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

Report

The majority of Australia's intercapital railway lines are single track and these all experience some degree of congestion. Various combinations of capital investment and improved operating practices are evaluated in this report, with a view to eliminating the growing congestion on the Victorian portion of the Melboune - Adelaide rail link.

BUREAU OF TRANSPORT ECONOMICS

MAIN LINE UPGRADING - EVALUATION OF A RANGE OF OPTIONS FOR THE MELBOURNE-SERVICETON LINK

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FOREWORD

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

The study was carried out by an interdisciplinary team but is largely the work of the Operations Research Branch under the direction of J.C.M. Jones. The working team was led by A.E. Walker, and her principal assistants were A.M. Currie and A.J. Green. The forecasts were provided by M.D. Fitzpatrick and the single track simulator was developed by A.J. Storry.

The BTE acknowledges the assistance received from Victorian Railways and Australian National Railways.

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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;

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

This part of the general assessment program examines the Victorian portion of the Melbourne-Adelaide rail link. The growing congestion problem along this track is quantified and a range of upgrading options are evaluated including electrification, deviations, upgrading an alternative route via Geelong, line doubling, extension of crossing loops and centralised traffic control.

Mainline 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. A common feature to all the best options is the extension of crossing loops to 915 metres allowing the use of heavier and therefore fewer trains. Centralised traffic control is also shown to be economically viable.

The capital cost of the preferred upgradings is estimated to lie between $1 million and $5 million in 1973 prices and the expected commercial rate of return is above 15% in all the preferred cases, but can be in excess of 30%.

The social benefit-to-cost ratio of the rail upgrading investment - ignoring likely congestion effects on road if the rail is left in its present state - is in the range 2 to 8, depending on the upgrading and on the discount rate.

CHAPTER 1 INTRODUCTION

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;

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

Serious congestion problems were anticipated by Victorian Railways on the main line to Adelaide towards the end of the 1970s. The Victorian section between Melbourne and Serviceton, which consists almost entirely of single track with mechanical signalling, is expected to determine the capacity for carrying the growing interstate traffic. The South Australian Section from Serviceton to Tailem Bend is also single track, but this section has recently been improved and now operates under Centralised Traffic Control (CTC). This portion of the line is not expected to become congested within the study period.

Loading and unloading of trains is an essential facility in the process of carrying interstate freight by rail and present terminals may become inadequate for this task within the study period. The whole question of freight wagon utilisation and terminal performance is under study at the BTE. 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 bottlenecks to the terminals.

Mainline 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 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 or road as a function of the

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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 growth in interstate freight traffic is carried by rail until rail capacity is reached; a further increase in general goods traffic is carried by road.

capacity of the railway. These two points of view are not necessarily compatible, but in this particular case it turns out that the upgrading options best meeting 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 Melbourne and Adelaide during the study period 1975/76 to 1994/95. The third chapter describes the upgrading options suggested by the Victorian and South Australian Railways to accommodate the expected growth in traffic. A comprehensive range of upgrading alternatives was considered:

- extension of crossing loops,
- four CTC schemes,
- upgrading an alternative route via Geelong,
- selective line doubling,
- various deviations,
- electrification, and
- curvature improvement between Adelaide and Murray Bridge.

The method and principal assumptions are detailed in the fourth chapter. Chapters five and six present the results of the evaluations and the conclusions.

CHAPTER 2 RAIL FREIGHT PROJECTIONS, 1975-1994

2.1 GENERAL

Over the last ten years there have been some fundamental changes in the type of goods railways carry and in the customers they serve. These changes have been prompted by technological advances, improved services, etc. which have enhanced the general competitive position of the rail mode. These changes have arisen mainly from two sources. Firstly, from freight forwarders who have developed door to door services, aggregating small consignments when necessary. Secondly, from the development of container shipping services, principally from Melbourne and Sydney, requiring significant internal movements of containers. In some cases, these changes have occurred rapidly, within two years.

Prediction of any economic activity over a long period of time is hazardous and this is particularly true of long distance rail transportation. Examination of trends over a short period 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. The aggregate annual figures under these circumstances cannot be taken as a true reflection of the growth in rail traffic. Instead it is necessary to look beyond the aggregate and examine the components. In this way it may be possible to detect and eliminate short run effects.

The Melbourne-Serviceton line provides four basic services:

interstate freight,
interstate passenger,
intrastate freight, and
intrastate passenger.

Initially these components were examined as separate entities.

2.2 INTERSTATE FREIGHT

The bulk of identifiable interstate freight traffic[1] (Annex A, Table A.1) is attributable to three types: overseas containers, motor vehicles and parts, and freight forwarders' goods. An extensive analysis was conducted on each of these important components, as detailed in Annex A. They all show strong growth, approximately 5% p.a. compound for freight forwarding and

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(1) Interstate rail freight is dominated by the inter-capital city traffic; intermediate origins and destinations may be neglected.

overseas containers, while motor vehicles and parts show a more complex trend with the rate of increase slowly decaying. The overseas container forecasts are subject to some uncertainty due to the anticipated container terminal at Port Adelaide. At this stage the impact of this new terminal on the flow of South Australia's exports is uncertain because shipping companies cannot say how frequently and for which routes this facility will be used. Our forecasts are based upon the assumption that the overseas container traffic between South Australia and the U.K./Europe will use these facilities while the remaining containers will continue to be shipped through Melbourne. Containerised exports to Japan and North America sail in ships which essentially operate along the eastern coast of Australia. For these ships to use Port Adelaide would require an extension of their current route operations. On the other hand ships sailing between Australia and the U.K./Europe would incur only port entry and exit delays to call at the Port of Adelaide. The result of this assumption upon the Melbourne-Serviceton rail traffic is a loss of the U.K./Europe import/export containers. The growth rate is largely unaffected by this assumption - only the base figure from which we project being influenced. Because of the importance of this assumption, a sensitivity test was made upon the various investment options using the above base case of no U.K. containers and an alternative of 50% of the U.K. container traffic being retained by the railways - the respective projections being designated 'low' and 'high'.

The remaining identifiable commodity of significance to the Melbourne-Serviceton line is steel. At this stage it is difficult to forecast future growth, if any, in the steel traffic by rail. Two ships have recently been built and others are currently nearing completion for the main purpose of moving steel around the Australian coast. Some Melbourne-Adelaide steel consignments will definitely be included in the shipments. Another factor in the steel forecasts lies in the impact of new steel mills at Westernport Bay in Victoria. The precise products of these mills are uncertain but some increase in traffic could result. In these circumstances some steel sections currently produced in N.S.W. and shipped to Adelaide via Broken Hill would be produced in Victoria. Efforts to clarify these interlocking questions were unsuccessful and it was therefore assumed for these forecasts that steel will continue to flow between Adelaide and Melbourne by rail, with the current absolute level being maintained for the next two years, after which period a growth rate of 2% compound p.a. was assumed.

2.3 INTRASTATE FREIGHT

The intrastate freight was divided according to the direction of travel. The 'up' traffic is predominantly the rural production of western Victoria bound for Geelong, Melbourne or Portland. An analysis of the yield/acreage statistics of the regions failed to establish any production pattern which is subject to fluctuating climatic and marketing effects. A detailed examination of 1971/72 grain shipments revealed that although this was a poor production year, the additional shipments from storage were sufficient to make 1971/72 a representative year. The intrastate freight flow in the up direction, including grain shipments, was therefore projected as remaining for the whole of ths study period at the same level as existed for 1971/72.

The freight shipments from Melbourne to the rural regions can be classified according to their use in rural production or otherwise. The major item in the former category is superphosphate, shipments of which also vary with climatic conditions. Following the same reasoning as applied to grain traffic, superphosphate shipments were assumed to remain at their current level. The second category was examined by regression analysis and found to be strongly correlated with the population of the regions. An examination of census figures revealed that the population of Victoria's western regions is declining, and a corresponding reduction in the demand for freight could be expected. However, it was assumed unlikely that rail services, in terms of frequency, could be significantly reduced from their present level during the study period.

2.4 PASSENGER TRAFFIC

The two passenger categories, interstate and intrastate, were also assumed to maintain their present levels. An examination of interstate patronage revealed a slight decline in traffic but it was insufficient to suggest any curtailment of the current services. A similar study of intrastate patronage indicates a very low level of utilisation of the currently scheduled trains. Although there seems considerable scope for a reduction in these rail services, discussions with Victorian Railway officials indicated that reductions were unlikely and the study therefore assumed that present intrastate services would be retained.

Although the commuter passenger service in close proximity to Melbourne is expected to grow, the few sections concerned are, or are planned to be, double track. Track capacity was therefore not considered to be affected by commuter traffic.

2.5 SUMMARY

The only class of traffic along the Melbourne-Serviceton line which is expected to experience any growth is the interstate freight. The remaining traffics have been assumed to retain their current level of operation. The derived projections are summarised in Tables 2.1, and 2.2 for the 'low' and 'high' projections corresponding to all or only half the U.K./Europe trade from the Adelaide hinterland being delivered directly to the future Adelaide container port, respectively. These two levels are included for the purpose of testing the sensitivity of the results to changes in projected traffic.

TABLE 2.1 - 'LOW' INTERSTATE RAIL FREIGHT PROJECTION

('000 tonnes)

Year	Melbourne to Adelaide		Adelaide to Melbourne	
	Containerised(a)	Total	Containerised(a)	Total
1975/76	77	598	85	571
77	80	621	90	592
78	83	645	96	617
79	86	673	102	640
80	90	701	108	669
1980/81	93	729	114	694
82	97	756	121	722
83	101	789	129	754
84	105	821	137	783
85	109	855	145	817
1985/86	114	892	154	852
87	118	926	164	887
88	123	966	174	928
89	128	1,007	184	966
90	133	1,047	195	1,005
1990/91	138	1,089	207	1,051
92	144	1,135	221	1,097
93	150	1,183	234	1,143
94	156	1,234	248	1,194
95	162	1,284	263	1,248

(a) Overseas containers only

TABLE 2.2 - 'HIGH' INTERSTATE RAIL FREIGHT PROJECTION

('000 tonnes)

Year	Melbourne to Adelaide		Adelaide to Melbourne	
	Containerised(a)	Total	Containerised(a)	Total
1975/76	95	616	160	646
77	99	640	169	671
78	103	665	179	700
79	107	694	190	728
80	111	722	201	762
1980/81	116	752	214	794
82	120	779	226	827
83	125	813	240	865
84	130	846	254	900
85	136	882	266	938
1985/86	141	919	286	984
87	146	954	303	1,026
88	152	995	321	1,075
89	158	1,037	340	1,122
90	165	1,079	361	1,171
1990/91	171	1,122	382	1,226
92	178	1,169	405	1,281
93	185	1,218	430	1,339
94	193	1,271	456	1,402
95	200	1,322	483	1,468

(a) Overseas containers only

CHAPTER 3 UPGRADING ALTERNATIVES

Before a list of upgrading alternatives on the Melbourne-Serviceton portion could be prepared, the full line between Melbourne and Adelaide was examined for possible bottlenecks. See Annex B for a description of the line and its traffic. Although the hilly Belair-Tailem Bend single track section on the South Australian side accounts for a disproportionately large part of the total transit time it was found that interstate expresses rarely cross there. Express freight and passenger trains cross between Dimboola and Serviceton on the Victorian side and once this section is improved the bottleneck tends to shift eastwards, nearer to Ararat. Thus, the Belair-Tailem Bend section is essentially transit time limiting rather than capacity limiting. South Australian Railways were consulted on possible upgradings on their part of the Adelaide-Melbourne link and their proposal is summarised in Annex C.

The following sections describe all upgrading measures proposed by Victorian Railways for the Melbourne-Serviceton link and considered in this study. The associated capital costs, in 1973 prices, are summarised in Table 3.1. In all schemes it is assumed that the Sunshine to Deer Park section is double line as recommended by the Melbourne Transportation Study, in accordance with the expected increase in commuter traffic.

TABLE 3.1 - COSTS OF PROPOSED UPGRADINGS

($ million, 1973 prices)

Proposed Upgrading	Cost
CTC Scheme 1	5.6
CTC Scheme 2	7.2
CTC Scheme 3	5.9
CTC Scheme 4	5.1
Geelong Diversion	3.4
Line Doubling	9.1
Deviations	
Parwan to Horseshoe Creek	1.8
Millbrook to Dunnstown	1.5
Electrification	8.0

Only approximate total capital costs and operating savings will be quoted in this chapter. For a more complete breakdown of costs reference may be made to Annex C.

3.1 CENTRALISED TRAFFIC CONTROL (CTC) SCHEMES

In addition to replacement of existing mechanical signalling by power signalling, and remote control of the power signals from one central point, CTC schemes may also incorporate construction of new loops or extension of existing loops. Selective extension of crossing loops produces marked decreases in delays on sections where long trains tend to cross. Further delay reductions are expected from the introduction of power signalling, especially on densely trafficked lines, because it reduces each crossing delay from about 4 minutes (for the manual exchange of staff - see Annex B), to about one minute. The value of 4 minutes is an average value; crossing delays increase with train length. For example, in the case of 1400 tonne (gross) trains the delay is 8 to 10 minutes. The residual one minute is the time lost by the train in decelerating to a stop and accelerating from rest following the passage of the conflicting train. Reduction of this crossing delay can be reflected in significant increases in line capacity.

Remote control of the power signals has no direct effect on line capacity but allows considerable manpower savings in not having to man stations for signalling purposes. Centralised control may, however, lead to more effective scheduling by considerably facilitating the train controller's task, and therefore improving line capacity indirectly. This possible improvement is not quantified in the study.

3.1.1 CTC Design Considerations

In an attempt to design cost effective power signalling and CTC schemes the planner has a number of options to consider.

(a) Signalling of existing crossing loops and their lengthening if necessary.

This solution is the least costly but often has the disadvantage of location, because crossing loops are positioned at existing settlements rather than at possibly better locations from an operational point of view. An added disadvantage is that lengthening of some loops is not possible because of the presence of nearby level-crossings and other terrain constraints.

(b) Signalling of new crossing loops.

Here the operational advantages of better positioning are acquired at a relatively high cost. However, as the new loops operate more effectively fewer loops may be sufficient to achieve the required capacity.

(c) Use of intermediate signals.

This allows shorter headways between trains travelling in the same direction, however the usefulness of intermediate signals strongly depends on the density of the traffic and on timetabling.

(d) The mixing of sections operating under CTC and of mechanically signalled sections.

This feature is undesirable in most cases as it is confusing from the train driver's point of view, especially on shorter stretches. Its introduction can be cost effective when there are large variations in traffic density along a line. CTC could then be introduced in densely trafficked areas while mechanically operated signals could be retained elsewhere.

3.1.2 CTC Alternatives Considered

In the following descriptions of the alternative CTC schemes four 'basic' CTC schemes (CTC1, 2, 3 and 4) are postulated for the complete stretch of line from Sunshine to Serviceton (Figures 3.1, 3.2, 3.3 and 3.4).

Variations on each of these schemes are also evaluated; these include as a first step introduction of part of the basic schemes over the critically congested western half of the line from Ararat to Serviceton. As a second step minimum upgrading of five loop extensions in absence of power signalling on the eastern half from Sunshine to Ararat can also be introduced concurrently or later. In addition to this being attractive in initially restricting the major upgrading to the more congested part of the line, it would also be a convenient way of phasing the construction and installation task. Such a break-up would also be compatible with the intention of installing the CTC control centre at Ararat. Later introduction of CTC over the eastern half may then be considered as a separate project.

The Salisbury loop is already power signalled and it forms part of all CTC schemes; the cost of incorporating it into the new schemes is assumed to be insignificant.

CTC Scheme 1 (Fig. 3.1)

This scheme is based on a minimum number of power signalled loops (a total of 22), supplemented by loop extensions. The capital cost of the scheme is about \$5.6 million with an annual operating saving of about \$0.4 million (Annex C). Only 12 of the existing

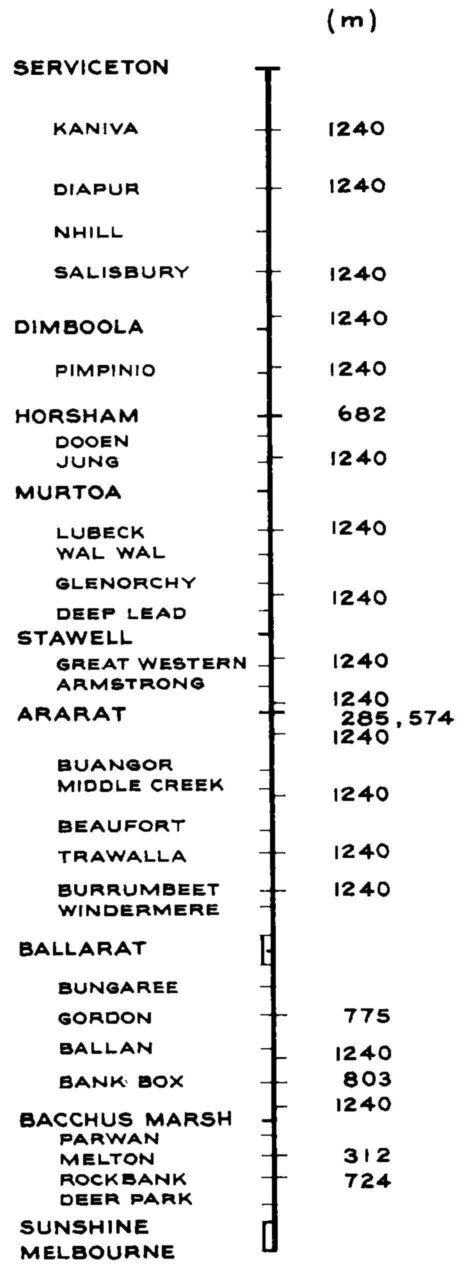

FIGURE 3.1

POSITION AND LENGTH OF LOOPS

CTC 1 SCHEME

loops are retained and 10 new ones introduced, as summarised below:

- 10 new loops, each 1240 metres long, at distances 56, 76, 179, 203, 214, 233, 258, 312, 348 and 367 km from Melbourne.

- 6 extended loops at Gordon, Burrumbeet, Trawalla, Lubeck, Diapur and Kaniva, each 1240 metres long except the loop at Gordon which cannot be extended beyond 775 metres.

- 6 existing loops at Rockbank, Melton, Bank Box Loop, Ararat (2 loops) and Horsham.

The original plan included 28 intermediate signals, but train diagrams developed during the study showed that these signals would not be effective in facilitating follow-on movements with the traffic and timetable expected during the study period.

Although 1240 metre loops are indicated here, the actual length of extended or new loops is not important as long as it exceeds 680 metres, the length of the longest trains considered in this study. The additional cost of extending to 1240 metres is small.

CTC Scheme 2 (Fig. 3.2)

This scheme represents the other extreme of requiring a large number of loops (a total of 29) made up of 17 new and 12 existing loops, some extended. As a result, it is the most capital intensive scheme of those evaluated, at a cost of about $7.2 million, with the same annual operating savings as CTC1. Its advantage is a potentially higher capacity than that of the other CTC schemes. The CTC Scheme 2 proposal includes:

- 17 new loops, each 1240 metres long, at distances 56, 76, 179, 203, 219, 233, 250, 266, 299 (2 loops), 316, 348, 361, 377, 411, 428 and 443 km from Melbourne;

- 5 extended loops at Parwan, Gordon, Burrumbeet, Trawalla and Lubeck each 1240 metres long except the loop at Gordon which cannot be extended beyond 775 metres; and

- power signalling of 7 existing loops at Rockbank, Melton, Bank Box Loop, Ararat, Stawell, Horsham and Nhill.

CTC Scheme 3 (Fig. 3.3)

This scheme retains all existing loops where feasible together with the addition of a minimum number

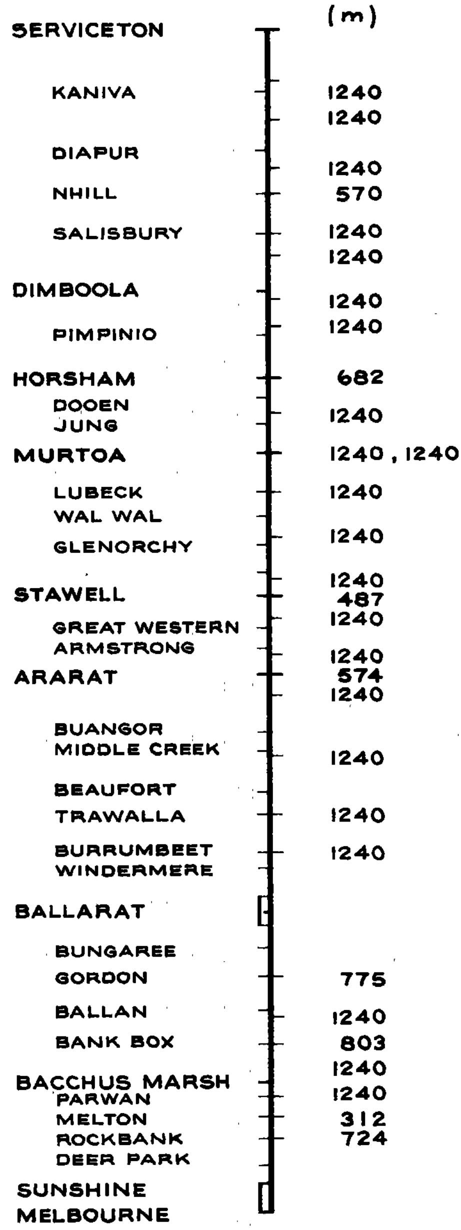

FIGURE 3.2

POSITION AND LENGTH OF LOOPS

CTC 2 SCHEME

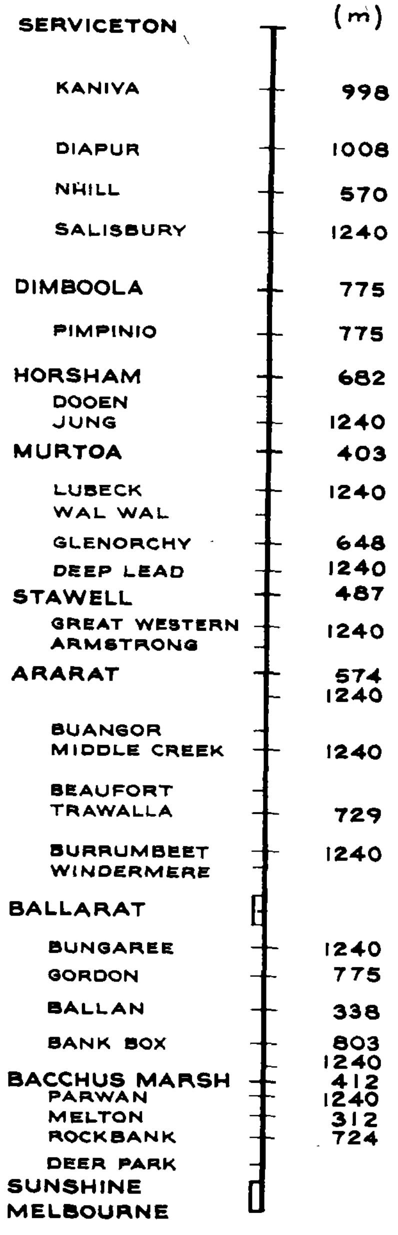

FIGURE 3.3

POSITION AND LENGTH OF LOOPS

CTC 3 SCHEME

of new loops (two). The large number of loops to be signalled (total of 27), combined with loop extensions leads to a capital cost of about $5.9 million. The annual operating saving is the same as for CTC Scheme 1. An additional feature of this scheme, examined in the evaluation, is the possibility of implementing it in two steps or more by first extending the existing crossing loops, followed by the new loops and CTC. This breakdown would be additional to the separation of western and eastern halves of the line described previously. Thus, the scheme offers flexibility in planning, allowing close correspondence of the timing of the upgrading with traffic demand. The proposal includes:

- 2 new loops at distances 56 and 203 km from Melbourne;

- 10 extended loops at Parwan, Gordon (775m), Bungaree, Burrumbeet, Middle Creek, Great Western, Deep Lead, Lubeck, Jung and at Pimpinio (775m), each 1240 metres long, except at Gordon and Pimpinio where the loops cannot be extended beyond 775 metres; and

- 15 existing loops signalled at Rockbank, Melton, Bacchus Marsh, Bank Box Loop, Ballan, Trawalla, Ararat, Stawell, Glenorchy, Murtoa, Horsham, Dimboola, Nhill, Diapur and Kaniva.

CTC Scheme 4 (Fig. 3.4)

This scheme is based on the power signalling of a minimum number of loops (a total of 22) made up of 3 new and 19 existing loops, some extended. It is the cheapest of the CTC schemes at a capital cost of about $5.1 million and an annual operating saving equal to that of CTC1. An additional advantage of this scheme is that it offers planning flexibility similar to that mentioned for CTC3. As a first step 5 existing loops would be extended west of Ararat at Great Western, Deep Lead, Lubeck, Jung and Pimpinio followed by the rest of the CTC scheme. Preliminary investigations have shown that because the capital cost of CTC4 is relatively low, there is no advantage in introducing the 10 extended loops option before CTC4. The full proposal consists of:

- 3 new loops at distances 56, 76 and 203 km from Melbourne;
- 8 extended loops at Gordon (775m), Burrumbeet, Middle Creek, Great Western, Deep Lead, Lubeck, Jung and at Pimpinio (775m), each 1240 metres long except at Gordon and Pimpinio;

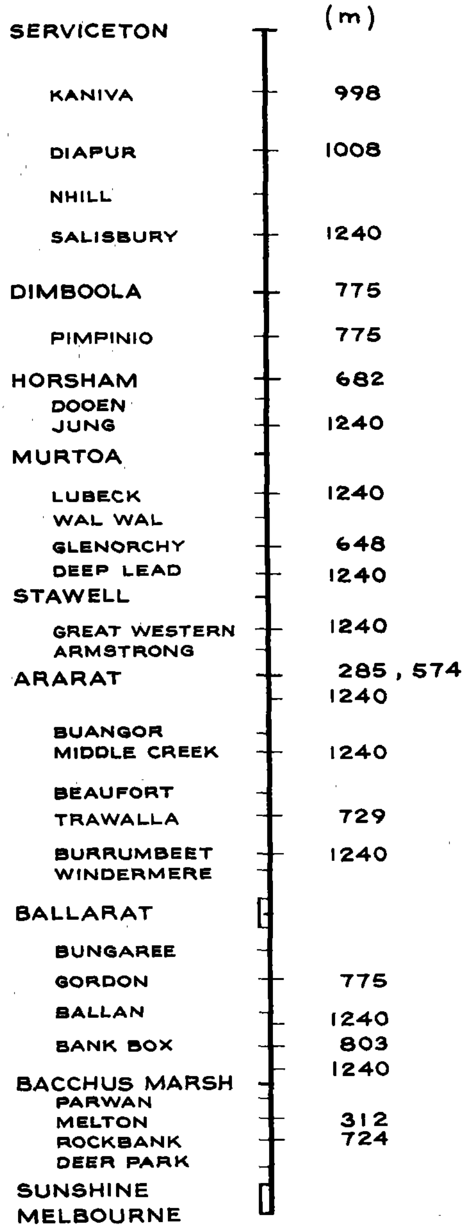

FIGURE 3.4

POSITION AND LENGTH OF LOOPS

CTC 4 SCHEME

11 existing loops signalled at Rockbank, Melton, Bank Box Loop, Trawalla, Ararat (2 loops), Glenorchy, Horsham, Dimboola, Diapur and Kaniva.

3.1.3 Variation of CTC Schemes

As explained in 3.1.2, the four basic CTC schemes could be split between east and west of Ararat, the latter being introduced first with optional loop extensions east of Ararat. These loop extensions would include:

- Parwan to 1240 metres
- Gordon to 775 metres (cannot be extended beyond this length)
- Bungaree to 1240 metres
- Burrumbeet to 1240 metres
- Middle Creek to 1240 metres

This increment would cost about $0.6 million.

3.2 GEELONG DIVERSION SCHEME

The scheme is based on the diversion of almost all express freight trains via Geelong, joining the main line at Ararat (Fig. 3.5). This separates the higher

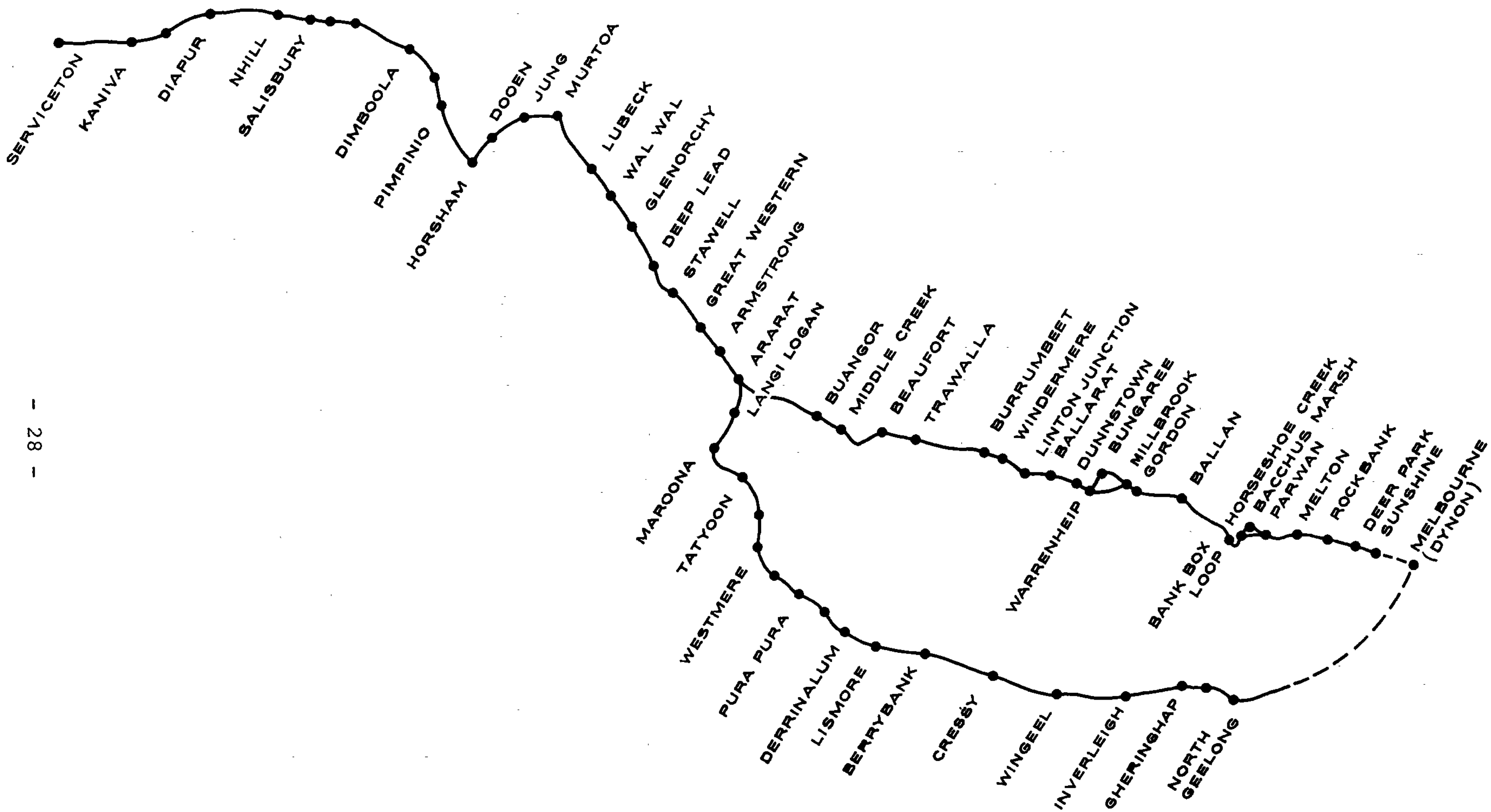

FIGURE 3.5
EXISTING LINE SHOWING GEELONG DIVERSION AND DEVIATIONS

priority freight trains from interstate and country passenger trains[1].

The Geelong Diversion has the additional advantage of reducing motive power requirements because its ruling grade is less severe than that of the main line east of Ararat (see Annex F). Although the route via Geelong is 53 km longer, travel time is not expected to increase because higher average speeds can be achieved on the less severe grades. However, express freight trains travelling between Melbourne and Geelong require about 50 minutes longer than those travelling between Melbourne and Sunshine. For this reason the interstate express passenger and the highest priority express freight trains - the overnight expresses, for example - would continue to use the main line.

Stations on the Geelong line are unmanned at present and the existing signalling requires trains to stop at every station (see Annex B). This type of operation is clearly unsuitable for express freight

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(1) Both with and without the diversion, mixing of the express freight trains with commuter trains occurs on the main line out to Bacchus Marsh, and on the Geelong Diversion between Melbourne and Geelong. Commuter traffic is expected to grow on both these lines and double/triple lines are currently under consideration to absorb this growth alone. So the problems associated with mixing freight and commuter trains will be similar in nature and magnitude whether the express freight trains use the route via Ballarat or via Geelong; these problems were therefore ignored for the purposes of the present study.

trains and power signalling with CTC is the best way of upgrading this stretch of line if additional manpower requirements are to be avoided. These measures have a capital cost of about $3.4 million. Upgrading requirements from Ararat to Serviceton remain the same as in all other cases since the express freight trains travelling via Geelong join the main line at Ararat. The Diversion proposal consists of:

- major alterations and extensions of loops to 1240 metres at Gheringhap and Maroona;
- minor extensions to all other loops (1240 metres each);
- new pole line.

The original scheme included six intermediate signals, but as before, these were shown to be ineffective during the study period and were therefore ignored.

Given a decision to upgrade the Geelong Diversion, an additional benefit would occur in the form of reduction of congestion at the Ballarat yard. This effect, however, was not quantified in this study due to lack of information.

3.3 LINE DOUBLING SCHEME

Lack of crossing loops long enough to accommodate the express freight trains is a major cause of delays on the line. Thus, crossing loop extension could be a first upgrading measure prior to doubling the line. As traffic increases further, congestion starts developing between Dimboola and Serviceton as more and more express freight trains cross there. Approximate train diagrams for the traffic projected for the end of the study period show that the three sections where the greatest number of express passenger and express freight trains cross are Kaniva to Serviceton, Dimboola to Salisbury Loop and Nhill to Diapur.

Sections Kaniva to Serviceton and Dimboola to Salisbury Loop will have to cope with 4 crossings of interstate trains per day by 1978 and 5 crossings per day by 1987, and section Nhill to Diapur with 4 crossings per day by 1978. All these crossings occur between 11 pm and 5.30 am, with a peak between 2 am and 5 am; the expected section occupancies during the 3 hours of peak will be in 1978:

83% Kaniva to Serviceton

75% Dimboola to Salisbury Loop

44% Nhill to Diapur.

As a preliminary to doubling the critical sections west of Ararat, the following loop extensions could be introduced as a first step:

- 10 extended crossing loops at Parwan, Gordon (775m), Bungaree, Burrumbeet, Middle Creek, Great Western, Deep Lead, Lubeck, Jung and Pimpinio (775m), each 1240 metres long except at Gordon and at Pimpinio where the loops cannot be extended beyond 775 metres.

Note that these loop extensions are identical to those for CTC Scheme 3 and can be considered as an incremental upgrading in their own right, as can also a split of these extensions between east and west of Ararat. The eastern extensions would be identical to those proposed as a variation of CTC Schemes described in Section 3.1.3. As a separate upgrading, the capital cost of the extension of these 10 loops is about $1.1 million.

As traffic grows further, doubling would then be introduced as follows, in three sequential increments:

(a) Section Kaniva to Serviceton at a capital cost of about $2.7 million;

(b) Section Dimboola to Salisbury Loop at a capital cost of about $3.2 million;

(c) Section Nhill to Diapur at a capital cost of about $2.1 million.

This scheme offers the greatest planning flexibility of all the schemes proposed as it can be introduced in four stages, including the loop extension stage.

3.4 DEVIATIONS

3.4.1 Parwan to Horseshoe Creek Deviation

This scheme, costing $1.8 million, includes construction of an 8 km long deviation between Parwan and Horseshoe Creek, bypassing Bacchus Marsh to avoid the descent to Bacchus Marsh followed by a steep climb (Fig. 3.5). It also includes keeping the existing track for use by commuter trains originating from or terminating at Bacchus Marsh. A 6 minute reduction in transit time is expected for both directions of travel if the deviation is introduced. Furthermore, the reduction in transit time would render one crossing loop unnecessary.

3.4.2 Millbrook to Dunnstown Deviation

It is proposed to straighten out the line between Millbrook and Dunnstown (Fig. 3.5) to reduce the distance between these two localities by about 5 km. A 5 minute reduction in transit time is expected for both directions of travel if the deviation is introduced at a capital cost of $1.5 million.

3.5 ELECTRIFICATION

Electrification can yield the following benefits:

- reduction of transit time in hilly areas;
- reduction of energy costs, depending on the relative prices of diesel fuel and electricity;
- reduction in locomotive maintenance cost; and
- possible reduction in locomotive capital cost.

Clearly the introduction of electrification will be most beneficial in densely trafficked and hilly areas. Electrification is proposed in three stages, first between Sunshine and Ballarat, (Melbourne to Sunshine is already electrified), then between Ballarat and Ararat, and finally between Ararat and Stawell, at a total capital cost of $8.0 million. There are heavy grades on each of these sections and it seems plausible that by reducing some section transit times a reduction in the number of crossing loops will follow. However, a closer investigation shows that the transit time savings are insufficient to justify closure of crossing loops. Most trains would also require an electric to diesel (or vice versa) locomotive change, resulting in extra delays, lower locomotive utilisation and possible congestion at the change-over goods yards (Ballarat, Ararat or Stawell).

Although electrification would not substantially affect through traffic or line capacity, electrification of the line may eventually extend out from Sunshine as commuter traffic develops. However, evaluation of electrification in this context would be better carried out as part of an urban transport improvement study.

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 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 time variable 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. Thus our approach to the commercial evaluation of upgradings 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 at 1973 prices. These two bounds will be used to test the sensitivity of the results to variations in the value of 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. Analysis of the costs of shipping general freight between Tasmania and the mainland[1] has indicated that the cost of sea transport between Melbourne and Adelaide would be about the same as rail. The main disadvantage of the sea alternative is 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.

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 upgrading.

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

4.1 TRAINS REQUIRED TO MEET PROJECTED DEMAND

Because interstate general goods traffic is the only rail service which is estimated as growing within the 20 year study period (Chapter 2), it was sufficient to restrict the analysis to the carrying capacity of interstate freight trains only in order to transform the freight projection into a future traffic schedule(1).

The use of heavier and therefore fewer trains leads to three types of benefits. Firstly, fewer but heavier trains can, in principle, increase the tonnage capacity of the line, provided that the corresponding increase in train length can be accommodated in the existing goods yards and passing loops. Secondly, fewer trains lead to reductions in the size of locomotive fleet and therefore motive power investment. Furthermore, because locomotive maintenance costs are almost exclusively dependent on distance and independent of tonnage hauled, there will also be savings in maintenance costs. Thirdly, fewer trains lead to train crew manpower savings. These three categories of benefits are quantified in detail in Annex C.

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(1) All growth traffics are assumed to be carried in containers by unit trains, similar to the present trains dedicated to freight forwarders' traffic on the Sydney-Melbourne link.

The operational factors constraining the carrying capacity of trains on the Melbourne-Serviceton section are train length and gross train weight. The length is restricted by passing loops because some crossings of long freight trains cannot be avoided. The upper limit of gross train weight is determined by available locomotive tractive effort for climbing the gradients at Bank Box Loop and east of Ballarat. These length and gross weight constraints are upper bounds, whereas actual train lengths and weights are subject to some variation. Thus, in order to obtain a realistic estimate of the number of trains required to haul a given tonnage, average length and weight values are used. Given that the line is to be upgraded, train length ceases to be an issue because the additional cost incurred in extending loops beyond the minimum necessary to accommodate, say, trains having the current average gross weight of 1000 tonnes, is relatively small. Locomotive tractive effort was therefore taken as the sole determinant of gross train weight, and it was determined (Annex F) that the gradients and the characteristics of available 1491 kW and 2237 kW locomotives were such that a feasible variation of average train gross weight would be from the present value of 1000 tonnes to 1400 tonnes. An average weight of 1400 gross tonnes corresponds to a maximum weight of 1800 gross tonnes and to a maximum length of about 680 metres. Table 4.1 summarises the motive power requirements corresponding to both train weights and to various sections of the line.

TABLE 4.1 - MELBOURNE-ADELAIDE : MOTIVE POWER REQUIREMENTS

Section	Motive power requirements (kW)	
	1000 gross tonne trains	1400 gross tonne trains
Sunshine-Serviceton	2 x 1491	2 x 2237
Geelong-Serviceton	1 x 2237	1 x 2237
Serviceton-Tailem Bend	1 x 1491	1 x 1491
Tailem Bend-Belair	2 x 1491	3 x 1491

Analysis of available operating statistics on the Melbourne-Serviceton line indicated ratios of gross train weight to load carried of 2.23 and 2.37 for the up and down directions respectively[(1)]. Applying these ratios to the freight projections gave the number of trains required corresponding to these gross train weights. Tables 4.2 and 4.3 summarise the results in the form of daily interstate freight train requirements in the up and down directions, spread over a six day week as Saturday and Sunday traffic approximately

(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.

TABLE 4.2 - NUMBER OF INTERSTATE FREIGHT TRAINS PER 'BUSY DAY' : LOW PROJECTION

Year	Melbourne to Adelaide(a)		Adelaide to Melbourne(b)	
	1000 gross tonne trains	1400 gross tonne trains	1000 gross tonne trains	1400 gross tonne trains
1975/76	4.6	3.3	4.1	3.0
77	4.8	3.4	4.3	3.1
78	4.9	3.5	4.5	3.2
79	5.2	3.7	4.6	3.3
80	5.4	3.9	4.8	3.5
1980/81	5.6	4.0	5.0	3.6
82	5.8	4.2	5.2	3.7
83	6.0	4.3	5.4	3.9
84	6.3	4.5	5.6	4.0
85	6.5	4.7	5.9	4.2
1985/86	6.8	4.9	6.1	4.4
87	7.1	5.1	6.4	4.6
88	7.4	5.3	6.7	4.8
89	7.7	5.5	7.0	5.0
90	8.0	5.7	7.2	5.2
1990/91	8.3	6.0	7.6	5.4
92	8.7	6.2	7.9	5.7
93	9.0	6.5	8.2	5.9
94	9.4	6.7	8.6	6.1
95	9.8	7.0	9.0	6.4

(a) Gross train weight/load carried = 2.37

(b) Gross train weight/load carried = 2.23

NOTE: Numbers of trains are calculated on the assumption of 312 'busy days' per year. Fractions of trains would in practice be equivalent to a relief train running each time a full train load becomes available.

TABLE 4.3 - NUMBER OF INTERSTATE FREIGHT TRAINS PER 'BUSY DAY' : HIGH PROJECTION

Year	Melbourne to Adelaide(a)		Adelaide to Melbourne(b)	
	1000 gross tonne trains	1400 gross tonne trains	1000 gross tonne trains	1400 gross tonne trains
1975/76	4.7	3.4	4.7	3.3
77	4.9	3.5	4.8	3.5
78	5.1	3.7	5.1	3.6
79	5.3	3.8	5.3	3.8
80	5.5	4.0	5.5	3.9
1980/81	5.8	4.1	5.7	4.1
82	6.0	4.3	6.0	4.3
83	6.2	4.5	6.2	4.5
84	6.5	4.6	6.5	4.6
85	6.7	4.8	6.8	4.8
1985/86	7.0	5.0	7.1	5.1
87	7.3	5.2	7.4	5.3
88	7.6	5.4	7.7	5.5
89	7.9	5.7	8.1	5.8
90	8.2	5.9	8.4	6.0
1990/91	8.6	6.1	8.8	6.3
92	8.9	6.4	9.2	6.6
93	9.3	6.7	9.6	6.9
94	9.7	6.9	10.1	7.2
95	10.1	7.2	10.5	7.5

(a) Gross train weight/load carried = 2.37
(b) Gross train weight/load carried = 2.23

NOTE: Numbers of trains are calculated on the assumption of 312 'busy days' per year. Fractions of trains would in practice be equivalent to a relief train running each time a full train load becomes available.

equals one weekday's traffic. Because of the small number of interstate freight trains at the start of the study period (5 in each direction) and the relatively slow growth rate, it was found that rounding up the figure for the daily number of trains leads to a noticeable overestimate of the cost of carrying the projected interstate traffic. To remedy this problem fractional trains were introduced into the analysis, which in practice would amount to a relief train running only when a full train load is available.

4.2 TIMETABLING THE PROJECTED INTERSTATE FREIGHT TRAFFIC

The capacity of a single track railway line, as determined by delays and hence the capability of meeting a given timetable, is heavily dependent on that timetable. On the other hand, timetabling is constrained by availability of manpower and facilities for loading and unloading and on the freight forwarders' and passengers' requirements. In consultation with Victorian and South Australian Railways, it was agreed that, for all traffic other than interstate freight, the present timetable be retained; this would be consistent with the traffic projections (Chapter 2). Timetables for the projected interstate freight trains were to be prepared according to the following guidelines.

(a) A limited number of trains travelling overnight should depart as late as possible in the afternoon and arrive as early as possible next morning in an attempt to achieve a 24 hour door to door service. The remaining interstate freight trains will provide say, a 48 hour door to door service.

(b) During the early part of the study period, interstate freight trains are 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. Because of constraints imposed by existing goods yards (especially Dynon), a minimum of 90 minutes is required between the departure of consecutive trains. Thus, at first, the working day is filled in at 1.5 to 2.0 hour intervals.

(c) By about 1980, it is likely - according to some freight forwarders - that city congestion or legislation will force most freight to be delivered at night. It is therefore likely 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 become more evenly spread by making use of what now amounts to an 'off peak' period.

The timetables developed within these guidelines are summarised in Table 4.4. Also in this table the order in which trains should be introduced as traffic increases is given. These timetables were considered acceptable by South Australian and Victorian Railway officials with some slight modifications which fell within the limit of the half to two hours tolerance set on the predicted departure times.

4.3 CONGESTION DELAYS AND CAPACITY

4.3.1 Congestion Delays

Various attempts have been made to obtain estimates of delays analytically on a single track railway line[1][2]. These models either neglect realistic constraints such as limitations on the length

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(1) N.S.W. Public Transport Commission Report 'Proposed Upgrading of Main Line, Albury-Junee' (Sydney, August 1972, unpublished).

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

TABLE 4.4 - INTERSTATE EXPRESS FREIGHT TRAINS UP TO 1994/95

Train number	Departure time		Order of introduction
	MELBOURNE-SERVICETON		
	From Melbourne		
909	7.00 am - 8.00 am		11
919	5.00 am - 6.00 am		10
929	10.00 am - 11.00 am		Existing
931	11.30 am - 12.30 pm		9
933	1.30 pm - 2.30 pm		Existing
935	2.30 pm - 3.30 pm		Existing
937(a)	5.00 pm - 6.00 pm		8
939(a)	7.00 pm		Existing
949	8.00 pm - 9.00 pm		6
959	9.30 pm - 10.30 pm		Existing
969	12.00 pm - 1.00 am		7
	SERVICETON-MELBOURNE		
	From Adelaide	From Serviceton	
940(a)	6.30 pm	1.00 am	Existing
950	8.00 pm	3.00 am - 3.30 am	Existing
954	10.00 pm	5.00 am - 6.00 am	Existing
964	12.00 pm	7.00 am - 8.00 am	5
920	5.00 am	12.00 noon - 1.00 pm	9
976	10.00 am	6.00 pm - 7.00 pm	8
938	12.00 noon	7.00 pm - 8.00 pm	Existing
934	1.30 pm	9.00 pm - 10.00 pm	7
944(a)	3.30 pm	11.30 pm	6

(a) These trains always run on the main line even if Geelong Diversion is used, in order to achieve overnight service.

or number of crossing loops or do not account for the interaction between one section of the line and another, (Annex D). The model, jointly developed by the BTE and IBM Systems Development Institute[1] and used in this study, realistically simulates all the pertinent operational procedures and constraints that determine the progress of a train along a single or double track line. The model allows for the input of departure times, sectional transit time data by 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 synthesised by the model compare realistically with delays computed from an actual train diagram of the already congested Albury-Junee section of the Sydney-Melbourne link (Annex D), while other single track simulators could not cope with processing the data derived from the same train diagram. Other research by Jones and Walker[2] has verified the validity of using

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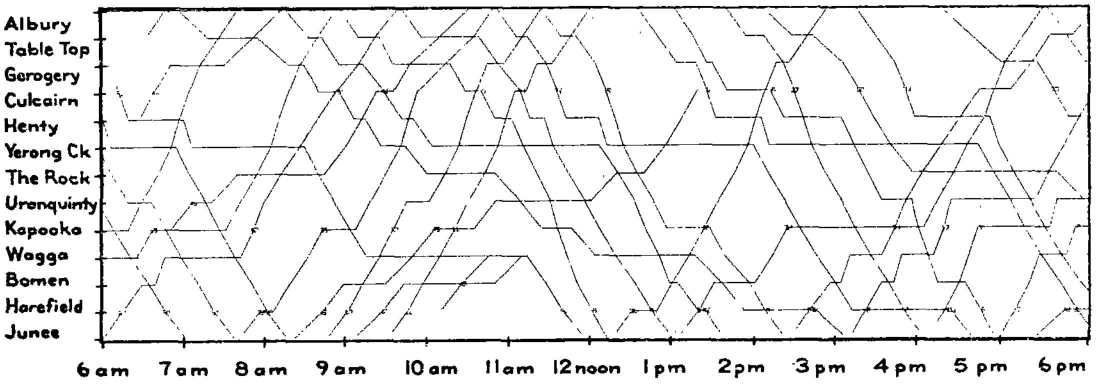
(1) D.A. Rudd & A.J. Storry, 'Single Track Railway Simulation (STS) - Documentation', IBM(SDI) Canberra, SDI0057 (December 1974).

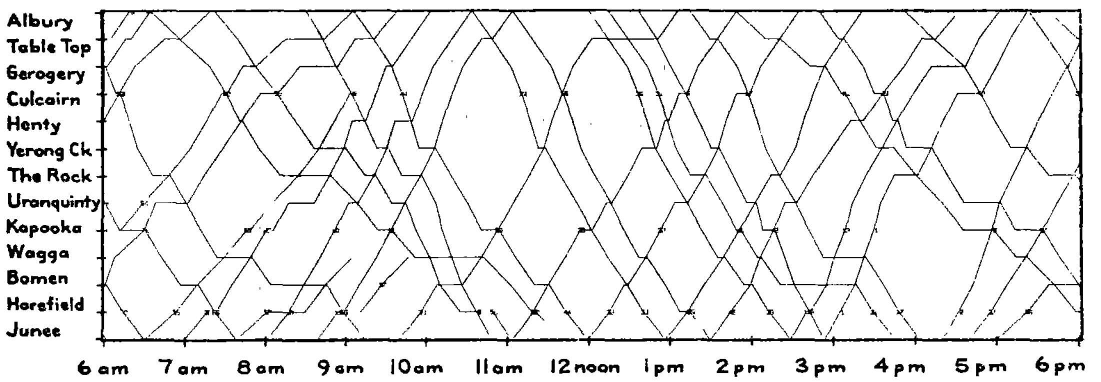
(2) J.C.M. Jones & A.E.G. Walker, 'The Application of Models of Single Railway Track Operation to Evaluate Upgrading Alternatives', Rail International, 7 (1973), pp 787-801.

weighted priority factors in resolving single track crossing conflicts in a realistic way. We are therefore confident that the delay parameters synthesised by the BTE/IBM model are realistic, given the deterministic nature of the assumed train departure schedules.

The performance of the line under each configuration is simulated with various traffic levels and the corresponding delay characteristics obtained. Physical capacity is reached when the next additional train cannot complete its journey within 24 hours. For illustrative purposes Figure 4.1 shows simulated train diagrams corresponding to near capacity situations on the Albury-Junee line. 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 D details the results of an analysis of the effect of late departure times on the delay pattern. 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 economically justified before physical capacity is reached. The physical capacities estimated by the model will tend to be higher than those achievable in practice; the effect of this on the evaluation results will be to understate the derived benefit/cost ratios accruing from upgrading, but the derived commercial rates of return from upgrading will be unaffected.



(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

4.3.2 Commercial and Resource Capacity

The approach to deriving the traffic capacity of a railway line is based on that proposed by Jones and Walker(1), also detailed in Annex E. 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 delayed to undelayed transit time per train.

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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 goods inventory in transit and on passenger time costs is negligible (Annex E, Section E.1.2).

As additional trains are scheduled, the revenue will be increasingly eroded by the increase in the congestion 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 <u>commercial capacity</u>. 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 <u>resource capacity</u>. It would be expected to be somewhere between commercial capacity and physical capacity, as previously defined (Section 4.3.1).

It is shown in Annex E 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.

4.4 SELECTION AND TIMING OF UPGRADING

Determining the optimal timing of an upgrading is a more or less complex process depending on whether it occurs before or after commercial capacity has been reached. As far as this study is concerned, the best upgrading measures are optimally timed before commercial capacity occurs and it will be shown in the following section that, in such a case, timing is independent of gross revenue rate and is the same according to both commercial and resource cost criteria. The same simplification however does not hold in cases where upgrading is only justifiable after the capacity constraint has occurred.

4.4.1 Upgradings Justifiable Before Capacity Constraint Occurs

We can extend the formulation of Section 4.3.2 to determine whether or not an upgrading should be considered from the commercial viewpoint. Using the same

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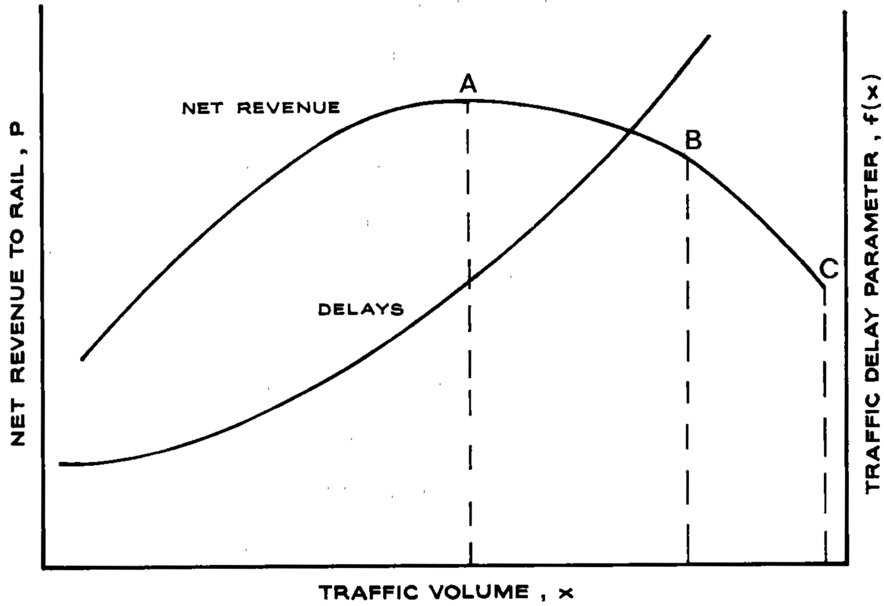
(1) Strictly speaking, some administrative costs which vary with traffic should be allocated to growth traffic.



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 nomenclature as before, it is evident that upgrading is justified when:

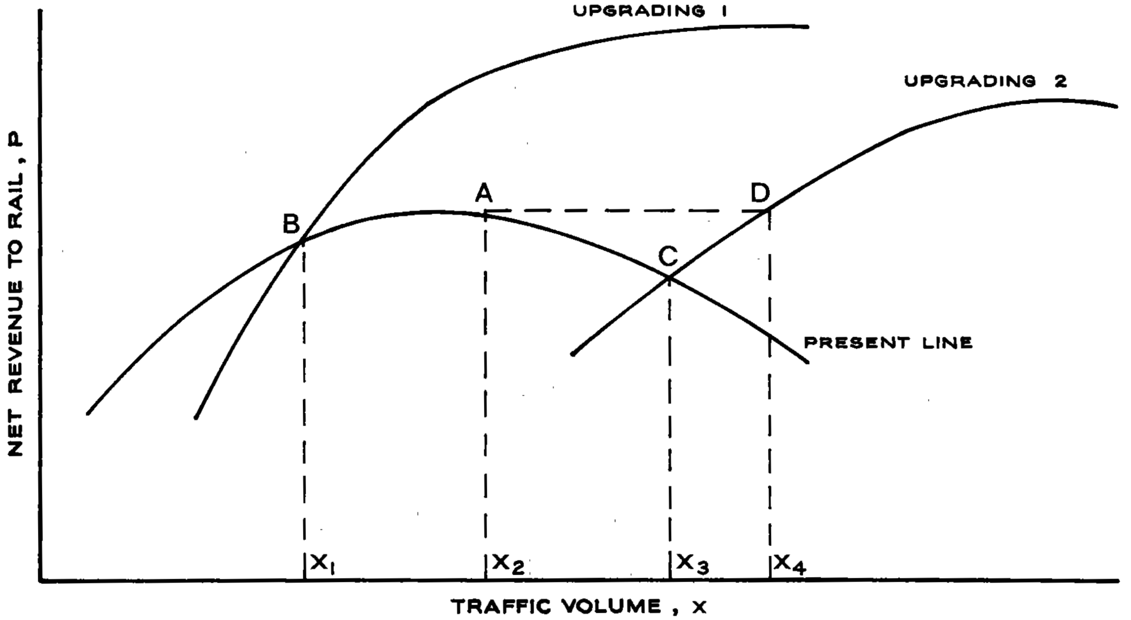
$$x\{R - C_1'(1 + D') - C_2'\} - C_3' \geq x\{R - C_1(1 + D) - C_2\} - C_3$$

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 costs of diverting to the next best mode or 'overflow' costs are added to the cost of carrying the capacity traffic on the existing line. Overflow costs would start occuring as soon as the resource capacity constraint applies, but the optimum point of introduction of the upgrading remains at x_1.



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

4.4.2 Upgradings Justifiable after 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). As shown in Annex E, the gross revenue term R can no longer be eliminated, the optimal timing of the upgrading from the commercial viewpoint being 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 in general occur at a different traffic volume[(2)].

4.4.3 Selection from a Large Number of Upgradings

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

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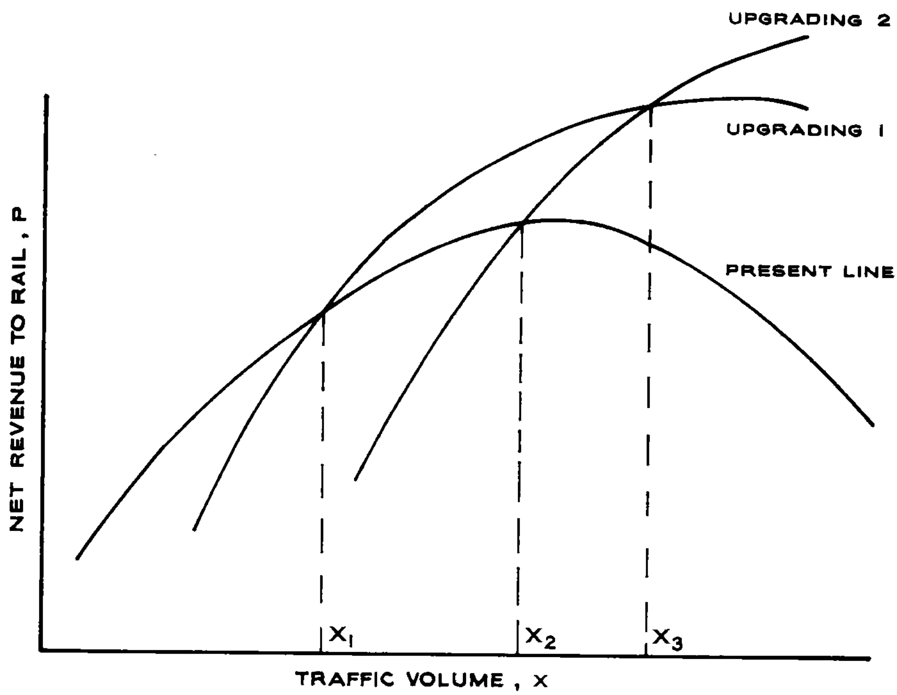
(1) Equation (E.3) indicates that the commercial capacity point is a function of the gross revenue per train R.

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

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 (see Annex D).

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 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.



X_1 : TRAFFIC VOLUME AT WHICH UPGRADING I 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 I

FIGURE 4.4

CHOICE BETWEEN UPGRADINGS, COMMERCIAL CRITERIA

4.5 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 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 railways' 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 Adelaide, is based on LCL traffic moving through consolidating depots, although in principle, the model suggested by the figure could also be applied to

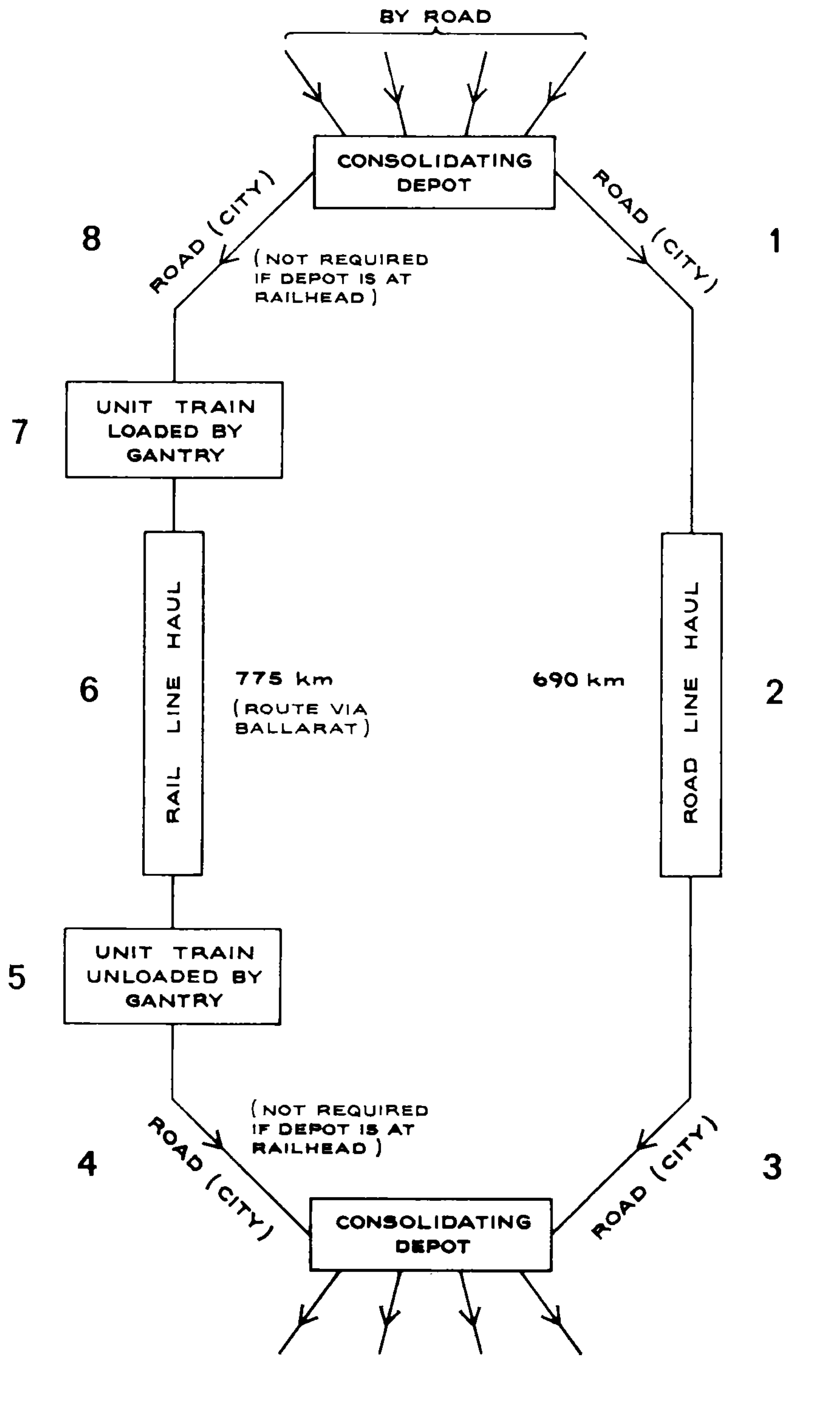


FIGURE 4.5

FLOW CHART FOR TRANSPORT OF GENERAL FREIGHT

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 fifty five kilometres.

In considering the cost of transporting the general freight diverted on to road, some estimates of average truck operating costs/km are required. The figures chosen for use in this study are based on present costs of operating a semi-trailer shuttle service between Sydney and Melbourne[2]. No estimates are available for the road link between Melbourne and Adelaide, but these are unlikely to be very different from the costs of operating trucks on the present Hume Highway. The overflow trucks are also likely to cause

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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.

(2) Bureau of Transport Economics, 'A study of Inter-system Railway Rating Practices with Particular Reference to the Riverina Area of N.S.W.' (Canberra, to be published).

delays to other traffic using the road between Melbourne and Adelaide; however, with the traffic volumes expected within the next twenty years, these additional congestion costs are expected to be negligible on that particular road and are not included in the analysis.

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.

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

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

The difference between the NPVs for the situation with and without rail upgradings 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 projection 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 the variations in the following parameters:

- projections (low and high),
- train weight (an average weight of 1000 and 1400 gross tonnes),
- discount rate (7%, 10%, and 12%), and
- 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(1) that the fuel price will only have a small effect on the modal split in the near future. It is estimated that a 30% rise in fuel cost is likely to change the modal split by about 2% in favour of rail, indicating that variations in fuel price are unlikely to influence the outcome of this particular study.

The freight projections were calculated from a base year of 1975/76. All costs are quoted in 1973 dollars. The study period is 1975/76 to 1994/95, 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 PRELIMINARY EXAMINATION

The upgrading schemes proposed by Victorian Railways and examined in this study may be grouped into three categories:

- **signalling improvements and line doubling as capacity increasing measures;**

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

- deviations to obtain better track alignments and faster running grades; and

- electrification to reduce running times on steep grades and to reduce locomotive maintenance costs.

In addition, possible upgradings to the South Australian sector were also examined.

A preliminary examination of all the proposals showed that the deviations, electrification and upgradings to the South Australian sector were clearly not justifiable on economic grounds considering the expected traffic levels within the next 20 years. These will therefore be examined only briefly before proceeding with the main comparisons of the various signalling improvements and line doubling proposals.

Two deviations, namely Parwan to Horseshoe Creek and Millbrook to Dunnstown, were proposed by Victorian Railways. Reference to Fig. 3.5 will locate these sections. Annex C quotes their estimated costs as $1.77 million and $1.50 million respectively and also demonstrates that each estimated cost saving from reduced running time would be in the region of $1 million discounted over the twenty year study period at 7%. Although the basic rate for train running costs does not account for the indirect costs of longer transit time, such as for example the consequent costs incurred by the shipper, the assumed rate would have to increase by a factor of about 2 to cover the cost of the deviations. In the absence of evidence to support such an increase, no further evaluation of the deviations was made.

Electrification was proposed in three stages - Sunshine to Ballarat, followed by Ballarat to Ararat, and completed by Ararat to Stawell for a total estimated capital cost of $8 million. This would include the major steep gradients on the Melbourne-Serviceton line. The corresponding train running time savings from using electric traction are estimated to be about 10 minutes per train. Most of this saving would be lost in changing locomotives at the end of the electrified section and additional locomotives would be required to sustain a mixed diesel, electric operation. Time saving was therefore ignored. The only data available on the reduction in locomotive maintenance costs to be expected from electric traction was an indication from the Public Transport Commission of N.S.W. who suggested that a reduction of 50% from diesel traction could be obtained. Taking a diesel locomotive maintenance cost of 15 cents per km, it was found that projected traffic on the line would have to grow by a factor of at least 5 before electrification could be economically justified on grounds of lower locomotive maintenance costs (Annex C). Electrification was therefore not considered further.

Upgrading of the South Australian sector was proposed in the form of curvature improvements between Adelaide and Murray Bridge at an estimated capital cost of $27.9 million (Annex C). These would reduce transit time by approximately 45 minutes. Using the same method to estimate cost savings as for the deviations, we obtain a total discounted saving (at 7%) of about $9.3 million (Annex C) for the twenty year study period. Because savings are only about a third of the costs, upgrading of the South Australian sector of the Melbourne-Adelaide line 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 between Sunshine and Serviceton, as derived from results given by the BTE/IBM Single Track Simulation Model (STS)[1]. The main features of the table are:

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(1) Details of this model are given in Annex D.

- In the case of 1000 tonne trains physical capacity does not occur within the study period;

- The use of heavier trains is counter-productive because their increased length exceeds the length of crossing loops at which most crossings take place i.e. west of Ararat. Had all the loops been sufficiently long to accommodate 1400 tonne trains, physical capacity would have occurred later than in the case of the shorter trains because fewer 1400 tonne trains are required to carry the projected tonnage.

TABLE 5.1 - YEARS IN WHICH PHYSICAL CAPACITY IS REACHED ON EXISTING LINE

Train Weight (gross tonnes)	Low Freight Projection	High Freight Projection
1000	20	(a) —
1400	11	10

(a) Option not considered in this study.

NOTE: Capacity years were estimated using the Single Track Railway Simulation model (STS).

5.2.2 Commercial Capacities

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 commercial capacity to be a function of both revenue and discount rate. This is brought out in Table 5.2 which summarises the estimates of commercial capacity for both train weights and for the low and high projections. 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 decrease as train weight is increased because of loop length limitations. These expectations are consistent with the results.

In the case of the low freight projection with 1400 tonne trains, 0.62 cent/tonne km revenue and the higher interest rates, the net revenue curve starts sloping downwards from the beginning of the study period, indicating that commercial capacity has been reached sometime in the past. It can be noted also, that

TABLE 5.2 - YEARS IN WHICH COMMERCIAL CAPACITY IS REACHED : EXISTING LINE

Freight projection	Average gross weight of interstate freight trains (tonnes)	Revenue (cents/tonne km)	Interest rate		
			7%	10%	12%
Low	1000	0.62	11	11	8
		0.81	17	15	15
	1400	0.62	11	1	1
		0.81	11	11	11
High	1400	0.62	6	6	6
		0.81	6	6	6

for the higher revenue rate, both the physical and commercial capacities occur in the same year; thus in this particular case, 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, all possible combinations of 19 basic upgrading increments were evaluated in detail - see Table 5.3. The results (Tables 5.4 to 5.9) will be expressed in terms of Net Present Value (NPV) of net revenue to the railway over a range of discount rate. The reasoning leading to the selection of this criterion is discussed in Section 4.4.

Tables 5.4 to 5.7 summarise the results for both train weights with the freight forecast set at the 'low' level and the revenue rate set at 0.62 and 0.81 cents/tonne km respectively. All upgrading sequences having an NPV greater than that of the existing line are included in the tables. Note that combinations involving line doubling are never in this category. The main implications are as follows.

TABLE 5.3 - BASIC UPGRADING INCREMENTS STUDIED IN DETAIL

Number	Description	Label
1	10 extended loops, Sunshine to Serviceton	EL
2	5 extended loops, Sunshine to Ararat (Eastern Section)	ELE
3	5 extended loops, Ararat to Serviceton (Western Section)	ELW
4	CTC Scheme 1, Sunshine to Serviceton	CTC1
5	CTC Scheme 1, Sunshine to Ararat	CTC1E
6	CTC Scheme 1, Ararat to Serviceton	CTC1W
7	CTC Scheme 2, Sunshine to Serviceton	CTC2
8	CTC Scheme 2, Sunshine to Ararat	CTC2E
9	CTC Scheme 2, Ararat to Serviceton	CTC2W
10	CTC Scheme 3, Sunshine to Serviceton	CTC3
11	CTC Scheme 3, Sunshine to Ararat	CTC3E
12	CTC Scheme 3, Ararat to Serviceton	CTC3W
13	CTC Scheme 4, Sunshine to Serviceton	CTC4
14	CTC Scheme 4, Sunshine to Ararat	CTC4E
15	CTC Scheme 4, Ararat to Serviceton	CTC4W
16	Geelong Diversion, Geelong to Ararat	GD
17	Doubling, Kaniva to Serviceton	DB1
18	Doubling, Dimboola to Salisbury loop	DB2
19	Doubling, Nhill to Diapur	DB3

TABLE 5.4 - COMMERCIAL RESULTS : LOW FREIGHT PROJECTION, 1000 GROSS TONNE TRAINS AND 0.62 CENTS/TONNE KM REVENUE

Interest rate								
7%			10%			12%		
Line configuration (a)	Best year of introduction (b)	NPV of net revenue ($million)	Line configuration	Best year of introduction	NPV of net revenue ($million)	Line configuration	Best year of introduction	NPV of net revenue ($million)
Existing	-	10.37	Existing	-	6.51	Existing	-	4.81
CTC4	1	11.40	ELW, EL, CTC4	3, 10, 14	6.85	ELW, CTC4	3, 17	4.86
ELW, CTC3	3, 11	11.10	ELW, EL	3, 10	6.79	ELW, EL	3, 18	4.86
CTC1	8	11.04	ELW, CTC3	3, 17	6.74	ELW	3	4.85
ELW, EL	3, 10	10.95	ELW	3	6.70	CTC3	18	4.81
CTC2	11	10.89	CTC1	11	6.63	CTC2	19	4.81
CTC3W	14	10.46						
CTC4W	16	10.40						

(a) See list of abbreviations in Table 5.3 (b) Year 1 is 1975/76

NOTE: All upgrading sequences having an NPV greater than that of the existing line are included.

TABLE 5.5 - COMMERCIAL RESULTS : LOW FREIGHT PROJECTION, 1000 GROSS TONNE TRAINS AND 0.81 CENTS/TONNE KM REVENUE

Interest rate								
7%			10%			12%		
Line configuration (a)	Best year of introduction (b)	NPV of net revenue ($million)	Line configuration	Best year of introduction	NPV of net revenue ($million)	Line configuration	Best year of introduction	NPV of net revenue ($million)
Existing	-	24.26	Existing	-	17.28	Existing	-	14.00
CTC4	1	25.62	ELW, CTC4	3, 10	17.85	ELW, EL, CTC3	3, 10, 18	14.27
ELW, EL, CTC3	3, 10, 11	24.35	ELW, EL, CTC4	3, 10, 14	17.85	ELW, EL	3, 10	14.26
CTC1	8	25.26	ELW, EL, CTC3	3, 10, 17	17.85	ELW, CTC4	3, 14	14.21
ELW, EL	3, 10	25.16	ELW, EL	3, 10	17.82	CTC1	11	14.03
CTC2	11	25.14	CTC1	11	17.62	CTC2	14	14.00
ELW, CTC3W	3, 18	24.72	CTC2	14	17.57			
ELW	3	24.69	ELW	3	17.54			
CTC4W	11	24.33	CTC3W	19	17.30			
CTC1W	19	24.29	CTC4W	19	17.29			

(a) See list of abbreviations in Table 5.3 (b) Year 1 is 1975/76

NOTE: All upgrading sequences having an NPV greater than that of the existing line are included.

TABLE 5.6 - COMMERCIAL RESULTS : LOW FREIGHT PROJECTION, 1400 GROSS TONNE TRAINS AND 0.62 CENTS/TONNE KM REVENUE

Interest rate								
7%			10%			12%		
Line configuration (a)	Best year of introduction (b)	NPV of net revenue ($million)	Line configuration	Best year of introduction	NPV of net revenue ($million)	Line configuration	Best year of introduction	NPV of net revenue ($million)
Existing	-	10.61	Existing	-	7.00	Existing	-	5.22
CTC4	1	14.99	EL	1	9.54	EL	1	7.10
EL	1	14.58	CTC4W, CTC4	1, 4	9.17	CTC4W, CTC4	1, 9	6.47
CTC1	1	14.51	CTC4W	1	8.91	CTC4W	1	6.40
CTC4W	1	14.16	CTC1W, CTC1	1, 6	8.74	CTC1W, CTC1	1, 9	6.08
CTC3	1	14.14	ELW, CTC3W, CTC3	1, 4, 9	8.59	ELW, CTC3W, CTC3	1, 5, 12	6.05
CTC1W	1	13.79	CTC1W	1	8.55	CTC1W	1	6.05
CTC3W	1	13.66	ELW, CTC3W	1, 4	8.50	ELW, CTC3W	1, 5	6.05
CTC2	1	13.54	ELW, CTC4WGD	1, 9	7.95	ELW, CTC4WGD	1, 9	5.60
CTC2W	1	13.05	ELW, CTC3WGD	1, 9	7.91	CTC2W, CTC2	10, 18	5.59
ELW, CTC4GD	1, 9	12.98	CTC2W, CTC2	6, 11	7.91	CTC2W	10	5.57
ELW, CTC4WGD	1, 9	12.90	ELW, CTC4GD	1, 10	7.87	ELW, CTC3WGD	1, 10	5.56
ELW, CTC3WGD	1, 9	12,85	CTC2W	6	7.84	ELW, CTC4GD	1, 11	5.48
ELW, CTC3GD	1, 9	12.75	ELW, CTC3GD	1, 11	7.71	ELW, CTC3GD	1, 11	5.35
ELW, GD	1, 11	11.76	ELW, GD	1, 11	7.26			
ELW	1	11.53	ELW	1	7.17			

(a) See list of abbreviations in Table 5.3 (b) Year 1 is 1975/76

NOTE: All upgrading sequences having an NPV greater than that of the existing line are included.

TABLE 5.7 - COMMERCIAL RESULTS : LOW FREIGHT PROJECTION, 1400 GROSS TONNE TRAINS AND 0.81 CENTS/TONNE KM REVENUE

Interest rate								
7%			10%			12%		
Line configuration (a)	Best year of introduction (b)	NPV of net revenue ($million)	Line configuration	Best year of introduction	NPV of net revenue ($million)	Line configuration	Best year of introduction	NPV of net revenue ($million)
Existing	-	23.97	Existing	-	16.96	Existing	-	13.53
CTC4	1	29.24	EL	1	20.60	EL	1	16.60
EL	1	28.83	CTC4W, CTC4	1, 4	20.23	CTC4W, CTC4	1, 9	15.97
CTC1	1	28.76	CTC4W	1	19.97	CTC4W	1	15.87
CTC4W	1	28.41	CTC1W, CTC1	1, 6	19.81	CTC1W, CTC1	1, 9	15.59
CTC3	1	28.39	ELW,CTC3W, CTC3	1, 4, 9	19.65	ELW, CTC3W, CTC3	1, 5, 12	15.55
CTC1W	1	28.04	CTC1W	1	19.61	ELW, CTC3W, GD	1, 5, 18	15.53
CTC3W, GD	1, 18	27.90	ELW, CTC3W, GD	1, 14, 18	19.55	CTC1W	1	15.52
CTC3W, CTC3GD	1, 18	27.84	ELW, CTC3W	1, 4	19.49	ELW, CTC3W	1, 5	15.50
CTC3W	1	27.81	ELW, CTC4WGD	1, 9	19.04	ELW, CTC4WGD	1, 9	15.12
CTC2	1	27.79	CTC2W, CTC2	6, 11	18.95	ELW, CTC4GD	1, 11	15.00
CTC2W	1	27.28	ELW, CTC4GD	1, 10	18.95	CTC2W, CTC2	6, 18	14.91
ELW, CTC4GD	1, 9	27.27	CTC2W	6	18.88	CTC2W	6	14.89
ELW, CTC4WGD	1, 9	27.18	ELW, CTC3GD	1, 11	18.79	ELW, CTC3GD	1, 11	14.86
ELW, GD	1, 11	26.02	ELW, GD	1, 11	18.32	ELW, GD	1, 11	14.60
ELW	1	25.36	ELW	1	17.98	ELW	1	14.38

(a) See list of abbreviations in Table 5.3 (b) Year 1 is 1975/76

NOTE: All upgrading sequences having an NPV greater than that of the existing line are included.

- The existing line offers no advantage to the use of heavier trains (compare Tables 5.4 and 5.5 to Tables 5.6 and 5.7). This is due to the additional delays which occur as a result of the longer trains not being able to use many of the existing, relatively short loops. Although most of the interstate express freight trains cross west of Ararat in the earlier years of the study period, crossings with passenger trains east of Ararat incur long delays as only 10 of the 17 loops are long enough to accommodate the 1000 tonne trains, and only 4 of the 17 loops can be used by the 1400 tonne trains. Thus benefits from the use of heavier trains will initially flow from locomotive and crew savings, rather than from savings in congestion delay. Delays will not be reduced until improvements involving passing loop extensions are introduced.

- Once the line is upgraded, 1400 tonne trains are clearly superior to the present 1000 tonne trains; this is shown by consistently higher NPVs of net revenue. In fact, the benefits from upgrading, calculated as the difference between NPVs of net revenue, are over four times greater for the heavier trains.

- In all cases, various combinations of the 'Extended loops' and the 'CTC Scheme 4' upgrading measures are shown to be superior to other improvements. Note that these measures are the two cheapest proposed. The higher capital cost of CTC4 is compensated by the savings in signalling manpower.

- The Geelong Diversion option, which results in considerable savings in motive power in the case of the heavier trains (Annex C, Section C.1.2) is not as attractive as upgradings to the main line. The relatively high cost of the upgrading, the additional 50 minutes delay and the longer journey (Section 3.2) resulting in higher locomotive and rolling stock maintenance costs are clearly not offset by the savings in motive power requirements. It was found that even if the 50 minutes additional delay between Melbourne and Geelong was completely eliminated as a result of an upgrading justified solely by benefits to commuter traffic, Geelong Diversion could still not match the best upgradings on the main line.

- The first stage of the best upgrading sequences involving extended loops or CTC Scheme 4 - are timed optimally within the next three years, this timing being insensitive to discount rates over the range 7% to 12% and revenue rate over the range 0.62 and 0.81 cents/tonne km. The timing of the second stage of these sequences is however sensitive to interest rate and would occur between 1975 and 1985 (1).

Tables 5.8 and 5.9 show the effect of increasing the freight projection to the 'high' level on selection and timing of upgrading for the preferred 1400 tonne trains at revenue rates 0.62 and 0.81 cents per tonne km respectively. The tables show that increasing the traffic merely advances the timing of upgrading; the preferred upgradings are unchanged.

Figure 5.1 shows plots of the differences in the NPVs of net revenue between the existing and upgraded lines for a range of discount rates. The plots are for

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(1) As discussed in Section 4.1, it is likely that development of special container wagons could reduce the ratio of gross train weight to load carried. The resultant increased train carrying capacity would ultimately be reflected as a reduction in congestion delays. However, the effect of such a development on the results of this study is small; the timing of the first stages of the preferred upgradings would only be delayed by about a year.

TABLE 5.8 - COMMERCIAL RESULTS : HIGH FREIGHT PROJECTION, 1400 GROSS TONNE TRAINS AND 0.62 CENTS/TONNE KM REVENUE

Interest rate								
7%			10%			12%		
Line configuration (a)	Best year of introduction (b)	NPV of net revenue ($million)	Line configuration	Best year of introduction	NPV of net revenue ($million)	Line configuration	Best year of introduction	NPV of net revenue ($million)
Existing	-	11.53	Existing	-	7.25	Existing	-	5.14
CTC4	1	16.00	EL	1	10.09	EL	1	7.45
EL	1	15.56	CTC4W, CTC4	1, 6	9.82	CTC4W, CTC4	1, 10	6.93
CTC1	1	15.52	CTC4W	1	9.49	CTC4W	1	6.78
CTC4W, CTC4GD	1, 18	15.14	CTC1W, CTC1	1, 6	9.40	CTC1W, CTC1	1, 10	6.55
CTC4W, GD	1, 18	15.12	CTC1W	1	9.14	CTC1W	1	6.43
CTC4W	1	15.09	CTC3W, CTC3	1, 10	9.13	CTC3W, CTC3	1, 12	6.34
CTC3W, CTC3	1, 5	15.07	CTC3, GD	1, 17	9.01	CTC3W, GD	1, 18	6.31
CTC2	1	14.78	CTC3W	1	9.00	CTC3W	1	6.29
CTC1W, CTC1GD	1, 18	14.76	CTC2W, CTC2	5, 11	8.77	CTC2W, CTC2	5, 13	6.03
CTC1W, GD	1, 18	14.75	CTC2W	5	8.53	CTC2W	5	5.90
CTC1W	1	14.73	ELW, CTC4WGD	1, 8	8.22	ELW, CTC4WGD	1, 10	5.76
CTC3W, GD	1, 17	14.61	ELW, CTC4GD	1, 10	8.14	ELW, CTC4GD	1, 10	5.63
CTC3W, CTC3GD	1, 17	14.59	CTC1WGD	9	8.04	CTC1WGD	10	5.54
CTC3W	1	14.52	ELW, CTC3GD	1, 11	7.98	ELW, CTC3GD	1, 13	5.52
CTC2W	1	14.11	CTC1GD	10	7.92	ELW	1	5.34
ELW	1	12.41	ELW	1	7.61			
ELWGD	10	11.96	ELWGD	14	7.29			

(a) See list of abbreviations in Table 5.3 (b) Year 1 is 1975/76

NOTE: All upgrading sequences having an NPV greater than that of the existing line are included.

TABLE 5.9 - COMMERCIAL RESULTS : HIGH FREIGHT PROJECTION, 1400 GROSS TONNE TRAINS AND 0.81 CENTS/TONNE KM REVENUE

Interest rate								
7%			10%			12%		
Line configuration (a)	Best year of introduction (b)	NPV of net revenue ($million)	Line configuration	Best year of introduction	NPV of net revenue ($million)	Line configuration	Best year of introduction	NPV of net revenue ($million)
Existing	–	25.05	Existing	–	17.98	Existing	–	14.47
CTC4	1	31.53	EL	1	22.13	EL	1	17.78
EL	1	31.08	CTC4W, CTC4	1, 6	21.86	CTC4W, CTC4	1, 10	17.26
CTC1	1	31.05	CTC4W, GD	1, 18	21.52	CTC4W	1	17.09
CTC4W, CTC4GD	1, 18	30.66	CTC4W	1	21.51	CTC1W, CTC1	1, 10	16.88
CTC4W, GD	1, 18	30.64	CTC1W, CTC1	1, 6	21.44	CTC1W	1	16.74
CTC4W	1	30.62	CTC3W, CTC3	1, 10	21.17	CTC3W, CTC3	1, 12	16.68
CTC3W, CTC3	1, 5	30.59	CTC1W, GD	1, 18	21.17	CTC3W, GD	1, 16	16.64
CTC2	1	30.30	CTC1W	1	21.15	CTC3W, CTC3GD	1, 18	16.59
CTC1W, CTC1GD	1, 18	30.29	CTC3W, GD	1, 16	21.05	CTC3W	1	16.58
CTC1W, GD	1, 18	30.28	CTC3W, CTC3GD	1, 18	21.00	CTC2W, CTC2	5, 13	16.36
CTC1W	1	30.25	CTC3W	1	20.97	CTC2W	5	16.21
CTC3W, GD	1, 16	30.15	CTC2W, CTC2	5, 11	20.81	ELW, CTC4WGD	1, 9	16.02
CTC3W, CTC3GD	1, 16	30.12	CTC2W	5	20.56	ELW, CTC4GD	1, 11	15.90
CTC3W	1	30.01	ELW, CTC4GD	1, 10	20.20	ELW	1	15.46
CTC2W	1	29.64	ELW	1	19.48	ELWGD	9	15.07
ELW	1	27.77	ELWGD	9	19.01			
ELWGD	8	27.16						

(a) See list of abbreviations in Table 5.3 (b) Year 1 is 1975/76

NOTE: All upgrading sequences having an NPV greater than that of the existing line are included.

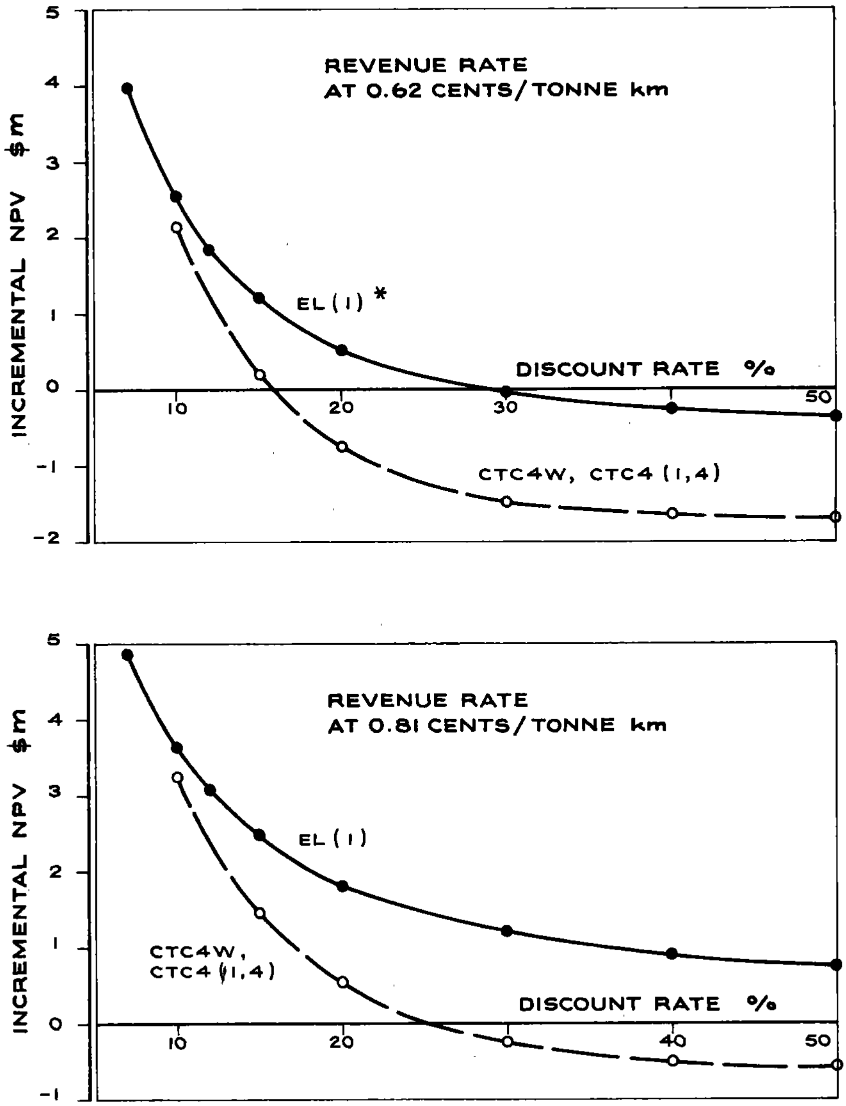

FIGURE 5.1

CALCULATION OF RATE OF RETURN TO INVESTMENT IN UPGRADING

LOW FREIGHT PROJECTION

AVERAGE WEIGHT OF INTERSTATE FREIGHT TRAINS : 1400 GROSS TONNES

* ABBREVIATIONS ARE LISTED IN TABLE 5.3

THE YEAR OF INTRODUCTION IS GIVEN IN THE BRACKETS the heavier train weight and indicate the internal rate of return to the railway which can be expected from implementing the best upgrading measures. If CTC is introduced the rate of return is expected to lie between 15 and 25%, depending on the revenue rate. However, the option involving extension of 10 crossing loops would generate a higher rate of return, 30% or higher in both cases.

Considering that some benefits of CTC4 could not be quantified (Section 3.1) while all benefits to loop extensions were evaluated, CTC4 may ultimately be preferred.

5.4 PHYSICAL AND COMMERCIAL CAPACITIES OF THE BEST UPGRADING OPTIONS

Table 5.10 shows the years in which commercial capacity is reached for some of the best upgrading increments. It turns out that physical capacity is not reached on the configurations shown until year 18 at the earliest. The estimates were obtained in the same way as those for the existing line (Section 5.2). As expected, commercial capacity occurs later with the heavier trains and with upgrading options covering the whole length of the Melbourne-Serviceton link.

TABLE 5.10 - YEARS IN WHICH COMMERCIAL CAPACITY OF SOME PREFERRED UPGRADING INCREMENTS IS REACHED: LOW FREIGHT PROJECTION

Upgrading Increment(a)	Revenue (cent/tonne km)	1000 tonne trains (Av)			1400 tonne trains (Av)		
		7%	10%	12%	7%	10%	12%
ELW	0.62	14	14	10	14	14	14
	0.81	20	17	18	14	14	14
EL	0.62	18	18	18	20	20	20
	0.81	20	20	20	20	20	20
CTC4W	0.62	15	15	11	20	20	18
	0.81	20	20	20	20	20	20
CTC4	0.62	18	17	15	20	20	20
	0.81	20	20	20	20	20	20

(a) See Table 5.3 for list of abbreviations.

NOTE: Physical capacities of the above upgrading increments do not occur within the study period except in the case of the ELW option; this option reaches its physical capacity in year 18.

5.5 EVALUATION OF UPGRADINGS - RESOURCE CRITERIA

From a resource point of view, we are concerned with the development of a Melbourne-Adelaide transport corridor that meets the total transport task in the most economic way.

Previous sections have indicated that, from the railway's point of view, the best way to upgrade the Melbourne-Serviceton line is to increase gross train weight to 1400 tonnes, and either extend the shorter crossing loops or introduce the cheapest CTC scheme. All these upgradings would be introduced before commercial capacity is reached and are primarily cost reducing measures. Thus, it would be expected that upgradings derived on commercial criteria would be consistent with those derived on resource criteria. It will therefore be sufficient to present resource benefit-cost ratios of the short list of options considered for the commercial evaluation.

Rail revenue is not included in resource calculations and the 'base case' consists of the existing rail link which carries all traffic in 1400 tonne trains up to physical capacity, beyond which further growth would be diverted to road.

Table 5.11 expresses as an NPV the total resource cost[(1)] 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 1400 tonne trains and the low forecast are shown for a range of discount rates. As expected, the best upgrading measures are consistent with the results based on the commercial viewpoint.

It is interesting to examine the breakdown of cost elements expressed in NPV terms. Table 5.12 presents, as an example, the breakdown of road and rail cost elements corresponding to the introduction of CTC4 and the 'do-nothing' case. In this particular example physical capacity is reached in year 11 if rail is not upgraded; all the projected traffic can be carried on the improved line.

The table shows that fuel, train and track maintenance 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, these costs would still dominate in all cases considered in this report.

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(1) Defined in Section 4.5.

TABLE 5.11 - RESOURCE RESULTS : LOW FREIGHT PROJECTION, 1400 GROSS TONNE TRAINS

Interest rate								
7%			10%			12%		
Line configuration (a)	Best year of introduction (b)	NPV of total resource cost ($million)	Line configuration	Best year of introduction	NPV of total resource cost ($million)	Line configuration	Best year of introduction	NPV of total resource cost ($million)
Existing	-	63.66	Existing	-	51.88	Existing	-	46.14
CTC4	1	55.55	EL	1	46.39	EL	1	41.66
EL	1	55.96	CTC4W, CTC4	1, 4	46.78	CTC4W, CTC4	1, 9	42.28
CTC1	1	56.03	CTC4W	1	47.02	CTC4W	1	42.38
CTC4W, CTC4GD	1, 18	56.37	CTC1W, CTC1	1, 6	47.19	CTC1W, CTC1	1, 9	42.67
CTC4W, GD	1, 18	56.38	ELW, CTC3W, CTC3	1, 4, 9	47.34	ELW, CTC3W, CTC3	1, 5, 12	42.70
CTC4W	1	56.39	CTC1W	1	47.38	ELW, CTC3W, GD	1, 5, 18	42.72
CTC3	1	56.40	ELW, CTC3W, GD	1, 4, 18	47.44	CTC1W	1	42.74
CTC1W, CTC1GD	1, 18	56.74	ELW, CTC3W	1, 4	47.50	ELW, CTC3W	1, 5	42.76
CTC1W	1	56.75	ELW, CTC4WGD	1, 9	47.92	ELW, CTC4WGD	1, 9	43.12
CTC3W, GD	1, 18	56.88	ELW, CTC4GD	1, 9	48.01	ELW, CTC4GD	1, 11	43.24
CTC3W, CTC3GD	1, 18	56.95	CTC2W, CTC2	6, 11	48.05	CTC2W, CTC2	6, 18	43.34
CTC3W	1	56.98	CTC2W	6	48.11	CTC2W	6	43.36
CTC2	1	57.00	ELW, CTC3GD	1, 11	48.18	ELW, CTC3GD	1, 11	43.37
CTC2W	1	57.51	ELW, GD	1, 11	48.67	ELW, GD	1, 11	43.67
ELW, GD	1, 11	58.80	ELW	1	49.23	ELW	1	44.13
ELW	1	54.54						

(a) See list of abbreviations in Table 5.3 (b) Year 1 is 1975/76

NOTE: All upgrading sequences having an NPV less than that of the existing line are included.

TABLE 5.12 - RESOURCE COST AND SAVING ELEMENTS: LOW FREIGHT PROJECTION, 1400 GROSS TONNE TRAINS AND 10% DISCOUNT RATE

($ million)

Cost elements	NPVs of savings		Net savings from upgrading
	CTC4W in 1975/76 and CTC4 in 1978/79	Existing line	
Rail costs[a]			
Cost of upgrading	- 3.91	-	-3.91
Manpower savings	2.48	-	2.48
Train capital	-12.44	-14.06	1.62
Train crew	- 4.61	- 5.74	1.13
Fuel, train and track maintenance	-25.71	-24.34	-1.37
Gantry capital	- 1.59	- 1.50	-0.09
Gratry operating	- 1.00	- 0.93	-0.07
Road costs[b]			
Truck capital	-	- 1.58	1.58
Driver's wages	-	- 2.08	2.08
Truck operating	-	- 1.65	1.65
TOTAL	-46.78	-51.88	5.10

(a) Only locomotive capital and crew delay costs are included in the case of passenger and local freight trains (Annex E)

(b) The cost of delays suffered by other road users is not included

NOTE: Costs and savings are expressed as negative and positive respectively.

This result highlights the scope for improvement, especially with regard to maintenance practices.

Notwithstanding the higher traffic volume carried by the upgraded line, the capital requirement for motive power and rolling stock ('Train Capital') is lower than for the existing line. In fact, the upgrading virtually pays for itself in railway cost savings alone. It is the additional revenue to the railway that boosts the commercial rate of return and the elimination of road spillover costs that leads to significant resource benefits. This is reflected in the benefit-cost ratios shown in Table 5.13. The cost term is simply the NPV of the capital cost of the upgrading; the benefits are calculated as the difference between all other costs and savings. The lowest B/C ratio is 2.2 returned by CTC4 at the highest discount rate of 12%; the highest, 8.3, is returned by extended loops at the lowest discount rate of 7%. Clearly, even CTC4 would be considered an attractive investment both in commercial and resource cost terms.

TABLE 5.13 - RESOURCE BENEFIT/COST RATIOS : LOW FREIGHT PROJECTION AND 1400 GROSS TONNE TRAINS

Upgrading	Interest rate					
	7%		10%		12%	
	NPV of cost, C ($million)	B/C	NPV of cost, C ($million)	B/C	NPV of cost, C ($million)	B/C
EL (a)	1.06	8.26	1.03	6.33	1.02	5.39
CTC4	4.76	2.70	4.09	2.25	3.27	2.18

(a) See Table 5.3 for list of abbreviations and Table 5.11 for best years of introduction

CHAPTER 6 CONCLUSIONS

An evaluation of the likely growth in rail traffic between Melbourne and Adelaide during the period 1975-1995 has indicated that upgrading of the Victorian portion of the line would be economically justified during this period. The main findings are as follows.

The average gross weight of interstate freight trains should be increased from 1000 tonnes to 1400 tonnes. The higher train weight would be within the capability of two 2237 kW locomotives on the main line or one 2237 kW locomotive on the route via Geelong. Heavier trains are to be preferred notwithstanding that they lead to an early requirement for longer crossing loops at certain critical sections of the line.

Of all the upgrading options considered, including selective line doubling, grade easement, diverting trains via Geelong and a range of CTC schemes, the introduction of lengthened crossing loops and the cheapest CTC scheme (CTC4) show the most favourable return to investment.

The lengthened crossing loops, at a cost of $1.1 million(1), would be located at Parwan, Gordon,

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(1) 1973 prices.

Bungaree, Burrumbeet, Middle Creek, Great Western, Deep Lead, Lubeck, Jung and Pimpinio. They should be introduced immediately, at a commercial rate of return in excess of 30%.

The CTC4 scheme costing $5.1 million[1], which also includes extension of eight of the loops under the first option, should be staged. Introduction of CTC between Ararat and Serviceton would be justified immediately; the second stage, improving the line east of Ararat, should be introduced some time in the late 1970s to early 1980s depending on the rate of freight traffic growth. The commercial return to CTC4 is between 15% and 25%, depending on the railway freight revenue.

If the rail link is not upgraded, increased interstate truck traffic on the road between Melbourne and Adelaide would be expected from the mid 1980s to mid 1990s. The social benefit/cost ratio of rail upgrading investment, ignoring any congestion effects on the road if the rail measures are not implemented, is in the range 2 to 3 in the case of the CTC4 scheme or 5 to 8 in the case of the loop extension scheme, depending on the discount rate.

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(1) 1973 prices.

ANNEX A MELBOURNE-SERVICETON RAILWAY

TRAFFIC FORECASTS

During the last decade rail traffic on the Melbourne-Serviceton route has undergone some fundamental changes, especially in the interstate freight category. These changes have frequently resulted from a switch to rail of some traffic causing a larger than usual increase in total traffic during the transition periods. The use of containers, for example, to ship overseas cargoes has resulted in a marked increase in interstate rail traffic since 1968 because South Australian containers are shipped through Melbourne. Furthermore the growth in this traffic has been rapid over the last two-three years as the containerisable cargoes quickly switched to the new style of shipment. As a result the total interstate freight traffic shows a considerable growth rate during the early years of containers but is being followed by a period where the influence of overseas trade on the total traffic growth is due almost entirely to the general growth in trade. A similar situation has occurred with general freight forwarding. The period during which forwarders switched from road to rail may give a misleading impression of the long run growth rate in rail freight traffic. If forecasts are based upon projections of aggregate traffic figures, they will include the short term effects of these structural changes and will therefore tend to over estimate the future growth in rail traffic.

Forecasts are generally based on past trends modified in the light of expected future events. In the case of total railway traffic, future events may influence only part of the traffic and it is important to identify the impact of these events upon sections of traffic which are relatively homogeneous and which can be combined to give the eventual overall forecast. To assist in our predictions the traffic along the Melbourne-Serviceton line was divided into four categories according to whether it was passenger or freight and interstate or intrastate. The passenger categories were regarded as homogeneous for our purposes, but the aggregated freight categories were further divided according to the general nature of the goods shipped.

A.1 INTERSTATE FREIGHT

The interstate freight carried during 1971/72 is shown in Table A.1. Approximately 60% of the traffic was attributable to three types: freight forwarding, overseas containers and motor vehicles and parts. The major effort in the interstate freight forecasts has been with these types.

TABLE A.1 - TOTAL INTERSTATE FREIGHT BETWEEN VICTORIA AND SOUTH AUSTRALIA 1971/72

('000 tonnes)

Freight Traffic	Total
Freight Forwarders	304
Motor Vehicles and Parts	137
Overseas Containers	284
Local Containers	18
Iron and Steel	92
Fruit and Veg.	33
Class A	49
Class B	16
Class C	29
Other	187[a]

(a) Includes 32,000 tonnes of barley and 26,000 tonnes of Soda Ash.

The motor industry and overseas container traffics have been estimated independently, while freight forwarders and the remaining traffics have been classified as growing at a rate determined by either the population or the economic growth rate. Projections of these growth rates were taken from Haig[1]. The population growth (2% compound) is possibly an overestimate since it is based upon an assumed annual migrant intake of 100,000. This figure may be too high in the light of the current review of Australia's migration policy. The economic variable chosen to reflect the impact of economic growth on rail traffic was real personal consumption expenditure which Haig predicts will grow at a rate of 4.5% compound per annum.

A.1.1 <u>Freight Forwarding</u>

Freight forwarding is unique in that it is classified according to the shipper rather than the nature of the goods. In view of the relative importance of freight forwarding some effort was made to identify those goods making up the bulk of this class. Although this information proved difficult to obtain, it was established after discussions with several forwarders that the majority

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(1) B.D. Haig, 'The Australian Economy to the year 2000' (prepared for the Commonwealth Bureau of Roads, Melbourne, June 1971).

of their traffic falls into the general consumer goods classification[1]. It was therefore decided to use the growth rate in the personal consumption sector as indicative of the likely growth rate of this traffic.

The implicit assumption in this decision is that the current transport split between freight forwarders and specialised operators concentrating on particular commodities will remain. To apply this growth rate of 4.5% compound to the rail portion of the forwarding traffic (in tonnes) assumes that the current modal split will continue, and that the value/weight ratio of this traffic remains constant. The railways already have 70% of the forwarder's traffic and it appears that where possible the forwarders have tended to use rail. Thus the potential to increase the rail share is limited. On the other hand several forwarders indicated that a swing back to road transport was possible. In this case rail's 70% share of the total traffic could be eroded, and the growth rate would be less than 4.5%. At this stage it is not possible to assess the impact of these influences but the 4.5% growth would seem to be optimistic.

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(1) See Mayne Nickless Annual Report 1972.

A.1.2 Motor Vehicles and Parts

Swan[1] has examined the Australian motor vehicle industry and the basic relationships used in our forecasts have been derived from his work. His assumptions concerning the growth rates of the population and the economy were consistent with the forecasts made by Haig. The equations for the desired stock of automobiles and the lag process between decision to purchase and the delivery date have been combined to obtain new sales per capita forecasts, under the assumption that future car prices will experience the same rate of inflation as the rest of the economy.

The interstate movements of motor vehicles and parts was assumed to be directly related to new sales. This assumption is plausible so long as the geographic pattern of production and sales remains unchanged. While this is anticipated for most companies, G.M.H. have a policy of 'production rationalisation' which could change the production location of their various models. These changes would certainly result in different types of freight over the Melbourne-Serviceton line (perhaps parts shipped instead of completed vehicles) and may lead to a change in demand,

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(1) P.L. Swan, 'A Model of Demand and Forecasts of Annual Sales of Automobiles in Australia, 1949-1980' (presented at Australasian Conference of Econometricians, Melbourne, August 1971).

depending on the popularity of the different models. G.M.H. were unable to indicate the changes over the next decade so the best forecast at this stage is derived by relating railway freight to new vehicle sales. The forecasts should then be used with the possibility of G.M.H. rationalisation in mind.

A.1.3 Overseas Containers

The introduction of container shipping to Australia has caused an increase in rail traffic between Adelaide and Melbourne as the South Australian containerised trade flows through the Melbourne terminal. The shipping conferences which currently use container ships serve Australia's trade with the U.K./Europe, the U.S. and Japan. It is not envisaged that additional container routes will come into operation and other routes were not considered.

Enquiries have indicated that Adelaide will have a container terminal by the end of 1975. It is still too early for the container companies to state accurately how the Adelaide port will fit into the operations of each conference. The forecasts presented here have proceeded on the assumption that the South Australia-U.K./Europe trade will use Adelaide as a container port but South Australian trade with Japan and the U.S. will continue to use Melbourne. This assumption was made after examining the additional sailing time necessary for each conference to use Adelaide. The U.K./Europe bound ships sail past South Australia and an extra day would be necessary. The other two conferences are essentially east coast operators and ships would have to sail from Melbourne and back again - an estimated three days. Again the U.K./Europe trade is the largest of the three and would have the greatest incentive tonnage-wise to call at Adelaide. For these reasons it seems that the U.K./ Europe container traffic to and from South Australia may be lost by rail but the other conference lines will probably continue to send their containers through the Melbourne terminal. Consequently the forecasts of future container traffic have concentrated upon the South Australian trade with the U.S. and Japan. Since all lines in the U.K./Europe may not choose to call at Adelaide, two projections have been postulated: a 'low' projection corresponding to all the U.K./Europe Trade moving through Adelaide and a 'high' projection with Melbourne retaining half of this traffic, forwarded by rail. In both cases, the percentage growth rate was assumed the same and equal to that for the U.S. and Japan trades.

The export contribution proved difficult to forecast. We could find no previous work from which the South Australian details could be derived and it was necessary to base our estimates upon past trends. The South Australian Year Books provide commodity/ destination tables giving the value of their principal exports. The broad commodity groups listed were used to isolate those commodities which were significant in the Japan and/or the U.S. trade and were likely to be shipped in containers.

Since the rail traffic is concerned with tonnage forecasts it was necessary to convert the value details found in the South Australian Year Books to tonnage terms. To allow for fluctuating prices during the period under examination (1964/65 to 1970/71) it was necessary to obtain weighted average prices for these commodity groups in each year. Average prices are obtainable for Australian goods sold in these markets(1) and a careful selection of the commodities appropriate for S.A. enabled a weighted average price to be obtained for the principal exports from S.A. Implicit in this approach is the assumption that the S.A. price received is the same as the average price received by other States.

The price series generated for each commodity group, for each destination, for each year was used to

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(1) Commonwealth Bureau of Census and Statistics, 'Overseas Trade'.

obtain a corresponding export tonnage series. Regression techniques were then employed to obtain the following overall growth rates of S.A. exports

Japan	5.5% compound p.a.
U.S.	7.0% compound p.a.

From these rates the overall growth rate in container traffic along the Melbourne-Serviceton line was estimated at 6% compound p.a.

Imports by S.A. are mainly influenced by domestic economic conditions. The imports from Japan and the U.S. were assumed to retain their current market share and would thus depend on the Australian economic growth rate. No attempt was made to forecast the future South Australian rate of development relative to the overall Australian performance; instead we assumed that the economic forecasts by Haig would be appropriate for S.A.

The import details in the South Australian Year Books were divided into those goods related to investment and those responsive to consumer demand. Haig indicates a growth rate for investment in the order of 3.6% compound p.a. Combined with the 4.5% compound growth in personal disposable income the overall anticipated growth rate of imports, and hence the Melbourne-Adelaide container traffic, is estimated at 4% compound p.a.

A.1.4 Other

Of the remaining items in Table A.1 only steel is both identifiable and significant. The future of the steel industry as a rail customer is uncertain. Special 'steel-carrier' ships have recently been built[1] to transport steel around the Australian coast and the Melbourne-Adelaide section is included in the envisaged area of operation. On the other hand Victorian Railways, after consulting the steel industry, are currently constructing special wagons to continue shipping this item. The issue is further complicated by the development of the new works at Westernport Bay. Enquiries were made regarding the rationalisation effects of this plant on the industry but nothing definite could be obtained at this stage. In the light of these uncertainties, a growth rate of 2% compound, based upon the current level, was selected for our forecasts.

The remaining commodities were assigned annual growth rates of 2% compound or 4.5% compound depending on whether the item was population or consumer demand oriented respectively.

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(1) Cargo Handling and Shipbuilding Quarterly, 'Australian and New Zealand Ships Under Construction and On Order', 11, 4 (1972), p 15.

A.2 INTERSTATE PASSENGERS

Monthly data on the number of passengers travelling between Melbourne and Adelaide were analysed to detect the trend in demand for this service. The raw data were influenced by strong seasonal effects resulting in exceptionally high traffic during the traditional holiday periods. A model, assuming a linear trend and an additive seasonal component is represented by:

Demand for rail services	=	Trend value in period t
in period t		+ Seasonal effect
		+ Error

i.e. $$D_t = a + bt + S_i + U_t$$

where i = 1, ...,12 represents the month under examination.

The seasonality feature was overcome by taking twelfth order differences. The usual regression assumptions regarding the error term then enable an estimate of 'b' to be obtained from this differencing

of the data. An estimate of 'a' is easily obtained by using this 'b' estimate:
i.e. we took

$$D_{t+12} - D_t = 12b + (U_{t+12} - U_t)$$

and obtained the following equations (seasonally adjusted) for the underlying trends in interstate passenger demand.

Melbourne to Adelaide Demand = 10,044 - 29.3t

Adelaide to Melbourne Demand = 9,830 - 19.1t

where t = 1 for January 1968.

The co-efficients of 't' indicate a slight decline in the interstate rail patronage. However, it was assumed for this study that the current level of interstate passenger services would continue.

A.3 INTRASTATE FREIGHT

The data used in the analysis of this traffic were in the main supplied by the Victorian Railways. They consisted of details on the flow of commodities to the various regions serviced by the rail line, for the year 1971/72. Unfortunately this single year breakdown requires the assumption that 1971/72 is a typical year. From the data it appeared that the traffic fell naturally into two groups according to the direction of travel. The outflows from the regions were predominantly agricultural produce with bulk grains being the major commodity. The inflows were either oriented towards primary production (principally superphosphates) or general goods.

A.3.1 Inwards Freight (away from Melbourne)

The general goods component was estimated after a population/tonnage analysis. Six districts were identified. These districts are based upon local government area boundaries and were characterised by a relatively large regional centre surrounded by small townships. The population of each district was obtained from the 1971 census. Regression analysis gave the following equation.

$$\text{General goods (ex Melb)} = -1600 + 2.1 \text{ Population}$$

Although the population of the Ballarat district is much greater than the others, a regression on the five districts excluding Ballarat did not significantly alter the value of the regression coefficient.

TABLE A.2 - DISTRICT POPULATION CHANGES

District	1966	1971
Dimboola-Serviceton	13,395	11,971
Horsham	11,436	11,806
Murtoa	14,655	13,005
Stawell	8,255	7,790
Ararat-Skipton	14,262	13,768
Ballarat	61,200	61,467

The equation derived above indicates that tonnages increase with population size. Table A.2, however, indicates that for the districts considered the populations are declining. Enquiries revealed that only Ballarat is considered likely for decentralisation and there seems little prospect of a marked reversal of the population trend. The impact of development on Ballarat-bound rail traffic is difficult to forecast as it depends partly on the industrial base for this development and the possibility of road haulage restrictions being lifted. Ballarat is sufficiently close to Melbourne and Geelong to make road haulage an attractive alternative to rail. In the light of these problems, the impact of Ballarat development was excluded from the study.

With the decline in rural population and the subsequent tonnage decrease there could be scope for rationalisation of some rail services. This would possibly be enhanced if the Bland Report[1] recommendations of regional freight centres with road carriers effecting local distribution are adopted. A decision on these recommendations has not been made yet. To allow for the possibility of a decision against the proposal and for a stabilisation or even a gradual increase of the population, the current level of general freight services was taken as the best available estimate of future levels.

Available superphosphate data[2] demonstrated a close relationship between superphosphate useage and grain acreage sown, which in turn depends upon climatic conditions. The future levels of production are not expected to significantly increase beyond those experienced during the last six years (i.e. including pre-quota levels) and the likely future superphosphate requirements should be met without any increase in present rail services.

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(1) Victoria, Legislative Assembly, 'Report of the Board of Enquiry into the Victorian Land Transport System' (Chairman: H.A. Bland), 1972 (Melbourne, 1972).

(2) Commonwealth Bureau of Census and Statistics, 'Rural Industries' (Victorian Office).

A.3.2 Outwards Freight (towards Melbourne)

The outwards freight from the rural districts is mainly agricultural with grain flows along the various branch lines being the major determinant of train requirements. Other types of freight are small and the present services can adequately handle the envisaged future needs.

The volume of grain to be moved in any year varies considerably according to current production, storage capacities, export sales etc. The train requirement along various sections of the Melbourne - Serviceton line is further complicated by the irregular variations occuring on a shire to shire basis. Even if an accurate forecast of total volume moved was possible, the pattern of movements along branch lines is unobtainable from the details of only one year. A review of the total production during the past 6 years showed that the acreage prepared for grain production varied little while the maximum wheat output was 1.21 million tonnes compared to an average of 1.06 million tonnes. The relative stability of production suggests that future demands are unlikely to exceed the present levels, barring a change in either technology or the grain type produced. The number of necessary trains could be influenced by variations in production from one area to another but these cannot be predicted.

The detailed year available, 1971/72, was not a good production year but was more typical for railway operations since stored grain was also moved. This detailed train pattern was taken as typical of the rail grain movements.

A.4 INTRASTATE PASSENGER

Data supplied by Victorian Railways indicated that intrastate passenger traffic is declining. Because of the nature of this service it was thought unlikely that the current services would be reduced despite this decline. The analysis assumed that the present level of intrastate services would be retained.

A.5 SUMMARY

It would appear that the only traffic along the Melbourne-Serviceton line with any potential for growth is interstate freight. Some uncertainty in the growth rates of particular components exists, but the overall trend in this traffic is upwards. A detailed forecast of this category is given in Tables A.3 to A.6.

The remaining categories have been forecast to continue at their current level. The grain traffic from the country regions is the most uncertain but the data available suggest that 1971/72 was a typical year.

TABLE A.3 - PROJECTIONS FOR RAIL FREIGHT: FROM VIC. TO S.A.

('000 tonnes)

Year	Commodity								
	Freight forwarders	Motor vehicles and parts	Local containers	Iron and steel	Fruit and vegetables	Beer	Class C	Other	Total
1971/72	184	45	8	27	16	8	6	64	358
73	192	48	8	28	17	8	6	65	372
74	201	51	9	28	18	9	6	67	389
75	210	54	9	29	18	9	6	66	403
1975/76	219	57	10	29	19	10	7	69	420
77	229	60	10	30	20	10	7	71	437
78	240	64	10	30	21	10	7	72	454
79	250	68	11	31	22	11	7	74	474
80	262	72	11	32	23	11	7	75	493
1980/81	273	76	12	32	24	12	7	77	513
82	286	80	12	33	25	12	7	78	533
83	299	85	13	34	26	13	7	80	557
84	312	90	14	34	27	14	8	81	580
85	326	95	14	35	28	14	8	83	603
1985/86	341	100	15	36	29	15	8	85	629
87	356	106	15	36	31	15	8	86	653
88	372	112	16	37	32	16	8	88	681
89	389	118	17	38	33	17	9	90	711
90	406	125	17	39	35	17	9	92	740
1990/91	425	132	18	39	36	18	9	93	770
92	444	139	19	40	38	19	9	95	803
93	464	147	20	41	40	20	9	97	838
94	484	155	21	42	42	21	10	99	874
95	506	162	22	43	44	22	10	101	910
Growth rate (%)	4.5	(a)	4.5	2.0	4.5	4.5	2.0	2.0	n.a.

(a) Growth based on the work of P.L. Swan (Section A.1.2)

NOTE: Overseas containers are not included.

TABLE A.4 - PROJECTIONS FOR RAIL FREIGHT: FROM QLD. AND N.S.W. TO S.A.

('000 tonnes)

Year	Commodity					
	Freight forwarders	Motor vehicles and parts	Iron and steel	Class A	Other	Total
1971/72	49	7	19	3	9	87
73	51	7	19	3	9	89
74	54	8	20	3	9	94
75	56	8	20	3	10	97
1975/76	58	9	21	3	10	101
77	61	9	21	3	10	104
78	64	10	21	3	10	108
79	67	10	22	3	11	113
80	70	11	22	4	11	118
1980/81	73	12	23	4	11	123
82	76	12	23	4	11	126
83	79	13	24	4	11	131
84	83	14	24	4	11	136
85	87	15	25	4	12	143
1985/86	91	16	26	4	12	149
87	95	17	26	5	12	155
88	99	18	27	5	13	162
89	104	19	27	5	13	168
90	108	20	28	5	13	174
1990/91	113	21	28	5	14	181
92	118	22	29	5	14	188
93	123	23	29	6	14	195
94	129	25	30	6	14	204
95	135	26	30	6	15	212
Growth rate (%)	4.5	(a)	2.0	2.0	2.0	n.a.

(a) Growth based on the work of P.L. Swan (Section A.1.2)

NOTE: Overseas containers are not included.

TABLE A.5 - PROJECTIONS FOR RAIL FREIGHT: FROM S.A. TO VIC.

('000 tonnes)

Year	Commodity									
	Freight forwarders	Motor vehicles and parts	Local containers	Iron and steel	Fruit and vegetables	Barley	Soda ash	Class A	Other	Total
1971/72	19	64	6	46	9	32	26	38	45	285
73	20	68	6	47	9	33	27	39	46	295
74	21	72	7	48	10	33	28	40	47	306
75	22	76	7	49	10	34	30	40	48	316
1975/76	23	81	7	50	11	35	31	41	49	328
77	24	86	8	51	11	35	32	42	50	339
78	25	91	8	52	12	36	34	43	51	352
79	26	96	8	53	12	37	35	44	52	363
80	27	102	9	54	13	38	37	45	53	378
1980/81	28	108	9	55	13	38	39	45	54	389
82	30	114	9	56	14	39	40	46	55	403
83	31	120	10	57	15	40	42	47	56	418
84	32	127	10	58	15	41	44	48	57	432
85	34	135	11	60	16	41	46	49	58	450
1985/86	36	142	11	61	17	42	48	50	59	466
87	37	150	12	62	18	43	50	51	60	483
88	39	158	13	64	19	44	52	52	62	503
89	41	167	13	65	19	44	55	53	63	520
90	42	177	14	66	20	45	57	54	64	539
1990/91	44	187	14	68	21	46	60	55	65	560
92	46	197	15	69	22	47	63	56	67	582
93	48	208	16	70	23	48	65	57	68	603
94	51	219	16	72	24	49	68	59	69	627
95	52	231	17	73	25	50	72	60	71	651
Growth rate (%)	4.5	(a)	4.5	2.0	4.5	2.0	4.5	2.0	2.0	n.a.

(a) Growth based on the work of P.L. Swan (Section A.1.2)

NOTE: Overseas containers are not included.

TABLE A.6 - PROJECTIONS FOR RAIL FREIGHT: FROM W.A. AND S.A. TO VIC.

('000 tonnes)

Year	Commodity								
	Freight forwarders	Motor vehicles and parts	Local containers	Fruit and vegetables	Class A	Class B	Class C	Other	Total
1971/72	52	21	4	8	8	16	23	3	135
73	54	22	4	8	8	16	24	3	139
74	57	24	4	9	8	17	24	3	146
75	59	25	5	9	9	17	24	3	151
1975/76	62	27	5	10	9	17	25	3	158
77	65	28	5	10	9	18	25	3	163
78	68	30	5	10	9	18	26	3	169
79	71	32	5	11	9	18	26	3	175
80	74	33	6	11	9	19	27	4	183
1980/81	77	35	6	12	10	19	28	4	191
82	81	37	6	12	10	20	28	4	198
83	84	40	7	13	10	20	29	4	207
84	88	42	7	14	10	20	29	4	214
85	92	44	7	14	10	21	30	4	222
1985/86	96	47	7	15	11	21	31	4	232
87	100	49	8	15	11	22	31	4	240
88	105	52	8	16	11	22	32	5	251
89	110	55	9	17	11	23	32	5	262
90	115	58	9	17	11	23	33	5	271
1990/91	120	61	10	18	12	24	34	5	284
92	125	65	10	19	12	24	34	5	294
93	131	68	10	20	12	25	35	5	306
94	137	72	11	21	12	25	36	5	319
95	143	76	11	22	13	26	37	6	334
Growth rate (%)	4.5	(a)	4.5	4.5	2.0	2.0	2.0	2.0	n.a.

(a) Growth based on the work of P.L. Swan (Section A.1.2)

NOTE: Overseas containers are not included.

Obviously an exceptional year could place extra strain on the rail facilities but it is impossible to forecast the occurrence of such an event.

ANNEX B THE MELBOURNE-SERVICETON LINE AND ITS TRAFFIC

B.1 DESCRIPTION OF EXISTING LINE

B.1.1 Physical Layout

Figure B.1 shows a schematic layout of the two lines considered in this analysis, together with the position and length of crossing loops. (A line connecting Gheringhap with Warrenheip was not considered as a viable alternative route to Ararat because of its length and grades.) The majority of the Melbourne-Adelaide and Melbourne-Ararat traffic uses the shorter route via Ballarat, with Melbourne-Portland/ Mt. Gambier traffic and Ararat-Geelong traffic using the other route via Cressy.

The sections of line between Melbourne and Sunshine (which is duplicated) and between Melbourne and North Geelong (which is duplicated except for 14 km between Little River and Corio) were not considered in this study. These sections both carry a high volume of commuter traffic and their upgrading is better evaluated in urban public transport studies. The line between Sunshine and Serviceton is single track except for 11 km of duplication near Ballarat

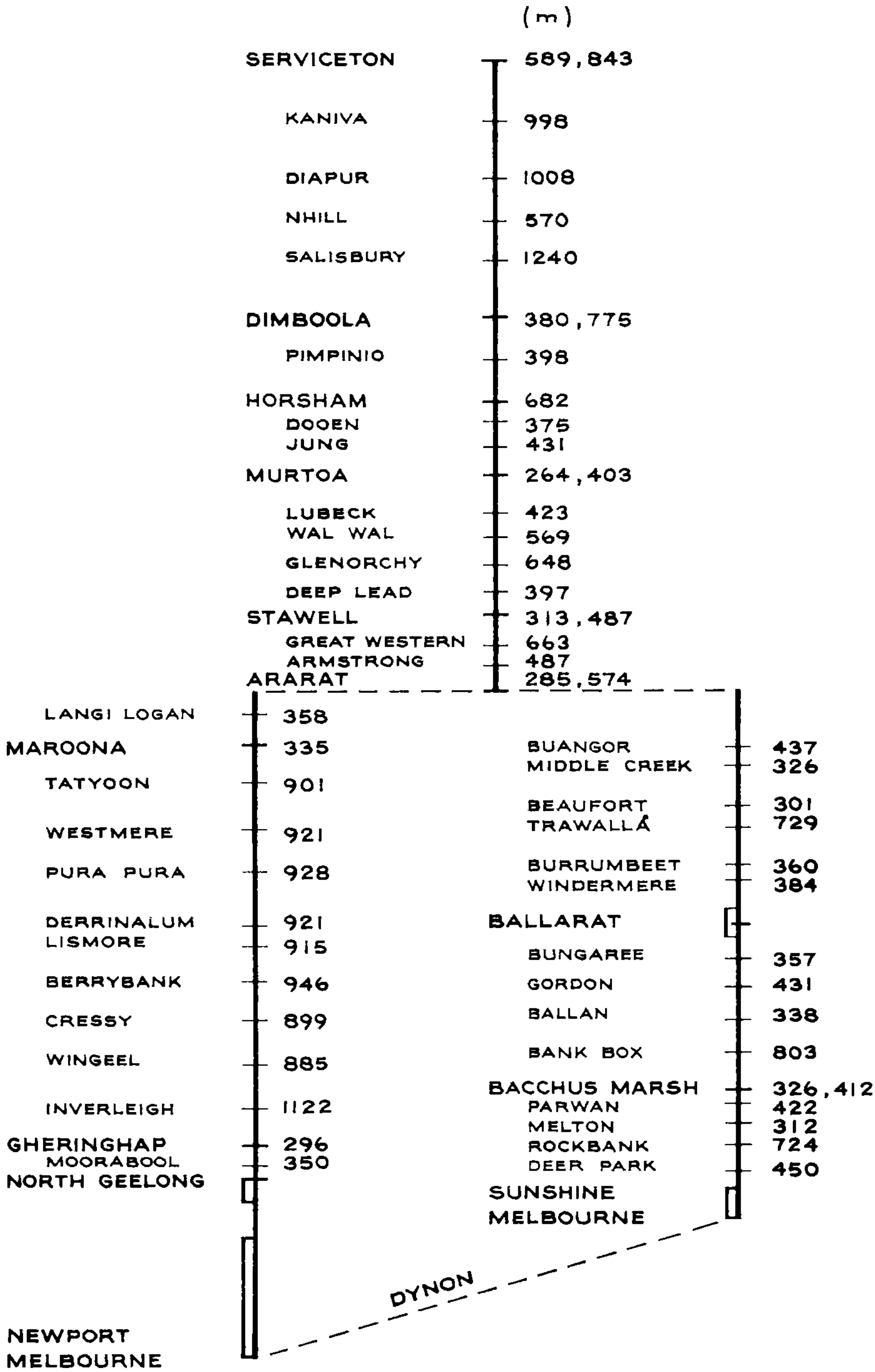

FIGURE B.1

POSITION AND LENGTH OF EXISTING LOOPS

between Warrenheip and Linton Junction. The line between North Geelong and Ararat is also single track.

The ruling grade loads (in gross tonnes) for a 1491 kW locomotive on the various sections are:

Section	UP	DOWN
Sunshine to Ararat (via Ballarat)	850	780
Newport to Ararat (via North Geelong)	1800	1500
Ararat to Serviceton	900	950
Ararat to Serviceton (Miram-Diapur regraded)	1100	1300

The majority of the lines are layed with 43 kg rail and the ages of existing rails are as follows:

- Sunshine to Ararat was re-railed between 1954 and 1957 and is due for re-railing between 1985 and 1990 at current traffic levels.

- North Geelong to Ararat was re-railed around 1970 and is not due for re-railing in the next twenty years at current traffic levels.

B.1.2 Signalling

With the exception of a 29 km section of CTC between Bacchus Marsh and Ballan, all sections of line rely on a token system of safeworking (the token being called a 'staff').

Between Sunshine and Serviceton, North Geelong and Gheringhap, and Maroona and Ararat, all locations at which safeworking is performed are manned by a signalman. This means that a train proceeding straight through can exchange staffs automatically (Fig. B.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 and give him a staff (Fig. B.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. Measurements by both N.S.W. Railways and Victorian Railways indicate that the average safeworking delay is of the order of 3 to 3.5 minutes, disregarding retardation and acceleration times. In practice some safeworking delays are assimilated in shunting or crew changes. However, on a busy line such cases are the exception rather than the rule, and thus these are not taken into account in this study.

Between Gheringhap and Maroona, all safeworking is performed by the train driver as the locations are unmanned. This means that each train has to stop at

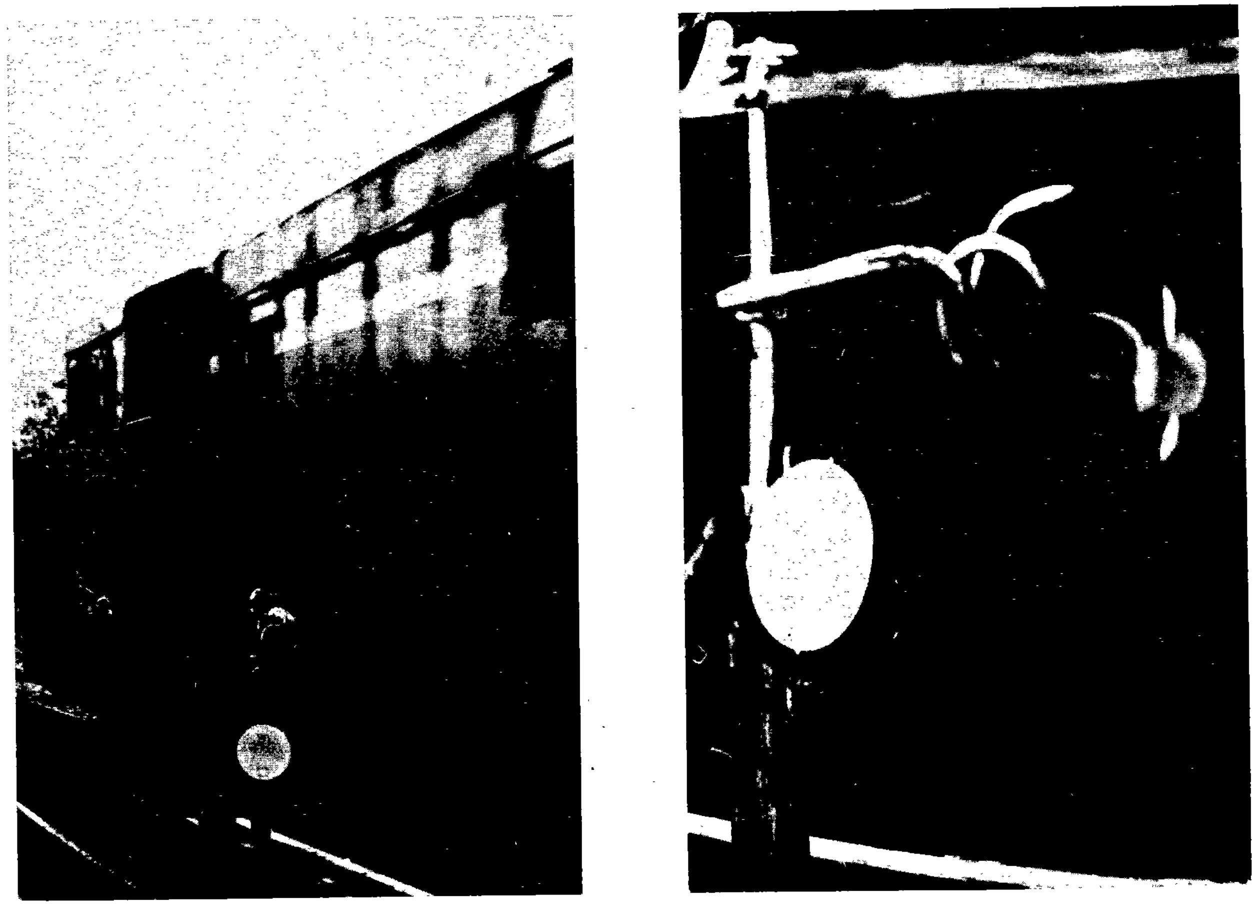

FIGURE B.2 AUTOMATIC EXCHANGE OF STAFF

FIGURE B.3

MANUAL EXCHANGE OF STAFF

each location for 4 or 5 minutes, whether or not it is crossing another train.

B.1.3 South Australian Section of Melbourne-Adelaide Link

On the South Australian portion of the line CTC has recently been introduced on the single track section between Tailem Bend and Serviceton; the line is double track between Belair and Adelaide and there is a 97 km long single track, mechanically signalled section between Belair and Tailem Bend.

B.2 PRESENT TRAFFIC

The trains on the line can be divided into 8 different classes depending on the relative importance of the traffic they are carrying. The priority allocated to each class for the purposes of computer simulation is shown below. (These priority levels coincide approximately with those used when timetables are prepared - the day to day decisions of a Train Controller are, of course, based on many additional factors.)

Priority No.	Train Type
1	Interstate passenger
2	Top priority interstate express goods
3	Intrastate passenger, including commuter
4	Other interstate express goods
5	Intrastate express goods
6	Fast goods
7	Goods
8	Roadside goods and light engines

Because of the presence of branch lines and important centres of population en route, the distribution of these train classes on a typical 'busy day' vary considerably over the different line sections as summarised in Table B.1.

TABLE B.1 - NUMBER OF TRAINS PER PRIORITY CLASS ON A 'BUSY DAY'

	Priority Class								Total
Section	1	2	3	4	5	6	7	8	
Sunshine-Ballarat	3	2	14	4	3	6	2	4	38
Ballarat-Ararat	3	2	4	5	1	4	-	1	20
Ararat-Serviceton	3	2	5	7	-	7	18	5	47
North Geelong-Ararat	-	-	-	2	2	-	11	2	17

In the above table the fast goods trains now running between Melbourne and Adelaide have been reclassified as express goods trains, because demand for a fast goods service is expected to decrease. This expectation is supported by the tendency of most firms to carry reduced inventory.

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 (unit trains are assumed to carry all growth in traffic) (1)
Lifetime	:	20 years

---

(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.

Number of Wagons (1) Required for	:	1000 tonne (gross) train: 25
		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 Requirement

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

Melbourne-Adelaide

1000 Tonne Trains

1 x 1491 kW loco Serviceton-Tailem Bend, 193 km

2 x 1491 kW loco Tailem Bend-Belair, 100 km

2 x 1491 kW loco Sunshine-Serviceton, 449 km

1 x 2237 kW loco Geelong-Serviceton, 502 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.

1400 Tonne Trains

1 x 1491 kW loco Serviceton-Tailem Bend, 193 km

3 x 1491 kW loco Tailem Bend-Belair, 100 km

2 x 2237 kW loco Sunshine-Serviceton, 449 km

1 x 2237 kW loco Geelong-Serviceton, 502 km.

Melbourne-Serviceton

Locomotive requirements are the same as those listed above for Sunshine-Serviceton and Geelong-Serviceton.

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. The parenthesised figures correspond to the Geelong Diversion route. 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.

TABLE C.1 - MOTIVE POWER AND ROLLING STOCK CAPITAL

(/km/train)

($)

Gross Train Weight (tonnes)	Locos	Rolling Stock	Total
	MELBOURNE-SERVICETON		
1000	3.106	2.200	5.306
	(2.070)	(2.200)	(4.270)
1400	4.141	3.080	7.221
	(2.070)	(3.080)	(5.150)
	MELBOURNE-ADELAIDE		
1000	2.701[a]	2.200	4.901
	(2.075)	(2.200)	(4.275)
1400	3.537	3.080	6.617
	(2.270)	(3.080)	(5.350)

(a) Calculations are based on a distance weighted average, for example:

$$\frac{(193 + 2 \times 100 + 2 \times 449)\ 300{,}000}{742 \times 193{,}200} = 2.701$$

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).

Parenthesised figures apply to the Geelong Diversion route.

C.1.4 Gantry Capital Costs (Melbourne-Adelaide)

Capacity of gantry facility

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

Train Weight (gross tonnes)	Gantry Capacity (trains/day)
1000	6.9
1400	5.3

Example: A 1000 gross tonne train carries 50 containers.

Train loading/unloading time $= \frac{50 \times 3}{60}$

$= 2.5$ hours.

Allow a generous 1 hour for placing and brake checking.

Capacity of facility $= \frac{24}{3.5} = 6.9$ trains/day.

Gantry requirements

The gantry requirements are based on the above capacities, together with the assumption that

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(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.

the projected growth in traffic will be carried in unit trains using gantry facilities. For the various train weights and projections, 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)	Freight projection	
	Low	High
1000	1975 1990	1975 1989
1400	1975 1991	1975 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, including the age of the locomotive, 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 maintenance costs of both 1491 kW and 2237 kW locomotives were the same at 15 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.

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 $k = 4.22 \times 10^3$ as appropriate for the Melbourne-Serviceton line and its traffic gives:

(a) Single Track

$T_1 = 2.69$ and $T_2 = 5.82$,

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

(b) Double Track

On the basis of equal tonnages in both directions, $T_1 = 1.34$ and $T_2 = 2.91$.

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

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 purposes 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)

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

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

w is the 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¢/gallon)

which used in conjunction with the above conclusion gives a value for the fuel cost of 26.1 cents/km for 1400 gross tonne trains.

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 (obtained from Victorian Railways).

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

'Overland' annual crew cost $620,000

Assuming 365 trips/annum with an average transit time of 12.8 hours then gives:

$$\text{Passenger Train Crew Cost} = \frac{620{,}000}{365 \times 12.8}$$

$$= \$133/\text{hour}$$

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.

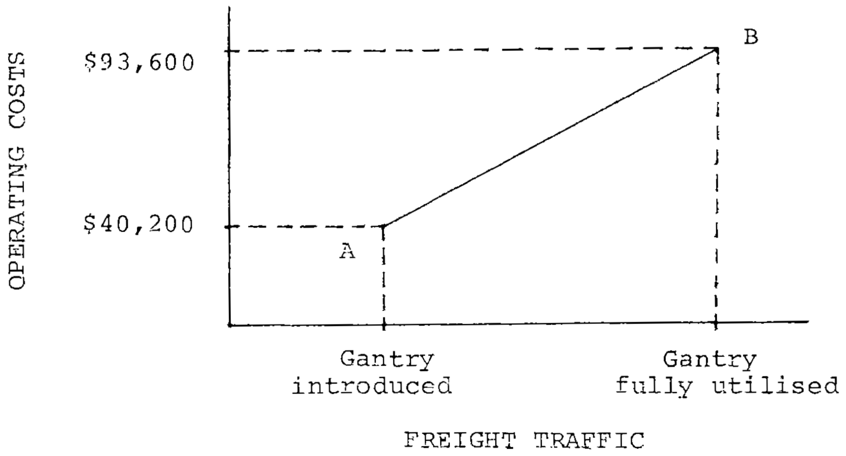
TABLE C.3 - MARGINAL FREIGHT TRAIN OPERATING COSTS/KM

($)

Gross train weight (tonnes)	Main line	Geelong diversion
MELBOURNE-SERVICETON		
1000	1.524	1.375
1400	1.897	1.748
MELBOURNE-ADELAIDE		
1000	1.486	1.394
1400	1.878	1.785

C.2.5 Gantry Operating Costs (Melbourne-Adelaide)

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 by the N.S.W. Public Transport Commission (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:

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

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 calculations the linear approximation should give a reasonable estimate of gantry operating costs.

C.3 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

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

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
Road maintenance cost[1] at 0.0213 cents/tonne km	0.43
	15.90

Total operating cost per vehicle km : 15.90 cents

C.4 CTC SCHEME 1 : FROM SUNSHINE TO SERVICETON

C.4.1 From Ararat to Serviceton

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.

	$
6 new loops @ $230,000 each	1,380,000
3 extended loops @ $172,500 each	517,500
3 existing loops signalled @ $115,000 each	345,000
156 km of track circuits @ $790 per km(1)	123,240
261 km of conductors @ $462 per km	120,582
33 switchlocks @ $10,350 each(2)	341,550
	2,827,872
Add 10% contingencies	282,787
	$3,110,659

Total : $3.11 million

The savings accrue from two sources:

- Firstly, once the CTC equipment is installed the need to slowly replace the 40 to 60 years old signalling equipment no longer exists and this results in an estimated saving of $46,000 per annum.

- Secondly, the introduction of CTC allows most stations to operate without signalling staff, controlled remotely from a central area. The savings in manpower were estimated by Victorian Railways at $113,850 per annum.

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(1) 8 km of track circuit per loop is included in the costs of signalling new, extended or existing loops.

(2) The number of switchlocks required is dependent on the number of stations which have no crossing loops.

C.4.2 <u>From Sunshine to Ararat</u>

The capital costs are as follows:

	$
4 new loops @ $230,000 each	920,000
3 extended loops @ $172,500 each	517,500
3 existing loops signalled @ $115,000	345,000
124 km of track circuits @ $790 per km	97,960
188 km of conductors @ $462 per km	86,856
30 switchlocks @ $10,350 each	310,500
	2,277,816
Add 10% contingencies	227,782
	$2,505,598

<u>Total : $2.51 million</u>

The savings are similar in nature to those described in Section C.4.1 and are as follows:

- $46,000 per annum by not having to replace old signals;
- $192,050 per annum manpower savings.

C.5 CTC SCHEME 2 : SUNSHINE TO SERVICETON

C.5.1 From Ararat to Serviceton

The capital costs are as follows:

	$
13 new loops @ $230,000 each	2,990,000
1 extended loop @ $172,500	172,500
4 existing loops signalled @ $115,000 each	460,000
84 km of track circuits @ $790 per km	66,360
261 km of conductors @ $462 per km	120,582
33 switchlocks @ $10,350 each	341,550
	4,150,992
Add 10% contingencies	415,099
	$4,566,091

Total : $4.57 million

The savings are similar in nature to those described in Section C.4.1 and are as follows:

- $46,000 per annum by not having to replace old signals;
- $113,850 manpower savings per annum.

C.5.2 From Sunshine to Ararat

The capital costs are as follows:

	$
4 new loops @ $230,000 each	920,000
4 extended loops @ $172,500 each	690,000
3 existing loops signalled @ $115,000 each	345,000
92 km of track circuits @ $790 per km	72,680
188 km of conductors $462 per km	86,856
30 switchlocks @ $10,350 each	310,500
	2,425,036
Add 10% contingencies	242,504
	$2,667,540

Total : $2.67 million

The savings are similar in nature to those described in Section C.4.1 and are as follows:

- $46,000 per annum by not having to replace old signals;

- $192,050 manpower savings per annum.

C.6 CTC SCHEME 3 : FROM SUNSHINE TO SERVICETON

C.6.1 Extension of 10 Crossing Loops

As detailed in Section C.8, the capital cost of extending one crossing loop is $103,500. Thus the extension of 10 crossing loops costs $1,035,000 or $1,138,500 if 10% contingencies are added.

Total : $1,138,500

C.6.2 From Ararat to Serviceton

If CTC Scheme 3 from Ararat to Serviceton is introduced after 10 existing loops have already been extended, the capital costs are as follows

	$
14 existing loops signalled @ $115,000 each	1,610,000
132 km of track circuits @ $790 per km	104,280
261 km of conductors @ $462 per km	120,582
33 switchlocks @ $10,350 each	341,550
	2,176,412
Add 10% contingencies	217,641
	$2,394,053

Total : $2.39 million

The savings are similar in nature to those described in Section C.4.1 and are as follows:

- $46,000 per annum by not having to replace old signals;
- $113,850 manpower savings per annum.

C.6.3 From Sunshine to Ararat

If CTC is introduced after 10 existing loops have already been extended, the capital costs are as follows:

	$
2 new loops @ $230,000 each	460,000
11 existing loops signalled @ $115,000 each	1,265,000
84 km of track circuits @ $790 per km	66,360
188 km of conductors @ $462 per km	86,856
30 switchlocks @ $10,350 each	310,500
	2,188,716
Add 10% contingencies	218,872
	$2,407,588

Total : $2.41 million

The savings are similar in nature to those described in Section C.4.1 and are as follows:

- $46,000 per annum by not having to replace old signals;
- $192,050 manpower savings per annum.

C.7 CTC SCHEME 4 : SUNSHINE TO SERVICETON

C.7.1 Extension of 5 Crossing Loops from Ararat to Serviceton

The capital cost is given in Section C.8.

Total : $569,250

C.7.2 From Ararat to Serviceton

If CTC Scheme 4 from Ararat to Serviceton is introduced after 5 existing loops have already been extended, the capital costs are:

	$
12 existing loops signalled @ $115,000 each	1,380,000
132 km of track circuits @ $790 per km	104,280
261 km of conductors @ $462 per km	120,582

33 switchlocks @ $10,350 each	341,550
	1,946,412
Add 10% contingencies	194,641
	$2,141,053

Total : $2.14 million

The savings are the same as in Section C.4.1:

- $46,000 per annum by not having to replace old signals;
- $113,850 manpower savings per annum.

C.7.3 From Sunshine to Ararat

The capital costs are:

	$
3 new loops @ $230,000 each	690,000
3 extended loops @ $172,500 each	517,500
4 existing loops signalled @ $115,000 each	460,000
124 km of track circuits @ $790 per km	97,960
188 km of conductors @ $462 per km	86,856
30 switchlocks @ $10,350 each	310,500
	2,162,816
Add 10% contingencies	216,282
	$2,379,098

Total : $2.38 million

The savings are the same as in Section C.4.2:

- $46,000 per annum by not having to replace old signals;

- $192,050 per annum manpower savings

C.8 5 EXTENDED LOOPS BETWEEN SUNSHINE AND ARARAT

The cost of loop extensions is $84 per metre, giving an average cost $57,500 per loop extended. An extra cost of $46,000 is incurred in the case of mechanically operated points: once the loop is extended beyond 310 metres, motor operation of points becomes a necessity, requiring the extra cost. All loops proposed for extension belong to this category, resulting in a cost per loop of $103,500. The cost of extending 5 loops is then: $517,500, or $569,250 if 10% contingencies are added.

No savings accrue from extension of crossing loops.

Total Capital Cost : $569,250

C.9 GEELONG DIVERSION

C.9.1 Capital Costs of Via Geelong Route

In order to obtain full benefit from the use of the diversion, the 1 in 50 grade between Miram and Diapur should be regraded at a cost of $69,000. This improvement would allow one 2237 kW loco to haul the heavier express freight trains through the Ararat to Serviceton portion of the line. The upgrading scheme of the line via Geelong requires the following capital costs:

	$
Minor extensions to 11 existing loops	230,000
Major alterations and extensions of loops at Gheringhap & Maroona @ $230,000 each	460,000
13 existing loops signalled @ $106,950 each(1)	1,390,350
New pole line	805,000
Track circuits and conductors	115,000
3 switchlocks @ $10,350 each	31,050
	3,031,400
10% contingencies	303,140
	3,334,540

(1) Signalling cost of existing loops is $8,050 cheaper than on the main line, because the design of the new pole line allows use of non-shielded cables for the distribution of power at crossing loops.

Regrading Miram to Diapur	69,000
	$3,403,540

Total : $3.40 million

C.9.2 Locomotive Cost Savings

By diverting some express freight trains via Geelong, one 2237 kW locomotive is capable of hauling the trains instead of two 1491 kW locomotives. This introduces savings in locomotive capital and maintenance costs, which are calculated on the bases given in Sections C.1 and C.2.

C.9.3 Rerailing Costs

If only the present traffic continues to use the via Geelong route, the line is scheduled for rerailing in 20 years time. However, if the traffic level is increased on this route, earlier rerailing will become necessary, resulting in a loss of benefit. On the other hand, it can be shown that just about all of this loss is compensated for by the deferral of rerailing on the via Ballarat route, due to the corresponding decrease in the traffic level there. For this reason, rerailing costs are not included in the analysis of the Geelong Diversion option.

C.10 SCHEME 7 : LINE DOUBLING

C.10.1 Extension of 10 Crossing Loops

As detailed in Section C.8 the capital cost of extending one crossing loop is $103,500. Thus the extension of 10 crossing loops costs $1,035,000, or $1,138,500 if 10% for contingencies is added.

Total : $1,138,500

C.10.2 Section Kaniva to Serviceton Doubled

The capital cost of doubling the Kaniva to Serviceton section is:

	$
23 km @ $117,850 per km	2,710,550

Total : $2.71 million

C.10.3 Section Dimboola to Salisbury Loop Doubled

The capital cost of doubling the Dimboola to Salisbury Loop section is:

	$
27 km @ $117,850 per km	3,181,950

Total : $3.18 million

C.10.4 Section Nhill to Diapur Doubled

The capital cost of doubling the Nhill to Diapur section is:

	$
18 km @ $117,850 per km	2,121,300
Total : $2.12 million	

C.11 SCHEME 8 : DEVIATIONS

C.11.1 Parwan to Horseshoe Creek Deviation

The capital cost of this deviation is estimated at $2 million. It is expected that by the introduction of the deviation the construction of one crossing loop can be saved ($230,000 maximum), reducing the capital cost to $1.77 million. Furthermore, a 6 minutes saving in transit time is also expected for both directions of travel. Assuming 30 trains per day and 312 'busy days' per year results in an approximate annual saving of

$$\frac{30 \times 312 \times 6}{60} = 936 \text{ hours.}$$

If this time saving can be fully utilised for train running (at 50 km/h), then the distance saving is 46,800 km.

The contribution of this project to the capacity increase of the Melbourne-Serviceton line is marginal, and so the only quantifiable benefits will be savings in train capital and operating costs. The introduction of the deviation in 1975 will then result in present values of the accumulated savings during the 20 year period of:

Capital (1400 tonne trains) : $46{,}800 \times 7.221 = 337{,}942$

Operating : $46{,}800 \times 1.897 \left\{\frac{1-(1+0.07)^{-20}}{0.07}\right\}$

$= 940{,}531$

<u>Total:</u> \$1,278,473 at 7% discount rate

<u>Total Discounted Cost:</u> \$1.77m - \$1.28m = **\$0.49m.**

C.11.2 <u>Millbrook to Dunnstown Deviation</u>

The capital cost of this deviation is estimated at \$1.5 million, and a 5 minute reduction of journey time is expected in both directions. Assuming 30 trains per day and 312 'busy days' per year, the resulting annual saving is about

$$\frac{30 \times 312 \times 5}{60} = 780 \text{ hours.}$$

If this time saving can be fully utilised for train running (at 50 km/h), then the distance saving is 39,000 km.

The contribution of this project to the capacity increase of the Melbourne-Serviceton line is marginal, and the only quantifiable benefits will be savings in train capital and operating costs. The introduction of the deviation in 1975 will then result in present values of the accumulated savings during the 20 year period of:

Capital	:	39,000 x 7.221 = 281,619
Operating	:	39,000 x 1.897 x 10.594 = 783,775
<u>Total</u>	:	$1,065,394 at 7% discount rate

<u>Total Discounted Cost</u> : $1.50m - $1.07m = $0.43m.

C.12 SCHEME 9 : ELECTRIFICATION

From the information available at present it appears that the only substantial benefit accruing from electrification would be due to savings in locomotive maintenance costs. No data is presently available on the magnitude of these savings in the case of locomotive hauled trains, however some indication can be obtained from the NSWPTC figures relating to multiple unit diesel passenger trains: electrification in such a case results in a 50% saving in maintenance costs. Although it is unlikely that savings of similar magnitude could be achieved in the case of locomotives, a 50% reduction in maintenance cost will be assumed here in an attempt to present electrification in a favourable light.

Electrification is proposed in three stages:

(a) 106 km from Sunshine to Ballarat, at a capital cost of \$4 million. Using \$0.15 per km as the maintenance cost of diesel locomotives (see Subsection C.2.1), and assuming 30 trains per day and 312 'busy days' per year the savings accruing from electrification would be

$$106 \times 30 \times 0.15 \times 0.5 \times 312 = \$74,412.$$

The present value of the savings accumulated during the 20 years study period is:

$$74,412 \left\{\frac{1 - (1 + 0.07)^{-20}}{0.07}\right\} = 788,320 \text{ at a 7\% discount rate}$$

<u>Total Discounted Cost</u> : \$4.00m - \$0.79m = <u>\$3.21m</u>

It can be seen that an increase of almost 500% in the number of trains is required before this electrification scheme becomes an economic proposition. Simulations of the line with both diesel and electric locomotive hauled trains indicate a transit time reduction of 10 minutes per train on the electrified line. However, most of this 10 minutes is lost by having to change locomotives at Ballarat, and any net saving would be lost by the cost of having to provide two locomotive fleets, one diesel and one electric.

(b) 92 km from Ballarat to Ararat, at a capital cost of $3 million. Assuming 25 trains per day and 312 'busy days' per year, the total discounted benefit at 7% is

92 x 25 x 0.15 x 0.5 x 312 x 10.574 = 570,169

Total Benefit : $570,169

Total Discounted Cost : $3.00m - $0.57m = $2.43m

(c) 31 km from Ararat to Stawell at a capital cost of $1 million. Assuming 20 trains per day and 312 'busy days' per year the total discounted benefit at 7% is

31 x 20 x 0.15 x 0.5 x 312 x 10.594 = 153,698

Total Benefit : $153,698

Total Discounted Cost : $1.00m - $0.15m = $0.85m

C.13 SCHEME 10 : IMPROVEMENTS BETWEEN ADELAIDE AND MURRAY BRIDGE

Two schemes will be considered, one proposing improvements to curvatures, the other a high speed rail link.

The capital cost of the curvature improvement scheme is estimated at $30 million. However, if the scheme is phased in at a time when the existing line is due for rerailing the actual cost can be reduced to $30.00m - 97 x $21,750 = $27.89 million. There is a corresponding 45 minute transit time reduction for freight and interstate passenger traffic (excluding commuter traffic). Assuming 30 trains per day and 312 'busy days' per year results in an approximate annual saving of

$$\frac{30 \times 312 \times 45}{60} = 7{,}020 \text{ hours.}$$

If this time saving can be fully utilised for train running (at 50 km/h), then the distance saving is 351,000 km.

The present values of the accumulated savings over 20 years will be:

Capital : 351,000 x 6.617 = 2,322,567

Operating[1] : 351,000 x 1.878 x 10.594 = 6,983,332

<u>Total</u>: $9,305,899 at 7% discount rate.

<u>Total Discounted Cost</u>: $27.89m - $9.31m = $18.58m

The improvement of this stretch of line is also being considered by planners of the proposed new city near Murray Bridge and their proposal forms the second scheme.

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(1) The operating costs are overestimated since it is assumed that the 45 minute transit time reduction is entirely attributable to a reduction in distance.

Commuters from the new city to Adelaide could either use bus, giving approximately a 1½ hour transit time, or rail which has a 2½ hour transit time at present. Clearly, the curvature improvements proposed above will not reduce the rail time sufficiently to compete with the bus. Further reductions in rail transit time can only be achieved by costly (of the order of $80 million) and time consuming tunnel building, in an attempt to introduce a high speed rail link. This link, however, is unlikely to be completed within the time frame of this study and no further consideration will be given in this report to the Adelaide-Murray Bridge high speed rail link.

ANNEX D 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.

D.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 8 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.

D.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.

D.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 project by the BTE and IBM Systems Development

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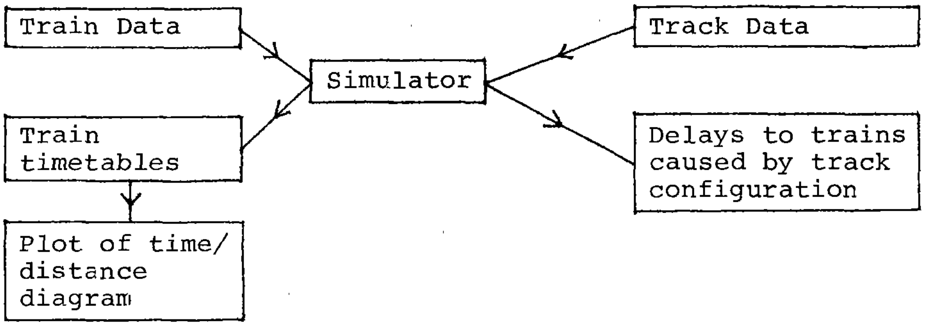
(1) D.A. Rudd & A.J. Storry, 'Single Track Railway Simulation - New Models and Old', IBM Systems Development Institute, Canberra, SDI 0058 (December 1974).

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].

D.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

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

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

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

classes of trains. Several sets of values were considered for the weighting factors and are given in Table D.1.

TABLE D.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 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 D.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 D.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, $(0, 0.5]$, $(0.5, 1.0]$, ..., $(3.5, \infty)$. However, it was necessary to combine the frequencies above 1.5 for the Chi-squared test. The results are also shown in Table D.3.

TABLE D.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.

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

TABLE D.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

case with lower statistic values would be better. This prompted a choice of Case 5.

D.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 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

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

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 D.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 D.5.

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.

TABLE D.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 D.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.

D.2 A MODEL FOR EVALUATING UPGRADINGS

Once the delay patterns of each upgrading have been determined by the Single Track Simulator (Section D.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 at 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 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 E). The information is edited and compressed into year by year net costs, for each upgrading and possible traffic flow pattern. This

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(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.

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. D.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.

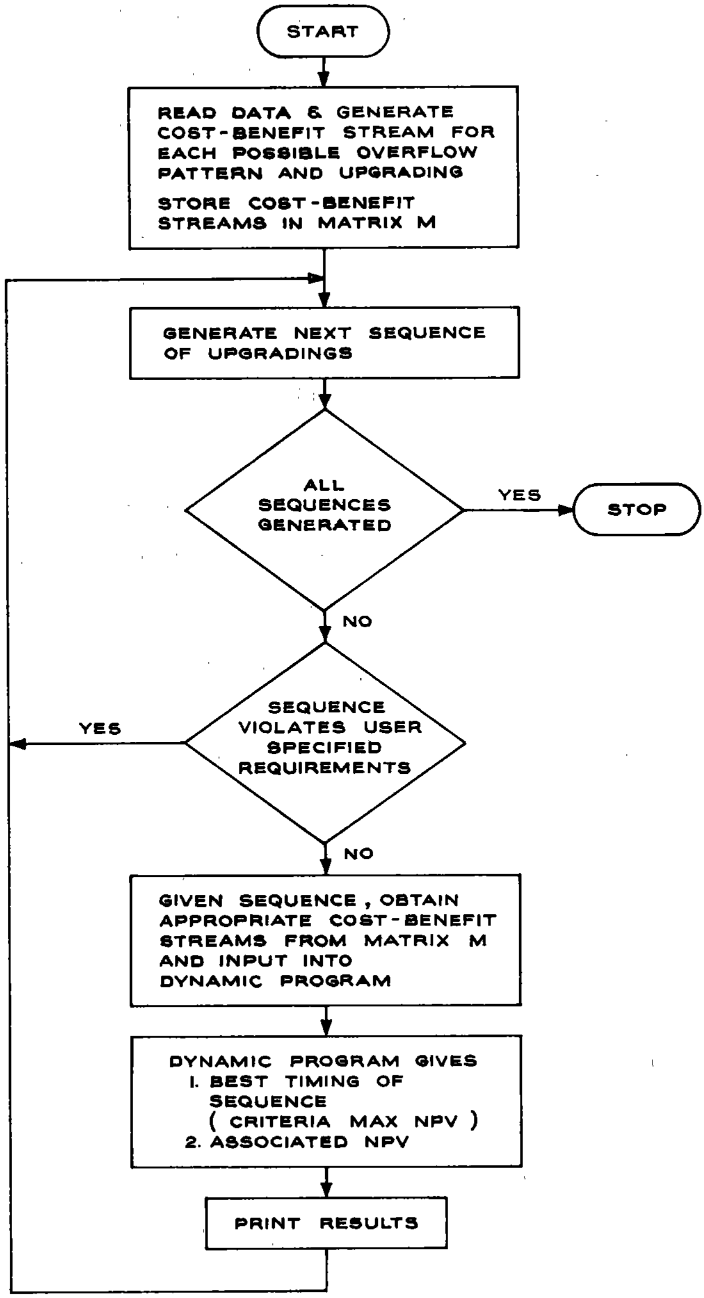

FIGURE D.1

DYNATREE SYSTEMS CHART

ANNEX E METHOD AND ASSUMPTIONS

E.1 ASSUMPTIONS

E.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.

E.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' (Canberra, 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 B) 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

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(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.

around continuously. In this situation, transit delays would be predominantly reflected as reduced utilisation of 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 intrastate 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 13 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

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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 'Overland' would typify this situation.

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.

E.2 METHOD

E.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 E.1 for a list of the variables).

Annual distance travelled by locomotives under delayed conditions

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

$$= \frac{A_M}{1 + f(x)}, \qquad \text{(E.1)}$$

TABLE E.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.

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

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:

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

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

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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%.

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 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,

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

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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.

This will be a maximum when

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

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:

$$P = \sum_{i=1}^{k} x_i \left[R_i - \left\{D_i\left(\frac{C_{M_i}}{A_{M_i}} + \frac{C_{R_i}}{A_{R_i}}\right) + H_i T_i\right\}\left(1 + f_i(x_1, x_2 \ldots x_K)\right) - D_i m_i\right]$$

$$+ \sum_{\text{all } j} n_j \left[R_j - \left\{D_j\left(\frac{C_{M_j}}{A_{M_j}} + \frac{C_{R_j}}{A_{R_j}}\right) + H_j T_j\right\}\left(1 + f_j(x_1, x_2 \ldots x_K)\right) - D_j m_j\right]$$

(E.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 (E.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 (E.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,

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

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:

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

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

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

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 4.3.

E.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 E.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

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

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

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:

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

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.

ANNEX F MOTIVE POWER AND TRAIN WEIGHT

F.1 Motive Power Requirements on the Via Ballarat Route

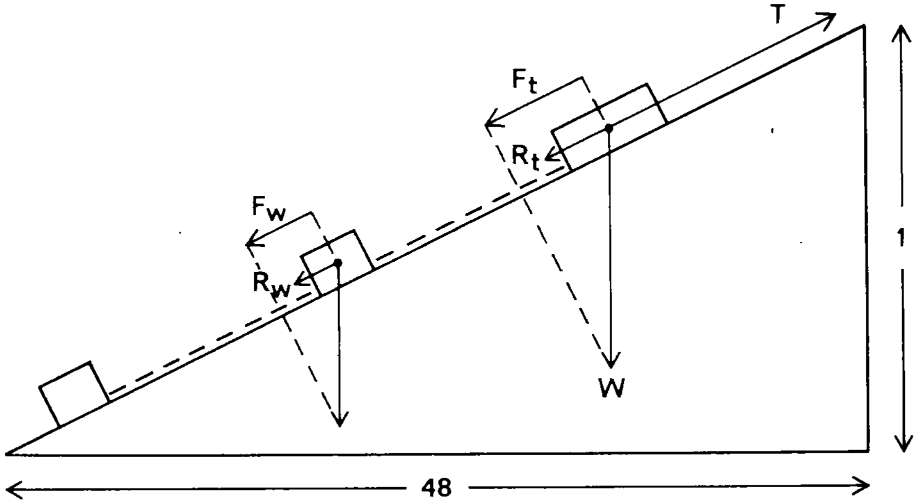
The problem area on the route via Ballarat is the crossing loop at Bank Box Loop, where the ruling grade is 1 in 48 and where some trains have to start uphill from rest. At present express freight trains are hauled by two 1491 kW locomotives on this route. The distribution of forces in such a case is shown in Fig. F.1. Forces T, F_t and R_t are applied at the centre of gravity of the locomotive; all other forces are applied at the centre of gravity of the train load including the weight of the wagons. Given an adhesion coefficient of 0.25, a starting resistance of 11 kg per tonne for both locos and wagons, and a weight of 114 tonnes for one 1491 kW loco, the tractive effort will be:

$$T = 2(114 \times 1000 \times 0.25) = 57,000 \text{ kg}$$

The tractive resistance of the two locomotives is:

$$R_t = 11 \times 114 \times 2 = 2,508 \text{ kg.}$$

$$\frac{F_t}{W} \simeq \frac{1}{48}, \text{ thus } F_t \simeq \frac{2 \times 114}{48} = 4.75 \text{ tonnes}$$



T is tractive effort

R_t is tractive resistance of locomotive on level track,

F_t is locomotive resistance due to sloping track,

R_w is tractive resistance of one wagon,

F_w is resistance of one wagon due to sloping track,

W is weight of locomotive, and

n is the number of wagons hauled by locomotive.

FIGURE F.1 - DISTRIBUTION OF FORCES APPLICABLE TO A TRAIN CLIMBING A 1 IN 48 GRADE

Taking an average weight of 40 gross tonnes per wagon, the tractive resistance of one wagon will be:

$$R_w = 40 \times 11 = 440 \text{ kg}$$

$$\frac{F_w}{40} \simeq \frac{1}{48}, \text{ thus } F_w \simeq \frac{40}{48} = 0.83 \text{ tonnes}$$

The maximum number of 40 gross tonne wagons that the 2 locomotives are able to haul is given by the equilibrium equation:

$$T - R_t - F_t - nR_w - nF_w = 0,$$

i.e. $57{,}000 - 2{,}508 - 4.75 \times 1000 - n(440+0.83\text{x}1000) = 0$, which gives

$n = 39$ wagons corresponding to a trailing load of <u>1560 gross tonnes</u>

Thus two 1491 kW locomotives are incapable of hauling trains of a maximum weight of 1800 gross tonnes (i.e. average weight of 1400 gross tonnes). A similar analysis shows that one 1491 kW locomotive together with one 2237 kW locomotive are capable of hauling a maximum trailing load of <u>1640</u> gross tonnes if the weight of the 2237 kW locomotive is taken as 126 tonnes. The corresponding figure for the case of two 2237 kW locomotives is 1720 gross tonnes and although this figure is below the set maximum of 1800 gross tonnes it will be assumed in this analysis that two 2237 kW locomotives will be used for hauling the longer trains on the main line. It is possible that Victorian Railways will eventually decide to use two 1491 kW locomotives and one 746 kW locomotive in this case as such a combination lifts the maximum trailing load to around 2000 gross tonnes, however the cost streams computed for the case of two 2237 kW locomotives will roughly apply as the total locomotive capital cost is similar in both cases. As far as this study is concerned, then, the longer trains will be hauled by two 2237 kW locomotives, except the overnight express freight trains for which overall transit time is critical. These trains will continue to carry an average of 1000 gross tonnes and will continue to be hauled by two 1491 kW locomotives.

F.2 Motive Power Requirements on the Via Geelong Route

The ruling grade on this line is between Miram and Diapur; the present grade is 1 in 50 for a length of 560 metres. The Geelong Diversion proposal makes provision for regrading this to a 1 in 62 balancing grade. There is also a 1 in 60 grade near Ararat and a 1 in 50 grade near North Geelong, which has a length of 40 metres - considerably shorter than one train length.

Motive power requirement calculations are rather complex under these conditions and a computer program (TPC) developed at NSWPTC which simulates the performance of the locomotive under various track and load configurations was used to determine the maximum weight of trains. The results are shown in Table F.1, indicating that on this route one 2237 kW locomotive is capable of hauling trains with a maximum weight of 180 gross tonnes (average 1400 gross tonnes) if the Miram to Diapur section is regraded.

TABLE F.1 - MAXIMUM TRAIN WEIGHT: VIA GEELONG ROUTE

(gross tonnes)

Motive Power	Max. Train Weight	
	Up	Down
2 x 1491 kW loco without regrading(a)	1800	1900
1 x 2237 kW loco without regrading	1650	1750
1 x 2237 kW loco with regrading	1800	1900

(a) Regrading refers to the Miram to Diapur section.