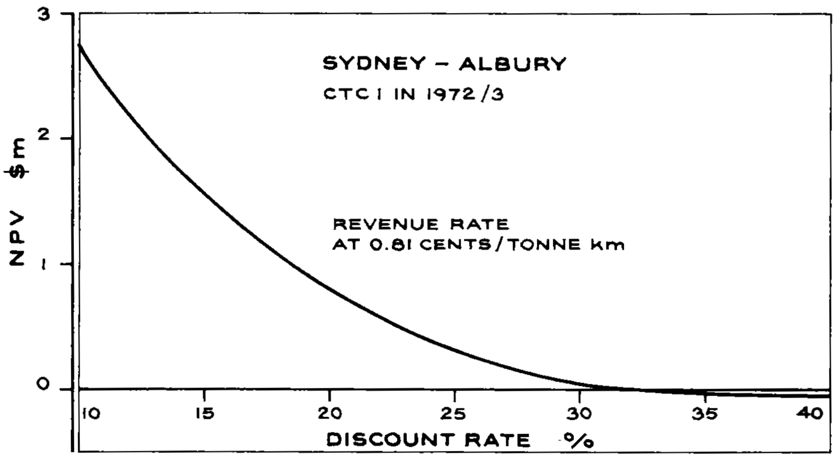


FIGURE 5.1

CALCULATION OF RATE OF RETURN

TO INVESTMENT IN UPGRADING

EXPECTED FORECAST

AVERAGE WEIGHT OF INTERSTATE FREIGHT TRAINS : 1100 GROSS TONNES

Victoria and CTC1 in N.S.W. generates a rate of return to the railway in excess of 30% on the investment in upgrading.

Put another way, the capital costs of these upgradings would be covered in about three years by operational savings. This suggests that the commercial viability of the investment is relatively insensitive to long term freight forecasts.

Another factor which is likely to affect the results of this study concerns the choice of the most common type of container carrying wagon. We assumed that all growth traffic will be carried in 7m containers on 14m long, 20 tonne tare weight wagons. Recently observed trends both overseas and in Australia indicate that in the future preferred wagons are likely to have a higher carrying capacity per tare weight. Such a development would gradually alter the ratio of gross train weight to load carried, which is required for the conversion of the freight projections into numbers of trains (Section 4.1). This would not alter the ranking of the best upgradings but would delay the optimum years of introduction. The optimum year of introduction of the best upgrading measure on the Albury-Sydney link remains at 1972 for the range of traffic forecasts and would be unaffected by any likely change in the ratio of gross train weight to load carried. On the Albury-Melbourne link, the maximum shift in the year of introduction of the 6 loops option would be about 2-3 years. This assumes no empty wagon or empty container movements on the unit trains. However, such a situation is unlikely given the fluctuations and imbalances characteristic of rail traffic demand.

It is interesting to examine the breakdown of cost elements expressed in NPV terms. Table 5.11 presents, as an example, the breakdown of some net revenue figures corresponding to the Sydney-Albury section. The table shows that train running costs are by far the highest single item in both the existing and upgraded configurations; although the cost breakdown would vary with the particular line under study and with train weight, running costs would still dominate in all cases considered in this report. This result highlights the scope for improvement, especially with regard to maintenance practices.

From the figures it is clear that the upgrading is justified by manpower savings due to the introduction of CTC and by delay reductions expressed as savings in train capital and crew costs. It is worth noting here that the addition of 6 loops on the Victorian side of the line would be solely justified by delay reductions.

TABLE 5.11 - SYDNEY-ALBURY COMMERCIAL REVENUE AND COST ELEMENTS: 1100 GROSS TONNE TRAINS, EXPECTED FORECAST, 0.81 CENTS/TONNE KM REVENUE AND 10% DISCOUNT RATE

($ million)

Line configuration	Net present values						
	Gross revenue from interstate freight	Manpower savings	Cost of upgrading	Train capital	Train crew	Fuel, train and track maintenance	Net revenue
CTC1	134.10	1.37	-2.14	-26.57	-9.35	-67.36	30.05
Existing line	134.10	-	-	-28.50	-11.05	-67.34	27.21
Savings from upgrading	-	1.37	-2.14	1.93	1.70	- 0.02	2.84

NOTE: Only locomotive capital and crew delay costs are included in the case of passenger and local freight trains (Annex D).

5.4 PHYSICAL AND COMMERCIAL CAPACITIES OF THE BEST UPGRADING OPTIONS

Table 5.12 shows the years in which physical and commercial capacities are reached for the best upgrading options, that is CTC1 between Albury and Junee and 6 additional loops between Melbourne and Albury (Section 5.3). The estimates were obtained in the same way as those for the existing line (Section 5.2). Note that in the upgraded configurations, the physical and commercial capacities of the line are only reached in a few cases within the study period.

5.5 EVALUATION OF UPGRADINGS - RESOURCE CRITERIA

From a resource point of view, we are concerned with the development of a Melbourne-Sydney transport corridor that meets the total rail task in the most economic way; ultimately, our analysis would need to comprehend land use alternatives as well as taking into consideration the total demand for transport within the corridor. However, sufficiently comprehensive models or data are not yet available to allow such an extensive analysis and our evaluations are therefore restricted in the sense of being sub-optimal. Provided that parameters such as forecasts and assumed developments on other modes do not

TABLE 5.12 - YEARS IN WHICH COMMERCIAL CAPACITIES ARE REACHED: 800 GROSS TONNE TRAINS[a] AND THE BEST UPGRADINGS

Line configuration	Revenue (cents/tonne km)	Forecast: Low, Interest rate 7%	Low, 10%	Low, 12%	Expected, Interest rate 7%	Expected, 10%	Expected, 12%	High, Interest rate 7%	High, 10%	High, 12%
Sydney-Albury										
CTC1	0.81	20	20	20	20	20	18	17	16	15
Melbourne-Albury										
6 loops	0.62	20	20	20	20	18	17	17	15	15
	0.81	20	20	20	20	20	20	17	17	17

(a) In the cases of 1100 and 1400 tonne trains, commercial capacity is not reached within the study period.

NOTE: Physical capacity is only reached with the high forecast: in year 19 with CTC1 and in year 17 with 6 loops.

influence the results, the implied investment allocation should be compatible with what would have been derived in a more comprehensive analysis.

Previous sections have indicated that, from the railway's point of view, the best way to upgrade the Melbourne-Sydney line is to increase the average gross train weight to 1100 tonnes, construct an additional six crossing loops on the Victorian standard gauge and introduce CTC (CTC1) between Albury and Junee. All of these upgradings would be introduced before commercial capacity is reached in the sections concerned and are primarily cost reducing measures. Upgradings derived on commercial criteria would therefore be entirely consistent with those derived on resource criteria, and, for the purposes of the resource evaluations it will be sufficient to obtain benefit to cost ratios corresponding to the best commercial rail upgradings. Given the rail upgradings, the benefit to cost ratio will then be a function of the state of the road and of the traffic projections.

It was found that, according to the previous definitions (Section 5.2), resource capacity of the existing line was coincident with physical capacity. So we have taken as "Base Case" the existing line carrying all traffic in 1100 tonne trains up to physical capacity beyond which further growth would be diverted to road and sea. Table 5.13 summarises the annual cost of the diverted road traffic from year 14 of the study period, corresponding to the onset of physical capacity on the existing line in year 13 with the "high" freight forecast level. The diversion cost is made up of Average Truck Operating Cost and Additional Road Cost as defined in Section 4.4; three road configurations are considered, also as previously defined (Section 4.4). The additional road costs with Configuration 1 are zero by definition and those for Configuration 3 are small and negative because the faster four lane highway effectively reduces the Average Truck Operating Cost. Note that by year 20 the annual Average Truck Operating Cost is about $16 million and the Additional Road Cost for Configuration 2 (the least upgraded highway) is about $6.5 million.

Table 5.14 expresses as an NPV the total resource cost(1) during the study period of transporting rail's modal share of interstate traffic, including the resource cost of diverted traffic when physical capacity is reached on the railway line. Results corresponding to "high" and "expected" forecasts(2) and three road

(1) Defined in Section 4.4.

(2) With the "low" forecast, physical capacity of the line with 1100 tonne trains is not reached by the end of the study period.

TABLE 5.13 - SYDNEY-MELBOURNE ANNUAL ROAD OVERFLOW COST: EXISTING RAIL AND HIGH FORECAST

($ million)

Year of study period (a)	Overflow in 20 tonne trucks per day	Road configuration 1 (b)			Road configuration 2 (c)			Road configuration 3 (d)		
		Average truck operating cost	Additional road cost	Total	Average truck operating cost	Additional road cost	Total	Average truck operating cost	Additional road cost	Total
14	15	0.99	-	0.99	0.99	0.20	1.19	0.99	-0.06	0.93
15	48	3.16	-	3.16	3.16	0.71	3.87	3.16	-0.18	2.98
16	83	5.47	-	5.47	5.47	1.38	6.85	5.47	-0.31	5.16
17	120	7.91	-	7.91	7.91	2.26	10.17	7.91	-0.45	7.46
18	160	10.54	-	10.54	10.54	3.38	13.92	10.54	-0.60	9.94
19	203	13.37	-	13.37	13.37	4.75	18.12	13.37	-0.74	12.63
20	248	16.34	-	16.34	16.34	6.44	22.78	16.34	-0.87	15.47

(a) Year 1 is 1973.

(b) Road upgraded to maintain the present average delays over the study period.

(c) Road maintained in its present state over the study period.

(d) Road upgraded to four lane standard by year 14.

TABLE 5.14 - SYDNEY-MELBOURNE RESOURCE RESULTS: 1100 GROSS TONNE TRAINS

($ million)

Forecast	Road configuration[(a)]	Interest rate 7%: NPVs of total resource costs – Upgraded line[(b)]	7%: Existing line	7%: Net resource cost savings	10%: NPVs of total resource costs – Upgraded line[(b)]	10%: Existing line	10%: Net resource cost savings	12%: NPVs of total resource costs – Upgraded line[(b)]	12%: Existing line	12%: Net resource cost savings
Expected	1	170.79	177.55	6.76	139.58	144.22	4.64	124.20	127.83	3.63
	2	170.79	178.40	7.61	139.58	144.72	5.14	124.20	128.18	3.98
	3	170.79	177.41	6.62	139.58	144.14	4.56	124.20	127.77	3.57
High	1	196.15	210.28	14.13	158.53	167.84	9.31	140.07	147.21	7.14
	2	196.15	215.77	19.62	158.53	171.16	12.63	140.07	149.60	9.53
	3	196.15	209.33	13.18	158.53	167.27	8.74	140.07	146.80	6.73

(a) Road Configuration 1. Road upgraded to maintain the present average delays over the study period.
2. Road maintained in its present state over the study period.
3. Road upgraded to four lane standard by year 14.

(b) CTC1 introduced in year 1, and 6 loops introduced in year 5.

NOTE: There is no road/rail interaction in the case of the low forecast.

configurations are shown for a range of discount rates. Spillover to sea only affects the results in the "high" forecast case by some 10 to 15%. The difference between the NPVs corresponding to existing and upgraded lines is shown as the net resource cost saving from upgrading; as would be expected, savings are highest for the least upgraded road configuration, Number 2. It can be noted that road Configurations 1 and 3 give rather similar results. Configuration 1 can be considered as a delayed version of Configuration 3 and it is not unreasonable to assume that it represents the most likely pattern of the actual road improvement program. For this reason Table 5.15 only considers road Configuration 1. This table isolates the NPV of the cost of upgrading from the NPVs quoted in the previous Table and derives corresponding values of benefit/cost ratio. Benefits are simply calculated as the difference between the NPVs of costs excluding upgrading capital for the existing and upgraded lines respectively. Benefit/cost ratios over a range of 1.7 to 5.2 are indicated, depending on forecast level and discount rate. Only for the "low" forecast does the benefit/cost ratio drop to less than 2.0. It should be remembered here that these ratios represent a lower estimate because of the way physical capacity has been defined (Section 4.2.1), indicating that rail upgrading is well worthwhile, irrespective of the state of the Hume Highway.

TABLE 5.15 - SYDNEY-MELBOURNE BENEFIT TO COST RATIOS WITH ROAD CONFIGURATION 1[(a)]

Forecast	Interest rate					
	7%		10%		12%	
	Discounted cost C ($ million)	B/C	Discounted cost, C ($ million)	B/C	Discounted Cost, C ($ million)	B/C
Low	3.07	2.21	2.83	1.88	2.69	1.71
Expected	3.26	3.07	3.04	2.53	2.91	2.25
High	3.40	5.16	3.22	3.89	3.01	3.37

(a) Road upgraded to maintain the present average delays over the study period.

NOTE: Upgraded line: CTC1 introduced in year 1, and 6 loops introduced in the best years (Table 5.9).

CHAPTER 6 CONCLUSIONS

An increase in the average gross train weight from the present 800-900 tonnes to 1100 tonnes for interstate general freight is shown to lead to a better utilisation of motive power and track capacity; the savings are comparable to those from upgrading. The higher train weight would be within the capability of one 2237 kW locomotive on the Victorian section and two 2237 kW locos on the N.S.W. section. The higher motive power requirements of the N.S.W. section are reflected as higher train operating costs; allocation of interstate freight revenues on a distance basis is therefore inappropriate.

With 1100 tonne trains, and the expected traffic growth, the Victorian section would reach its limit of physical capacity by 1989/90. The N.S.W. section would do so two years later.

The most effective way to reduce congestion delays and increase the capacity on the Victorian section is to add six crossing loops at 72, 130, 165, 194, 263 and 296 km from Melbourne. The loops should be operational by some time between 1977 and 1982, depending on the rate of traffic growth. If present train weights are retained, the loops should be introduced immediately. For N.S.W., the most effective measure is Centralised Traffic Control of the Albury-Junee section, with all present loops between Bomen and Table Top extended to 915 metres. Irrespective of traffic growth or train weight, this upgrading should be introduced immediately.

The commercial rate of return on the upgrading investment is in excess of 30% for both the Victorian and N.S.W. sections.

If these measures are not implemented, increased interstate truck traffic on the Hume Highway would be expected from the mid to late 1980s, depending on freight traffic growth.

The social benefit/cost ratio of rail upgrading investment, ignoring any congestion effects on the Hume Highway if the rail measures are <u>not</u> implemented, is in the range 1.7 to 5.2 depending on discount rate and traffic growth. With the expected growth and at a discount rate of 10%, the B/C ratio is 2.5.

ANNEX A THE MELBOURNE-SYDNEY LINE AND ITS TRAFFIC

A.1 DESCRIPTION OF EXISTING LINE

The Melbourne-Sydney line has been divided into three sections : Melbourne-Albury, Albury-Junee, and Junee-Sydney.

The Melbourne-Albury section is single track but has the advantage of operating under Centralised Traffic Control (CTC). Furthermore all crossing loops are of sufficient length as shown in Figure A.1.

The Albury-Junee section is also single track and relies on a mechanical token system of safeworking (the token being called a "staff"). This means that a train proceeding straight through can exchange staffs automatically (Figure A.2) without slowing down. However, the train being passed has to wait an additional time after the through train has passed to allow the signalman to walk to the driver for the purposes of exchanging staffs (Figure A.3). This extra delay is termed "safeworking delay" and is defined as the time difference between the departures of the through train and of the delayed train. An additional problem with this section is the inadequate length of many of the crossing loops. Figure A.4 is a schematic layout of the section between

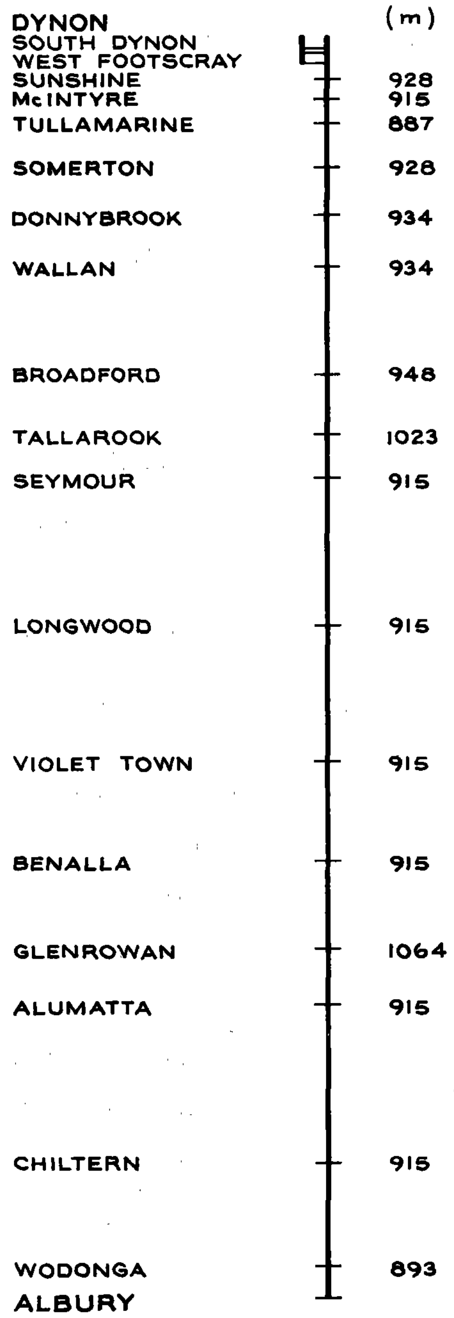


FIGURE A.1

POSITION AND LENGTH OF EXISTING LOOPS
MELBOURNE - ALBURY

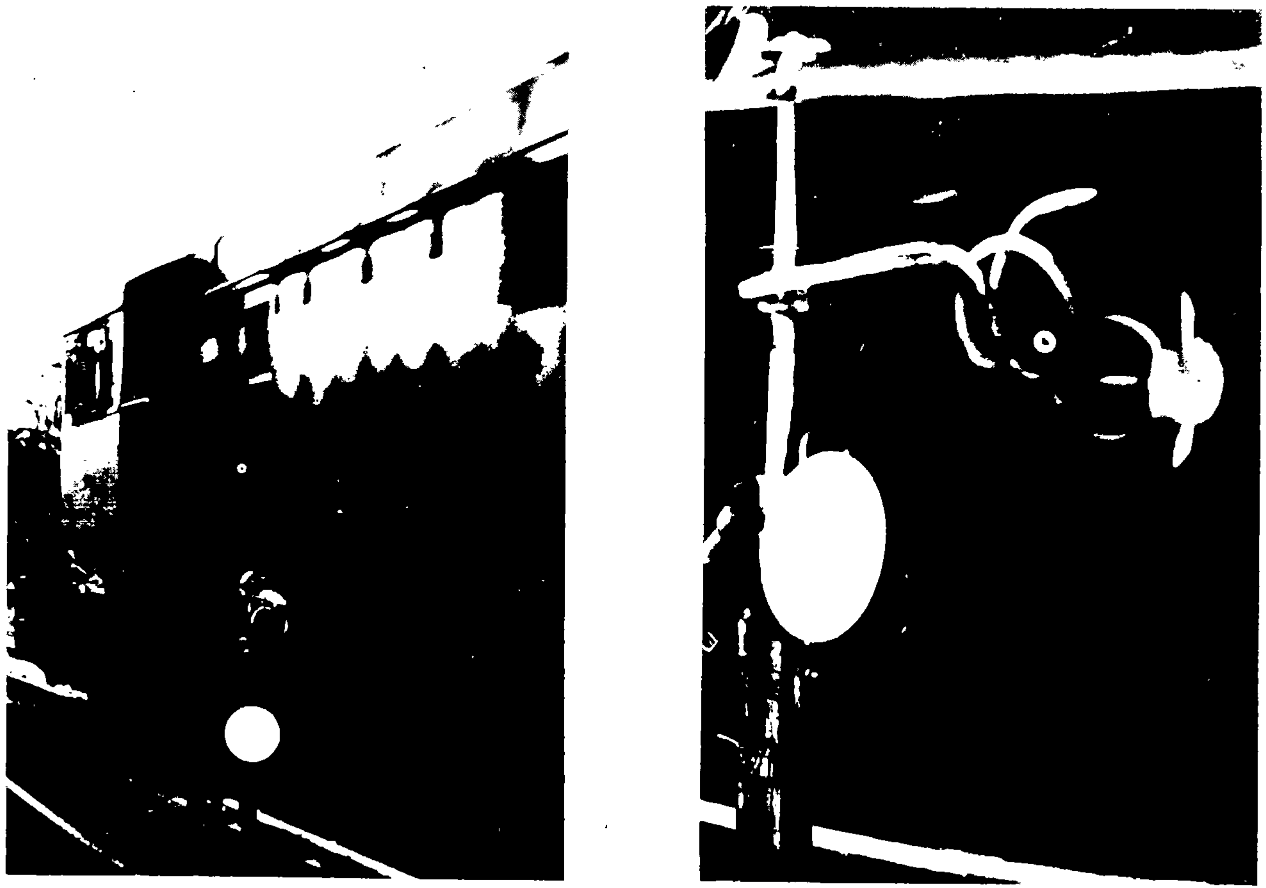


FIGURE A.2 AUTOMATIC EXCHANGE OF STAFF

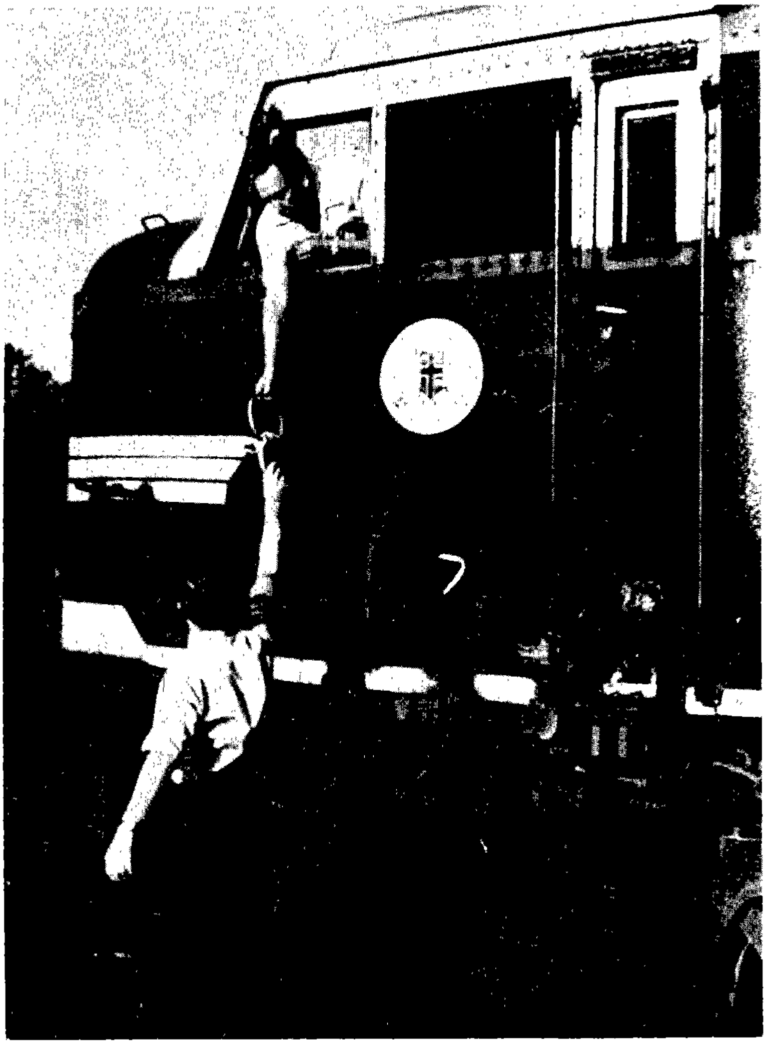


FIGURE A.3

MANUAL EXCHANGE OF STAFF

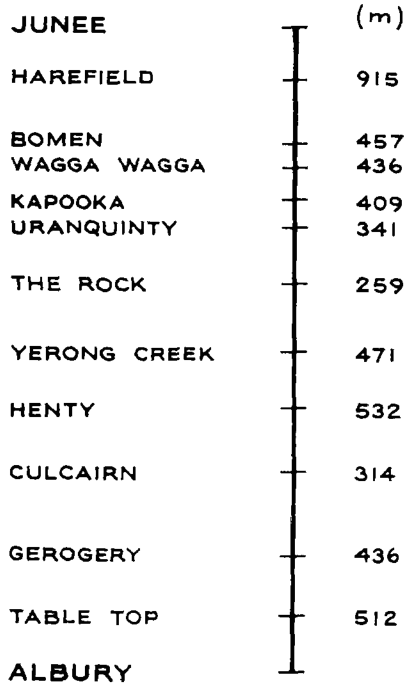


FIGURE A.4

POSITION AND LENGTH OF EXISTING LOOPS

ALBURY - JUNEE

Albury and Junee showing the position and length of the existing crossing loops.

The Junee-Sydney section is already double track with mixed mechanical and electrical signalling. Although there are problems associated with the numerous 1 in 40 grades in the down direction and some of the refuge loops which are inadequate in length or are of the set back type, a preliminary analysis has indicated that this section is unlikely to become congested during the study period. For this reason no further reference will be made to the Junee-Sydney section in this Annex.

A.2 PRESENT TRAFFIC

For the purposes of computer simulation, the present traffic has been divided into 5 different priority classes:

Priority Class	Traffic Type
1	All passenger
2	Express Interstate Freight
3	Other Interstate Freight
4	Steel
5	Intrastate Freight

The distribution of this traffic over train classes for a typical busy day in 1972 is shown in Table A.1.

TABLE A.1 - NUMBER OF TRAINS PER PRIORITY CLASS

Section	Priority Class					Total
	1	2	3	4	5	
Melbourne-Albury	6	10	6	5	-	27
Albury-Junee	8	12	5	5	12	42

The Melbourne-Albury standard gauge section only carries the interstate traffic; intrastate traffic uses the broad gauge line which runs parallel to the standard gauge line. In addition to interstate traffic, however, the Albury-Junee section also carries a considerable volume of intrastate traffic.

There is a slight discrepancy in the numbers of interstate freight trains (Classes 2 and 3 in Table A.1) in Victoria and New South Wales because they are not unit trains and differences in the operating policies of the two States result in considerable reorganisation of this traffic at the border.

ANNEX B MODELS USED IN EVALUATION

This annex briefly outlines the types of models available for the required evaluations, and examines the selected models in greater detail.

B.1 MODELS FOR ESTIMATING TRAIN DELAYS

The problem of estimating traffic delays to trains is essentially one of timetabling. Generally speaking, timetabling trains is an evolutionary process; changes tend to be gradual, mainly because train operation is subject to many constraints, not least of which are those associated with the terminals at the end of the journey. Overnight express passenger trains for instance would leave at about 7 pm and arrive at about 9 am. Similar constraints exist for interstate freight trains. So compilation of timetables has tended to remain, in Australia at least, a manual process concerned with small adjustments against a background of breadth of knowledge of railway operations. This approach would be impractical for line upgrading investigations involving significant and numerous changes to the configuration of the line, composition and volume of traffic. For this reason various ways of automating the computation of delays were considered, some of which are described in this Annex.

B.1.1 Analytical Models

Analytical models for calculating train delays on a single track railway have been developed by a number of authors including Petersen (1). These models are limited by such common basic assumptions as:

- departure times for trains are independent random variables uniformly distributed over the day,
- sufficient passing loops are always available at the ends of each section, and
- all loops are of sufficient length to accommodate any train.

Consequently it is impossible to investigate in detail the effects of train scheduling, or the introduction of small upgrading measures such as a new passing loop or an extension to an existing loop. In order to achieve the required accuracy we have resorted to a simulation model.

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(1) E.R. Petersen, 'Over-the-Road Transit Time for a Single Track Railway', Transportation Science, 8, 1 (1974), pp 65-74.

B.1.2 Simulation Models

The BTE investigated several models including the Train Working Simulator (TWS) written by the NSWPTC and the Canadian National Railways' SIMTRAC. Unfortunately these models had unacceptable limitations(1):

- TWS assigns strict priorities to trains determined simply by the order of the trains' appearance in the input data, resulting in unrealistically large delays being forced on lower priority trains, whereas

- SIMTRAC is a very detailed simulation with greater running time and storage requirements and would also have difficulties with the high traffic densities of interest to the BTE.

To overcome these problems, a program called Single Track Simulation (STS) was developed as a joint

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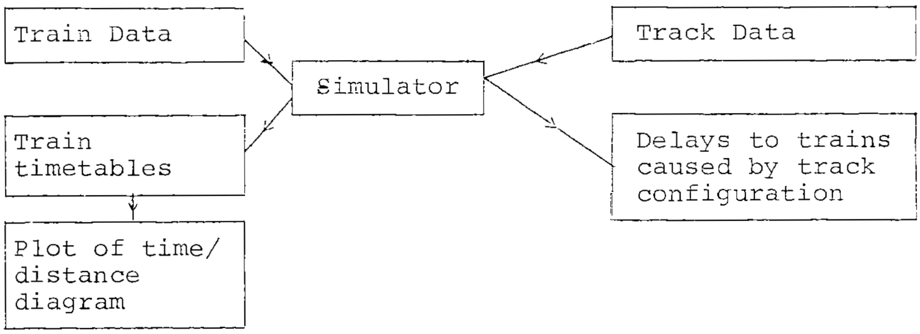
(1) D.A. Rudd & A.J. Storry, 'Single Track Railway Simulation - New Models and Old', IBM Systems Development Institute, Canberra, SDI 0058 (December 1974).

project by the BTE and IBM Systems Development Institute. The organisation of the STS model is represented by the following diagram:



The Railway line is described as a series of sections of track separated by signals; passing loops of specified length existing at some of these signals. Each train, of given length, speed group and priority class, should leave its station of origin at the scheduled departure time and proceed along the track, the simulation deciding whether to delay or continue that train depending on interaction with other trains, until the train reaches its destination.

Upon reaching a signal the train may stop on its current section of track, enter the next section or enter a passing loop. The train is allowed to proceed only if this will not cause a jam further up the line or delay another train, ahead or behind, which should have priority according to the method used for resolving crossing and passing conflicts. Factors considered in this decision are:

- length, position and availability of passing loops,
- length, position and destination of trains,
- time for each train to traverse each section,
- signalling method, and
- train priorities and delays as required by conflict resolution method.

The decisions are made in chronological sequence so no decision will negate a previous decision. A complete documentation of the STS program is given by Rudd and Storry[1].

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(1) D.A. Rudd & A.J. Storry, 'Track Railways Simulation (STS) - Documentation', IBM Systems Development Institute Canberra, SDI 0057 (December, 1974).

B.1.3 Adjustment of Simulation Parameters to Match Train Operating Procedures

Whenever a crossing conflict or a passing conflict occurs, the resolution of this conflict means that a train must incur a delay by entering a passing loop or by waiting on a section of track. STS determines which of the two trains will suffer this delay by calculating each train's priority from one of three functions:

(a) Accumulated Delay x Weighting Factor ÷ Progress,

(b) Current Delay x Weighting Factor, and

(c) Accumulated Delay x Weighting Factor,

where Progress is the minimum of the number of sections traversed and an upper limit coded in the input data.

The simulation was calibrated for the actual delay statistics extracted from the train diagram for Wednesday/Thursday, 15th of December 1971, on the

Albury-Junee section of the Sydney-Melbourne link[1]. This was done by selecting an appropriate function for resolving conflicts together with suitable values for the weighting factors of the five priority classes of trains. Several sets of values were considered for the weighting factors and are given in Table B.1.

TABLE B.1 - WEIGHTING FACTORS

Case	Priority Class				
	1	2	3	4	5
1	200	100	150	50	1
2	500	200	300	100	1
3	200	100	150	15	1
4	200	100	150	10	1
5	40	12	11	5	3

Case 5 values were estimated from the actual mean delays using the following argument. The train controller allocates delays in an attempt to optimise the traffic flow from the railways point of view, and the actual mean delays reflect his perceived weighting factors for the different priority classes. In this

(1) Bureau of Transport Economics 'Analysis of the Differences Between Simulated Train Movements and Actual Movements' (to be published).

case, if it is assumed that his judgement is based on Function (c), we expect the value of:

Mean Actual Delay x Weighting Factor

to be the same for all priority classes.

Initial results based on the three different functions all compared favourably with the actual delays but Function (a) was selected for all subsequent simulations because it represents a compromise between Functions (b) and (c).

The means and standard deviations of delays, in minutes, taken over all trains in each class, for the actual and simulated movements are given in Table B.2.

To assess the performance of STS, these mean simulated delays in each class have been divided by the mean actual delays for the same class. The resulting "normalised delays" have then been averaged over all trains and the deviations of the averages from 1 measured with the t-test as shown in Table B.3.

The t-test is a test for differences in means only and so two additional tests, the Chi-squared and the Kolmogorov-Smirnov (K-S) tests were used to measure differences between the distributions themselves. The frequency distributions of the normalised delays were calculated on the intervals: 0 , (0,0.5], (0.5, 1.0], ..., (3.5, ∞). However, it was necessary to combine the frequencies above 1.5 for the Chi-squared test. The results are also shown in Table B.3.

TABLE B.2 - MEANS AND STANDARD DEVIATIONS OF DELAYS PER TRAIN

(minutes)

Case	Priority Class				
	1	2	3	4	5
Actual	7 (6)	23 (15)	25 (11)	53 (52)	92 (132)
1	15 (21)	30 (29)	48 (23)	53 (40)	93 (95)
2	21 (15)	31 (23)	47 (17)	33 (35)	72 (73)
3	13 (20)	23 (20)	52 (18)	71 (42)	72 (95)
4	15 (11)	25 (25)	25 (12)	76 (31)	56 (57)
5	9 (12)	30 (21)	41 (19)	45 (26)	46 (39)
No. of trains in each class	8	12	5	5	12

NOTE: Parenthesised figures are standard deviations.

TABLE B.3 - RESULTS OF STATISTICAL TESTS FOR DIFFERENCES BETWEEN SIMULATED AND ACTUAL DELAY DISTRIBUTIONS

Case	Statistic Values		
	t-test	Chi-Squared	K-S[a]
1	1.45	3.85	4
2	1.78	6.91	6
3	0.86	4.86	4
4	0.87	4.05	4
5	0.27	0.254	2

Critical Values			Significant
K-S	Chi-Squared	t-test	levels
		1.67	5%
11.2		1.30	10%
10.5			15%
9.8	5.99		20%
	4.88		30%

(a) Kolmogorov-Smirnov test.

With the possible exception of Case 2, there is no significant difference between each simulated performance and the actual performance. Nevertheless, since each simulation is perfectly reproducible, we might, with some confidence, feel that a simulation case with lower statistic values would be better. This prompted a choice of Case 5.

B.1.4 Effect of Stochastic Variations in Departure Times on Delays

The fluctuations in the actual day to day timetabling of trains have not been included in STS, although an estimate of their effect on delays was obtained by the following procedure.

An analysis of the lateness of Express Goods trains and Interstate Passenger trains on the Melbourne to Albury line for the month of October 1972[1], produced continuous probability distribution functions for the deviations from the scheduled arrival times at Albury. Random sampling from these distributions then gave the required variations in departure times for the present Albury-Junee section, and simulations over the

(1) Bureau of Transport Economics, 'Analysis of Lateness of Trains on the Melbourne to Albury Run' (to be published).

sample resulted in mean delays which could be compared with simulation delays obtained using the scheduled departure times.

In order to fit continuous distributions to the empirical distributions, however, it was necessary to postulate a model in which trains are either dead on time with a certain probability p, or late with a probability q=1-p. If a train is late, then the number of minutes late follows a continuous distribution. The best fit of the Erlang family was found to be an exponential distribution and appropriate values of the exponential parameter were estimated by the Maximum Likelihood method. The results are given in Table B.4.

Since it is expected that variations in departure times will produce the greatest effect on delays at high traffic densities, the simulations covered a range of densities approaching the capacity of the line. For each train appearing in the simulation input data, one random number determined whether that train departed on schedule or was late, and a second random number then determined the number of minutes late from the exponential probability distribution. The results were averaged over the sample of 8 runs, and are shown in Table B.5.

TABLE B.4 - LATENESS PROBABILITY DISTRIBUTIONS

Probability Distribution Parameters	Train Type	
	Passenger	Goods
Probability of being on time, p	0.716	0.651
Parameter of exponential distribution for late trains	0.0525	0.040

TABLE B.5 - SIMULATED MEAN DELAYS PER TRAIN WITH VARIATIONS IN DEPARTURE TIMES

(minutes)

Train Type	Total No. of Trains		
	48	51	54
Passenger	26 (17)	28 (21)	53 (41)
Goods	57 (53)	67 (62)	86 (78)

NOTE: Parenthesised figures are for scheduled departures, i.e. no late trains.

Thus stochastic variations in departure times can lead to an increase of about 30% in passenger train delays, and an increase of about 10% in goods train delays.

B.2 A MODEL FOR EVALUATING UPGRADINGS

Once the delay patterns of each upgrading have been determined by the Single Track Simulator (Section B.1.2), the upgradings can be compared in order to find the best upgrading sequences together with their optimal phasing. For this purpose a computer program was developed by the BTE (DYNATREE), which allows the processing of a large number of cases within a relatively short period of time.

DYNATREE is organised in three stages:

(a) editing and condensing data for a set of upgrading increments;

(b) generation of each possible sequence of upgradings, and collation of the relevant upgrading data, in preparation for submission to the dynamic program; and

(c) the dynamic programming stage, which efficiently determines the optimal years of introduction for the various upgradings in the sequence under consideration using the criterion of net present value maximization.

Dynatree can consider any number of separate modes[1] (e.g. sea, rail, road), and any number of separate traffic types[2] (e.g. train classes) can be assigned to a mode. Overflow between different traffic types and modes is permitted, and the overflow assumes the cost and revenue structure of the receiving type and mode. Any mode can be upgraded, but only one upgrading can be implemented in any year. (e.g. upgrading road in year 5 precludes any other upgrading to rail or road being undertaken in that year).

Each upgrading is completely described by its delay patterns, its capacity and its cost structure. The delay patterns are given year by year and for each traffic type carried on the mode. The capacity of the

---

(1) A mode is defined as a set of traffic types whose delay and cost structures are totally determined by an upgrading implemented on that mode.

(2) A traffic type is a homogeneous traffic class with a single forecast of traffic flow and a uniform cost and revenue structure.

upgrading is given in terms of upper limits to the daily traffic flows, for each of the mode's traffic types. The cost structure takes into account such items as crew cost per hour, signal maintenance, fuel cost, capital cost of the upgrading, revenue earned etc. (see Annex D). The information is edited and compressed into year by year net costs, for each upgrading and possible traffic flow pattern. This condensed information is then stored in a master array which is referred to in stage (b) of the processing.

Once all the data pertaining to the basic upgrading increments is processed, the second phase of the algorithm follows, which generates all possible sequences of upgradings from the set of upgradings described in stage (a). The upgradings considered may refer to any mode; for example the sequence, u_1, u_2, u_3 may represent road upgrading u_2 and rail upgradings u_1 and u_3.

When an upgrading sequence has been generated, it is checked to make sure that it does not violate any user specified constraint. For example, if the user has specified that u_1 must occur in year 10, but that u_2 must occur before year 6, or that u_3 cannot follow u_1, then the sequence u_1, u_2, u_3 is rejected. If the sequence is disallowed, then another is generated and checking starts again. However, if the sequence is allowed, the corresponding cost benefit streams are copied from the master storage matrix (generated in stage (a)) into the dynamic programming matrix.

The dynamic programming algorithm is then used to efficiently determine the optimal phasing of the sequence and the associated net present value. The results are printed and then the program returns to the sequence generator for a new sequence, until all permissible sequences have been processed. The major logical sequence of DYNATREE is illustrated in Fig. B.1.

DYNATREE is reasonably flexible and allows a great variety of cost structures and intermodal flow patterns to be considered. Both resource cost and commercial criteria can be used and very complex upgrading sequences can be constructed with very little effort on the part of the user.

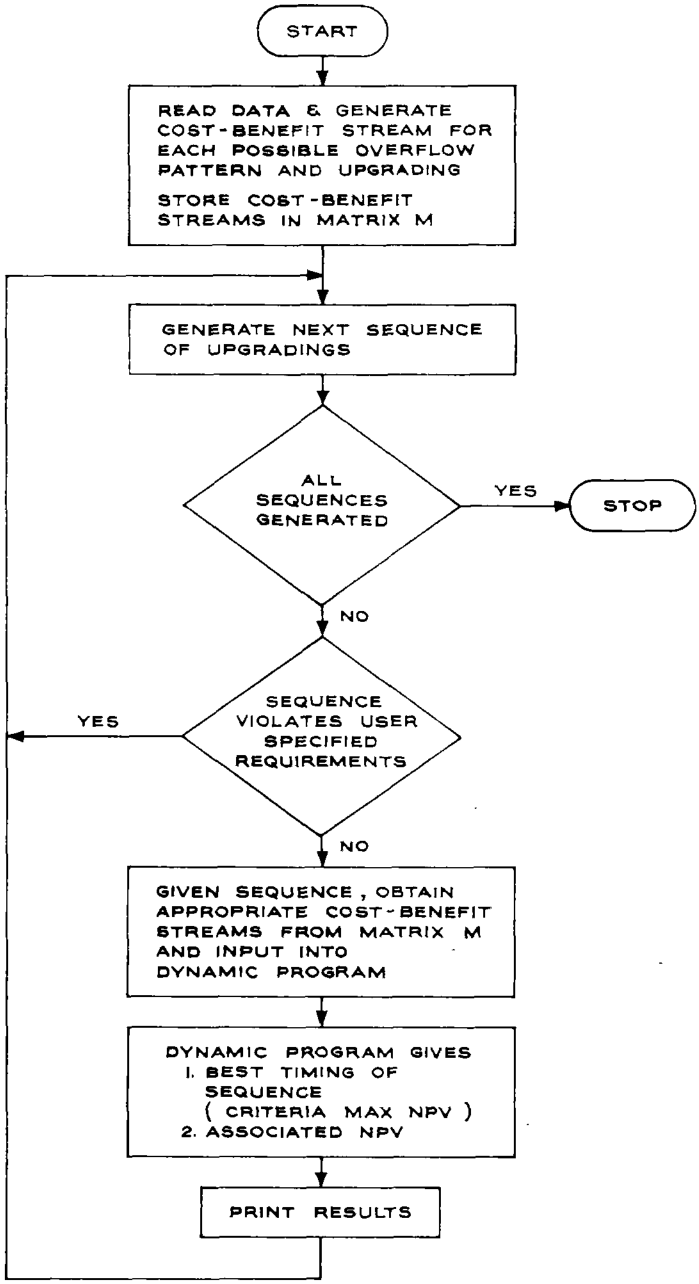


FIGURE B.1

DYNATREE SYSTEMS CHART

ANNEX C COSTS (1973)

C.1 CAPITAL COSTS OF LOCOMOTIVES, ROLLING STOCK AND GANTRIES

C.1.1 Common Data

The following information is common to all the train configurations considered.

Locomotives

Capital Cost	: 1491 kW : $300,000
	2237 kW : $400,000
Annual distance travelled	: 193,200 km (data obtained from Victorian Railways relating to main line 1491 kW locos)
Lifetime	: 20 years

Rolling Stock

Capital Cost	: flat bogie wagon: $17,000
Annual distance travelled	: 193,200 km(1) (unit trains are assumed to carry all growth in traffic)

---

(1) Note that locomotives and rolling stock both travel the same annual distance. This is reasonable considering that locos are being serviced 20% of time, while rolling stock is only serviced 5% of time.

Lifetime	: 20 years
Number of wagons (1) required for	: 800 tonne (gross) train: 20 1100 tonne (gross) train: 28 1400 tonne (gross) train: 35

Gantries

Capital cost of each facility	: $0.75 million
Loading or unloading time	: 3 minutes/container
Time taken for placing the train and brake checking	: 1 hour

C.1.2 Particular Locomotive Requirements

For all configurations considered, the same number of locomotives are required for both directions of travel.

800 tonne trains

2 x 1491 kW loco Sydney-Albury, 652 km

1 x 1491 kW loco Albury-Melbourne, 311 km

---

(1) In calculating train length, the present average wagon length of 14m was assumed. Recent trends indicate that unit trains would use 20m wagons; thus train lengths quoted in this report, for a given train gross weight, will be understated towards the end of the study period. However, the net effect of this discrepancy on the results of the evaluation is negligible.

1100 tonne trains

2 x 2237 kW loco Sydney-Albury, 652 km

1 x 2237 kW loco Albury-Melbourne, 311 km

1400 tonne trains

3 x 1491 kW loco Sydney-Albury, 652 km

2 x 1491 kW loco Albury-Melbourne, 311 km

C.1.3 Train Capital Costs

The capital costs of locomotives and rolling stock (/km/train) for the particular cases studied have been calculated from the above data and are shown in Table C.1. In order to obtain annuities from these figures it is necessary to multiply them by an interest rate dependent factor, as detailed beneath the table.

C.1.4 Gantry Capital Costs (Melbourne-Sydney line)

Capacity of gantry facility

On the basis of 2 containers per bogie wagon[1], gantry capacity varies with gross train weight as follows:

---

(1) This gives an upper limit for the number of containers per train because a unit train may carry some empty wagons due to fluctuations in demand and sometimes to an imbalance in the directional freight flows.

TABLE C.1 - MOTIVE POWER AND ROLLING STOCK CAPITAL

(/km/train)

($)

Gross Train Weight (tonnes)	Locos	Rolling Stock	Total
	SYDNEY-ALBURY		
800	3.106	1.760	4.865
1100	4.141	2.464	6.605
1400	4.658	3.080	7.738
	ALBURY-MELBOURNE		
800	1.553	1.760	3.313
1100	2.070	2.464	4.534
1400	3.106	3.080	6.185
	SYDNEY-MELBOURNE		
800	2.604 [(a)]	1.760	4.364
1100	3.473	2.464	5.937
1400	4.157	3.080	7.237

(a) Calculations are based on a distance weighted average, e.g.

$$\frac{(2 \times 652 + 311)\ 300,000}{963 \times 193,200} = 2.604$$

NOTE: Figures in the above table are to be multiplied by

$$\frac{i}{1-(1+i)^{-n}}$$

to obtain an annual cost, where i is the interest rate/annum, and n is the train lifetime in years (n=20)

Train weight (gross tonnes)	Gantry capacity (trains/day)
800	8.0
1100	6.3
1400	5.3

Example: An 1100 gross tonne train carries 56 containers.

Train loading/unloading time $= \frac{56 \times 3}{60}$

$= 2.8$ hours.

Allow a generous 1 hour for placing and brake checking.

Capacity of facility $= \frac{24}{3.8} = 6.3$ trains/day.

Gantry Requirements

TNT and Mayne Nickless both have gantry facilities, each hiring a train each way/day, giving a total of 4 trains/day.

The projected growth in traffic is mainly due to increases in freight forwarder's type of traffic and it can be assumed that the projected growth in traffic will be carried in unit trains using gantry facilities.

As an example, the projected growth with the expected forecast up to 1992 in the case of 1100 tonne trains is equivalent to an additional 19 trains/day (both directions excluding steel). The total number of unit trains in 1992 is then 4 + 19 = 23/day. But the capacity of the existing facilities is 12 trains/day. Therefore one pair of new gantries will be required when the traffic exceeds 12 unit trains/day and another pair when the traffic exceeds 18 unit trains/day.

Using the above reasoning for the various train weights and forecasts new gantry facilities will be required in the years shown in Table C.2.

TABLE C.2 - YEARS IN WHICH NEW GANTRY FACILITIES ARE REQUIRED

Gross train weight (tonnes)	Forecast		
	Low	Expected	High
800	1988	1985 1990	1983 1987 1990 1992
1100	1988	1984 1990	1982 1986 1990 1992
1400	1986	1985 1990	1982 1987 1990

C.2 OPERATING COSTS OF LOCOMOTIVES, ROLLING STOCK AND GANTRIES

C.2.1 Maintenance Costs

Locomotives

The evaluation of locomotive maintenance cost savings presents some difficulties. Locomotive maintenance is dependent upon many factors, some of which are its age, its utilisation and the average load it carries. There are many 1491 kW locos in Australia and for these accurate maintenance costs can be obtained. In general, the maintenance schedule is dependent only on the distance travelled, and this basis was used in preference to the normal published statistic of maintenance cost per 1000 gross ton mile. Maintenance costs for 2237 kW locos are more difficult to obtain, as there are only a few of these units in operation in Australia, and they are all relatively new. However, some allowance can be made for the differing average age of 1491 and 2237 kW loco fleets.

The following data were obtained from Commonwealth and Victorian Railways:

Locomotive Type	Maintenance Cost (cents/km)	Source
GM 1343 kW (1800 hp)	16.2	Commonwealth Rail
CL 2237 kW (3000 hp)	20.4	Commonwealth Rail
SX 1491 kW (2000 hp)	13.5	Victorian Rail
2237 kW (3000 hp)	12.3 (estimate)	Victorian Rail

In view of the scatter in the data and the lack of good information on 2237 kW locomotives, it was assumed that the Victorian maintenance costs of both 1491 kW and 2237 kW locomotives were the same at 15 cents/km.

For New South Wales the NSWPTC figure for 1973 was used giving a maintenance cost for both 1491 kW and 2237 kW locomotives of 31 cents/km.

Rolling Stock

Data on maintenance for type SFX flat bogie wagons were collected by Victorian Railways and resulted in a figure of 1.24 cents/wagon km.

For New South Wales the NSWPTC figure of 1.99 cents/wagon km was used.

Track

The following formula for track maintenance cost, as a function of gross tonnage only, was derived by the BTE from a regression analysis of N.S.W. data:

$$M_c = kT^{0.28},$$

where: M_c is the total annual maintenance cost per kilometre of track ($),

T is the annual gross tonnage (millions of tonnes), and

k is a constant for particular train and track characteristics.

The annual marginal maintenance cost per kilometre/million gross tonnes is $\frac{dM_c}{dT}$, but has been approximated by the chord gradient:

$$\frac{M_c(T_2) - M_c(T_1)}{T_2 - T_1}$$

where the gross tonnage range studied is from T_1 to T_2.

Taking $k = 3.80 \times 10^3$ as appropriate for the Melbourne-Serviceton line and its traffic gives:

(a) Single Track

$T_1 = 2.23$ and $T_2 = 5.16$,

Annual Marginal Maintenance Cost = 0.04 cents/km /gross tonne.

(b) Double Track

On the basis of equal tonnages in both directions,

$T_1 = 1.11$ and $T_2 = 2.58$,

Annual Marginal Maintenance Cost = 0.07 cents/km (total of both directions) /gross tonne.

C.2.2 Fuel Costs

To determine fuel costs for different train weights, reference has been made to an internal BTE publication: "Train Performance Characteristics". The following demonstrates that, for the purpose of this study, fuel consumption can be considered as being directly proportional to total train mass.

Freight train resistance on level tangent track is given by (Eqn 2.2)

$$R_R = 6.4 + 129/w + 0.03V + KV^2/wn_a,$$

where: R_R is running resistance (N/tonne),

w is mean axle load (tonne),

V is speed (km/h),

K is a constant depending on wagon type, and

n_a is the number of axles per wagon.

Hence the total train running resistance is WR_R, where W is the total train mass (tonnes), and at constant speed

$$T = WR_R$$

where T is the tractive effort (kN). T may be expressed in terms of the tractive power P (kW) as (Eqn 4.4)

$$T = 3.6\ P/V$$

i.e. $$P = VT/3.6$$

The fuel consumption C (kg/h) is given by (Eqn 5.1)

$$C = bP + c,$$

where: b is specific fuel consumption (kg/kWh) in terms of wheel tread power, and

c is idling or coasting fuel consumption (kg/h).

Substituting from the above equations then gives

$$C = \frac{bVW}{3.6}\ (6.4 + 129/w + 0.03V + KV^2/wn_a) + c$$

The last term in this equation may be neglected for the speed and train masses considered, since the appropriate value for c is approximately 20.4.

Therefore, assuming equal axle loading for all trains, the fuel consumption is directly proportional to gross train mass, at a given speed. The assumptions that axle loading and average speed do not vary with train mass are reasonable in the case of this particular study.

The Victorian Railways have supplied the reference point:

Locomotive Fuel Cost = 18.6 cents/1000 gross tonnes/km
(9 cents/gallon)

which used in conjunction with the above conclusion gives:

Gross Train Weight (tonnes)	Locomotive Fuel Costs (cents/km)
800	14.9
1100	20.5
1400	26.1

C.2.3 Crew Costs

A freight train crew comprises 3 men and the cost has been based on an hourly rate of $5 per crew member.

The passenger train crew cost has been calculated from annual figures supplied by Victorian Railways:

'Southern Aurora'	\$ 735,000
'Spirit of Progress'	\$ 488,000
'Intercapital Daylight'	\$ 326,000
Total annual crew cost:	\$1,549,000
Average annual crew cost:	\$ 516,333

Assuming 365 trips/annum an average transit time of 13 hours then gives:

$$\text{Passenger Train Crew Cost} = \frac{516{,}333}{365 \times 13}$$

$$= \$109/\text{hour}$$

C.2.4 Train Operating Costs

The marginal freight train operating costs (/km) for the particular cases studied have been calculated from the above data and are shown in Table C.3.

TABLE C.3 - MARGINAL FREIGHT TRAIN OPERATING COSTS/KM

($)

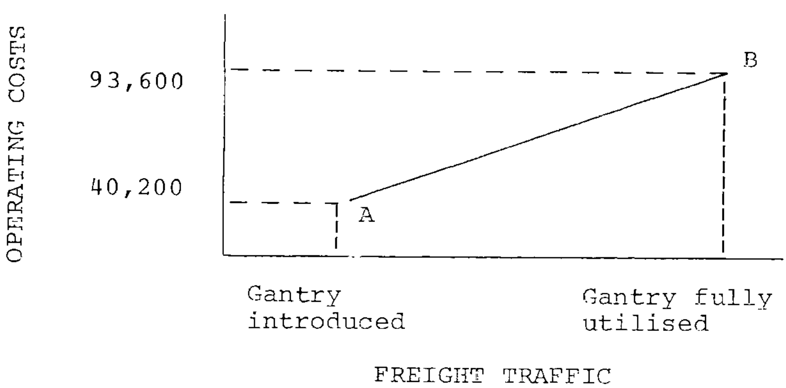
Gross Train Weight (tonnes)	Sydney-Albury	Albury-Melbourne	Sydney-Melbourne
800	1.816	1.195	1.616 [(a)]
1100	2.161	1.481	1.942
1400	2.798	1.903	2.509

(a) Calculations are based on a distance weighted average, e.g.

$$\frac{1.816 \times 652 + 1.195 \times 311}{963} = 1.616$$

C.2.5 Gantry Operating Costs (Sydney-Melbourne)

The operating costs per annum for a single gantry facility vary with utilisation as shown by the line AB in the figure below.



The above costs are based on estimates of manpower requirements for operating the 4 gantries which are planned for the Enfield goods yards (NSWPTC). For 24 hours running, 3 shifts are needed, each made up of:

4 x 1 gantry operator + 1 for relief (at $5,500, 1971 wages)

4 x 1 Dogman + 1 for relief (at $4,500, 1971 wages)

4 x 1 yard supervisor (at $6,000, 1971 wages).

The average annual manpower cost per gantry is:

$$\frac{(5 \times 5,000 + 5 \times 4,500 + 4 \times 6,000)}{4} \times 3 = \$55,500.$$

Other operating costs, such as power cost and repair and maintenance costs are estimated to amount to $22,500 (1971). Adjusting the total by 20%, a figure of $93,600 is obtained corresponding to point B (1973 prices).

The figure corresponding to point A is obtained by allowing for 1 shift backed up by 1 relief team. It is then assumed that gantry operating costs will vary linearly between A and B over the years. In reality, the costs are expected to follow a step function, however, in terms of net present value calculation the linear approximation should give a reasonable estimate of gantry operating costs.

C.3 OVERFLOW COSTS

C.3.1 Cost of Overflow to Road

The truck costs were obtained from firms running a semi-trailer shuttle service on the Hume Highway between Melbourne and Sydney[1]. They are based on 20 tonne/5 axle trucks achieving an average speed of 56 km/h and travelling 159,000 km each year. The costs relevant to this study are as follows:

Truck capital (excluding sales tax)	$40,800
Truck life	5 years
Operating costs per vehicle km (cents)	
Fuel, wholesale less excise at 22 cents/gallon	2.80
Oil and maintenance	1.24
Tyres (excluding tax)	1.49
Wages (excluding overtime)	8.88
Workers compensation	1.06

(1) Bureau of Transport Economics Report 'A Study of Intersystem Railway Rating Practices with Particular Reference to the Riverina Area of N.S.W.' (Canberra, to be published).

Road maintenance cost (1) at 0.0213 cents/tonne km	0.43
	15.90

Total operating cost per vehicle km: 15.90 cents

C.3.2 Cost of Overflow to Sea

For the purposes of this study it was assumed that in the long run the rates charged for coastal shipping will just about cover the costs involved in transporting the general goods traffic by sea. The 1974 rate for carrying a full container weighing a minimum of 15 tonnes between Sydney and Melbourne was $12.81/tonne. Adjusting this rate for 1973, a figure of about 1.24 cents/tonne km is obtained as an estimate of the cost of transporting excess rail traffic by sea.

C.4 JUNEE-ALBURY UPGRADINGS

C.4.1 CTC Scheme 1

The capital costs are as follows:

(1) G.J. Both, K.E. Thompson, G.T. Lack, 'The Evaluation of Rural Road and Bridge Improvements', Australian Road Research Board Proceedings, 6, 2 (1972), pp 145-171.

	$
1 existing loop connected to CTC at Harefield	25,000
10 extended loops @ $172,500 each	1,725,000
80 km of track circuits @ $790 per km	63,200
97 km of conductors @ $462 per km	44,814
65 km of conductors @ $3,385 per km	220,025
10 switchlocks @ $10,350 each	103,500
	2,181,539
Add 10% contingencies	218,154
	2,399,693

Total: $2.40 million

Savings accrue from the introduction of CTC because most stations may then operate without signalling staff. The savings in manpower were estimated by the New South Wales Railways to be $180,000 per annum.

C.4.2 CTC Scheme 2

The capital costs are as follows:

	$
1 existing loop connected to CTC at Harefield	25,000
11 new loops @ $230,000 each	2,530,000
10 extended loops @ $172,500 each	1,725,000

97 km of conductors @ $462 per km	44,814
65 km of conductors @ $3,385 per km	220,025
10 switchlocks @ $10,350 each	103,500
	4,648,339
Add 10% contingencies	464,834
	5,113,173

Total: $5.11 million

The manpower savings are the same as for CTC1 at $180,000.

C.4.3 Doubling Scheme A

The two doubling schemes are considered to be introduced in stages. The capital costs for Scheme A are as follows:

	Stage Cost $	Total Cost $
CTC1	2,399,693	2,399,693
Stage 1	6,610,000	9,009,693
Stage 2	7,181,100	16,190,793
Stage 3	7,108,500	23,299,293
Stage 4	12,690,000	35,989,293

Total: $36 million

The total manpower savings are just those of CTCl at $180,000.

C.4.4 Doubling Scheme B

The capital costs are as follows:

	Stage Cost $	Total Cost $
CTCl	2,399,693	2,399,693
Stage 1	6,610,000	9,009,693
Stage 2	4,330,000	13,339,693
Stage 3	8,558,000	21,897,693
Stage 4	14,110,000	36,007,693

Total: $36 million

The total manpower savings are just those of CTCl at $180,000.

C.5 ALBURY-MELBOURNE UPGRADINGS

C.5.1 Six New Crossing Loops

The capital costs are as follows:

	$
6 new loops @ $230,000 each	1,380,000
Add 10% contingencies	138,000
	1,518,000

Total: $1.52 million

C.5.2 Ten New Crossing Loops

	$
10 new loops @ $230,000 each	2,300,000
Additional Central Control Equipment	500,000
	2,800,000
Add 10% contingencies	280,000
	3,080,000

Total: $3.08 million

C.5.3 Eighteen New Crossing Loops

The capital costs are as follows:

	$
18 new loops @ $230,000 each	4,140,000
Additional Central Control Equipment	500,000
	4,640,000

Add 10% contingencies	464,000
	5,104,000

Total: $5.10 million

C.5.4 Doubling of Section Somerton to Broadford

The capital cost of doubling the Somerton to Broadford section is:

	$
52 km @ $117,850 per km	6,128,200

Total: $6.13 million

C.5.5 Doubling of Section Seymour to Wallan

The capital cost of doubling the Seymour to Wallan section is:

	$
52 km @ $117,850 per km	6,128,200

Total: $6.13 million

ANNEX D METHOD AND ASSUMPTIONS

D.1 ASSUMPTIONS

D.1.1 Railway Revenue

Railways carry a wide range of commodities, each of which is distinguished by certain physical characteristics and by certain processes through which a given consignment passes during that part of its journey involving the railway. For example, at one extreme general goods consignments in less than full wagon lots require the use of major railway resources in marketing, loading, unloading and distribution; whereas at the other extreme the railway may merely function as the hauler of a wagon leased to a freight forwarder.

However, because we attribute congestion costs to the growth traffic only, the trade-off between the costs and benefits of upgrading is greatly simplified. Aside from the question of congestion costs, we need only consider the costs and revenues of the growth traffic and ignore all other traffic. This makes aggregation of revenue, on a tonne-km basis, more acceptable to the extent that we are dealing with relatively homogeneous traffics - i.e. freight forwarders' traffic and steel traffic. Both these traffics tend to be carried under contract rather than according to a published schedule and some variation between contracts would be expected. For commercial reasons, railways do not divulge contract revenue information; we have reason to believe, however, that the present revenue rate lies between 0.62 and 0.81 cents per tonne km in 1973 prices.

D.1.2 Railway Costs

The railways' assessment of upgrading investment is simply a 'trade off' between the additional net revenue and operating economies generated by the upgrading on the one hand and capital cost of the upgrading on the other. Capital cost is the total cost of designing and installing the upgrading, phased in time. Operating economies are savings that arise from the use of the upgrading e.g. signalling manpower reductions arising from the introduction of CTC. Net revenue is the surplus remaining to the railway after the incremental cost of carrying the traffic being considered is subtracted from its gross revenue. The following five cost items are included in the analysis.

(a) Fuel and crew

(b) Motive power and rolling stock maintenance

(c) Track maintenance

Following research at the BTE into track maintenance costs[(1)], it appears that these costs are essentially usage dependent, expressed, say, in dollars per gross[(2)] tonne kilometre. By including all components of track in the maintenance function, and treating existing earthworks, bridges, tunnels and drainage as having an infinite life, the imputed cost is, in fact, the long term cost of maintaining the track indefinitely, treating the original investment in earthworks etc. as sunk. There could be occasions when track is renewed before it is worn out - e.g. re-railing with heavier rail or re-sleepering, but generally this would be justified by long term savings in maintenance cost. This investment would be assessed on its own merits.

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(1) Bureau of Transport Economics, 'Permanent Way Maintenance Cost Functions' (to be published).

(2) Gross tonnage of a train is its total weight made up of locomotive(s), wagon tare weights, and payload.

(d) Motive power and rolling stock capacity

We visualise that, under steady traffic conditions over the long term, average annual distances travelled can be imputed to locomotives and wagons engaged in a given traffic. Thus, expressing their capital cost as an annuity at a given discount rate, a motive power and rolling stock capital cost component can be assigned to a traffic, train by train, given the train weight and the number of journeys per year. The implicit assumption is that each increment in traffic is continuously absorbed by a continuously replenished and expanded stock of locomotives and wagons.

(e) Traffic congestion delay costs

These can be conveniently divided into two parts - direct delay costs, i.e. crew, and indirect delay costs resulting from degraded utilisation of equipment. Direct costs should also include the cost to the Railway's customers of holding extra stock, and the value of inventory in-transit. However, very little is known of the way stock sizes are affected by transit delays, and preliminary indications are that the likely changes in the value of the inventory in-transit are small compared to other costs and savings[1]. Also passenger time costs are considered negligible since the transit time of high priority passenger trains (Annex A) would only suffer a slight increase with traffic growth. This increase in delay is expected to be offset by the decrease in the number of passengers (Chapter 2). Indirect delay costs have been simplified by aggregating equipment costs.

There are two bounds to the effect of traffic delays. At one extreme, there is the situation in which delays do not lead to loss of motive power and rolling stock utilisation - as would be typified by, say, an infrequent service to a remote railhead. Other than additional crew costs, the only cost to the railway may be idle manpower cost at the terminal. At the other extreme we have delayed arrivals at a busy terminal, working 24 hours per day, and turning trains around continuously. In this situation, transit delays would be predominantly reflected as reduced utilisation of

---

(1) The increase in the value of the inventory in-transit is estimated to be less than $200,000 (expressed in NPV terms) for a delay of one hour on the Melbourne-Sydney link, accrued over the 20 year study period.

wagons and locomotives, in terms of annual distance travelled. This would, in turn, lead to a requirement for a larger vehicle fleet to meet a given task. This may be expressed simply as an inflation of the motive power and rolling stock capital, in direct proportion to the fractional increase of transit time caused by delay. We have assumed that interstate rail freight operations tend to the latter extreme.

The growing traffic also causes congestion delays to other traffic. While the cost of the total trip is included in the case of the growing interstate freight traffic, only the increase in congestion delays need to be quantified in the case of the non-growing traffic and intrastate freight. Delays to all locomotives are computed in exactly the same way as previously, but delays to wagons need to be treated with discretion, because wagon utilisation is relatively insensitive to transit delays for some traffics, such as intrastate freight. Most commodities travelling intrastate are carried in older type four wheel wagons, and according to railway officials, there is a surplus of this particular wagon type. It is therefore unlikely that the size of the four wheel wagon fleet will be noticably affected by delays of the order of one hour. Consequently delays suffered by rolling stock attached to intra-state trains are ignored.

Some allowance is also made for delays to long distance passenger trains, although country and suburban services are ignored[1]. Long distance passenger trains are generally typified by low frequency and rolling stock that can be treated as unique to the service[2]. Passenger coaches tend to operate in sets, travelling in each direction on alternate days; for a typical intercity transit time of about 15 hours, then, a delay of one or two hours would not directly affect utilisation of rolling stock. Some time between trips is required for carriage cleaning etc. but it has been assumed that adequate tolerance is available to absorb delays. Delay costs for train crews are treated in the same way as for freight trains, noting that passenger trains carry conductors and catering staff.

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(1) Interference between long distance freight trains and suburban services can be significant, during peak hours on heavily used shared lengths of track. This requires analysis in its own right, generally as part of an urban transport study.

(2) The 'Southern Aurora' would typify this situation.

D.2 METHOD

D.2.1 Railway Line Capacity

First consider railway line capacity in the simple case of homogeneous traffic.

A change in the delay characteristic of the railway line is expected to affect the size of the locomotive and rolling stock fleet. The cost of delays is then estimated as follows (see Table D.1 for a list of the variables).

Annual distance travelled by locomotives under delayed conditions

$$= \frac{A_M \ T}{T + \delta T_X}$$

$$= \frac{A_M}{1 + f(x)} \qquad (D.1)$$

where $f(x) = \delta T_X/T$, describing the delay characteristics of the line as a function of traffic volume(1).

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(1) A more accurate analysis can be based on the assumption that Standing Time/km is a constant, where Standing Time includes loading/unloading time, waiting time at terminals and maintenance time. This approach leads to:

$$\text{Annual distance travelled by locomotives under delayed conditions} = \frac{\text{Number of hours in a year}}{\frac{T + \delta T_X}{D} + \text{Standing Time/km}}$$

which for a typical upgrading option reduces the savings in train capital by about 5%.

TABLE D.1 - LIST OF VARIABLES USED IN ANALYSIS OF DELAY

Variable	Description
C_M	Capital cost of motive power, per train, expressed as an annuity.
C_R	Capital cost of rolling stock, per train, expressed as an annuity.
A_M	Annual distance travelled by locomotives under datum conditions.
A_R	Annual distance travelled by wagons under datum conditions.
T	Transit time per single trip under datum conditions.
D	Distance per trip.
x	Traffic volume expressed in number of single trips per year.
H	Hourly rate for crew.
m	Maintenance (including track) and fuel costs per train per km.
δT_x	Delay per trip, at a traffic volume x, the delay being calculated as an increase in transit time compared to datum conditions.
R	Revenue per trip, net of attributable costs not accounted for in this analysis.
P	Annual net revenue.

Similarly, annual distance travelled by rolling stock under delayed conditions

$$= \frac{A_R}{1 + f(x)}$$

Therefore annual capital component of train cost at traffic volume x is:

$$xD\left\{\frac{C_M}{A_M} + \frac{C_R}{A_R}\right\}(1 + f(x)) \qquad (D.2)$$

NOTE: This formulation implies that locomotive and wagon life are independent of usage. This would be true if technological obsolescence were expected. In the absence of technological change, it is conceivable that equipment could be maintained indefinitely, or say for 30 years(1). At this life, and for discount rates in the range of interest (say 10% for resource cost evaluations and higher for commercial evaluations), the annuity term applied to capital cost is insensitive to life(2). We therefore argue

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(1) Less than half of the Australian freight wagon fleet is less than 20 years old.

(2) The annuity factor is given by $\frac{i(1+i)^n}{(1+i)^n-1}$ where i is the discount rate and n the life. Clearly, as either i or n increase it tends to i.

that our formulation is valid, although in principle, at the cost of some numerical complication, a formulation could be developed on the basis of a life tied to total distance travelled.

Other costs are given by:

Crew: : $xHT(1+f(x))$

Maintenance and fuel : xDm

Therefore annual net revenue,

$$P = x\left[R - \left\{D\left(\frac{C_M}{A_M} + \frac{C_R}{A_R}\right) + HT\right\}(1 + f(x)) - Dm\right]$$

This will be a maximum when

$$f(x) + x\frac{d}{dx}f(x) = \frac{R - Dm}{D\left(\frac{C_M}{A_M} + \frac{C_R}{A_R}\right) + HT} - 1 \qquad (D.3)$$

Thus, given the delay characteristic of the line, the traffic corresponding to maximum net revenue may be determined. Note that this point is not only a function of revenue, but also of the discount rate used in deriving the motive power and rolling stock capital annuity terms.

If the traffic is non homogeneous, the formulation is not so simple. In the most general case, some traffics will grow, others will remain constant - say i and j traffics respectively. Each increment to the "i type" traffic will delay all other traffics, including j traffics. If there are K "i type" traffics, the delay characteristic for any given traffic will be multidimensional of the form:

$$1 + f(x_1, x_2, \ldots, x_K)$$

where $x_1, x_2, \ldots, x_K$ are the traffic volumes of the "i type" traffics. The "j type" traffics have fixed traffic volume n_j. Using the same nomenclature as before, adding suffixes where necessary, the annual net revenue may be calculated from:

$$\begin{aligned} P = & \sum_{i=1}^{k} x_i \left[R_i - \left\{D_i\left(\frac{C_{M_i}}{A_{M_i}} + \frac{C_{R_i}}{A_{R_i}}\right) + H_i T_i\right\}\left(1 + f_i(x_1, x_2 \ldots x_K)\right) - D_i m_i\right] \\ & + \sum_{\text{all } j} n_j \left[R_j - \left\{D_j\left(\frac{C_{M_j}}{A_{M_j}} + \frac{C_{R_j}}{A_{R_j}}\right) + H_j T_j\right\}\left(1 + f_j(x_1, x_2 \ldots x_K)\right) - D_j m_j\right] \end{aligned} \qquad (D.4)$$

Clearly, for all but the simplest cases, the combined traffic volume corresponding to maximum annual net revenue would be deduced numerically; this was done in the study. The actual computation also discounted the annual net revenues (Equation D.4) and summed them to obtain the net present values. Nevertheless, the principle is unchanged from our formulation for homogeneous traffic and the extensions to be discussed will be in terms of the simplified formulation (Equation (D.3)).

Let us now extend the analysis to include consideration of the resource cost of rejected rail traffic spilling over on to road. We shall use the same nomenclature as before, it being understood that transfer payments such as taxes have been excluded where necessary[1]. With a resource cost criterion, the point at which growth traffic should spill over on to road is given by equality between the marginal costs of transporting the freight by road or rail, expressed as follows:

$$\frac{d}{dx}\left[x\left\{(1 + f(x))\left\{D\left(\frac{C_M}{A_M} + \frac{C_R}{A_R}\right) + HT\right\} + Dm\right\}\right] = L \qquad (D.5)$$

where L is the marginal resource cost of carrying one train load by road. This reduces to the differential equation:

$$f(x) + x\frac{d}{dx}f(x) = \frac{L - Dm}{D\left(\frac{C_M}{A_M} + \frac{C_R}{A_R}\right) + HT} - 1 \qquad (D.6)$$

(1) State railways do not pay sales tax on equipment or excise on fuel. Commercial and resource costs are therefore identical for these categories.

Again, given the delay characteristic of the line, the spill over point may be determined. The formulation could be extended to two or more traffics as before.

The above results can be summarised as follows:

(a) The freight traffic volume corresponding to maximum total net revenue to the railway can be identified as a function of the delay characteristic of the line, unit revenue and fixed cost parameters. We call this volume the "commercial capacity" of the line.

(b) From a resource viewpoint, the maximum traffic volume which the railway should carry before further traffic is diverted to road can be identified as a function of the delay characteristic of the line and fixed cost parameters for road and rail. This volume would correspond to the "resource capacity" of the line. In this particular study it turns out that "resource capacity" coincides with physical capacity as defined in Section 4.2.

D.2.2 Capacity Upgrading

Generally, capacity upgrading is essentially an improvement to the delay characteristic of the line. At the same time, it is possible that direct operational benefits could accrue from, say, reduced maintenance costs and signalling manpower savings. Motive power cost may also be affected - for example by upgrading measures that reduce the limiting grade. We shall retain the original nomenclature (Table D.1), with the addition of:

- suffix $_1$ to indicate the cost parameter after upgrading,
- I = Capital cost of upgrading, expressed as an annuity, and
- S = Annual manpower saving after upgrading.

As before, annual net revenue after upgrading is given by:

$$P_1 = x\left[R - \left\{D\left(\frac{C_{M_1}}{A_M} + \frac{C_R}{A_R}\right) + HT\right\}\left(1 + f_1(x)\right) - Dm_1 - I + S\right]$$

and upgrading is justified providing

$$\left\{D\left(\frac{C_{M_1}}{A_M} + \frac{C_R}{A_R}\right) + HT\right\}\left(1 + f_1(x)\right) + Dm_1 + I - S$$

$$- \left\{D\left(\frac{C_M}{A_M} + \frac{C_R}{A_R}\right) - HT\right\}\left(1 + f(x)\right) - Dm \leq 0$$

Note that this condition is independent of revenue.

For a "pure" capacity upgrading, having no effect on undelayed motive power costs and traffic dependent maintenance, but offering some annual manpower savings, as in the case of centralised traffic control, for example, the upgrading condition simplifies to:

$$\left\{D\left(\frac{C_M}{A_M} + \frac{C_R}{A_R}\right) + HT\right\}\left(f_1(x) - f(x)\right) + I - S \lesseqgtr 0$$

That is, the upgrading evaluation is simply a trade off between reduced delay costs and manpower savings on the one hand and capital cost on the other. Again, the principle could be applied to non homogeneous traffic, and the independence of revenue would still apply.

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