Scheduling Investment in Main Railway Lines

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ABSTRACT

As interstate freight forwarders' traffic continues to grow, congestion problems are expected on several sections of Australian railway main line. Two criteria are applied in evaluating investment in main line upgrading - net revenue to the railway and transport resource cost. Both take account of congestion delay costs in terms of degraded motive power and rolling stock mileage utilisation and additional crew cost. The idea of main line 'capacity' is developed, both from a commercial and resource cost point of view. The trade-off between rail upgrading and the road transport alternative is also examined, both in terms of diverted traffic and additional costs to other road users.

INTRODUCTION

The analytical content of railway line upgrading evaluations is similar in many respects to that required for other modes; probably the main reason for the relative lack of attention to railway investment matters in the transport economics literature is that the emphasis in public transport investment, until recently, has been on roads and airports and, more recently, on urban public transport. In fact, in the US, the problem has been one of railway disinvestment rather than the converse.

The recent major investments in specialised railway mineral traffic in Australia are well known and have tended to overshadow other less spectacular but nevertheless important growth sectors of railway undertakings. Interstate freight is one of these. Following the entry of major freight forwarders into railway business, the trend has been for certain interstate general freight traffics to gravitate to rail because this mode offers tangible long term advantages. Thus, rail's share has tended to stabilise and the traffic is growing at between 3 and 5 percent, depending on the commodity. Steel is another possible growth commodity; this is discussed later in the context of the interaction between the rail and sea modes.

The advantage of rail over road is the significantly lower marginal cost of line haul as compared to road. Its major disadvantage is the high cost of intermodal transfer at the ends of the journey. As is outlined in the Annex, the freight forwarders' system of direct transfer of large unit loads, e.g. containers and flexivans[1], from wagons to trucks reduces these handling costs to a small proportion of the line haul cost difference between road and rail, particularly as the line haul distance increases.

The growth in interstate freight forwarders' traffic has led to congestion in several parts of the railway system, including terminals and some sections of main line. This paper is concerned with the latter and the methods we are using to evaluate investment to overcome congestion. We have divided our topic into three parts. In the first part we argue through the more important simplifications of our analysis. We go to some trouble to justify our assumptions

1. Flexivans are large open containers that just fit an articulated truck.

because they enable us to develop a simple and direct approach to the evaluation. The second part describes the methods used to estimate congestion on the line, and to estimate the effect of upgrading on costs and revenues and, finally, how investment may be scheduled in an optimum way. The third part presents some recent results obtained for the Sydney-Melbourne link.

INTERACTION BETWEEN RAIL AND OTHER MODES

Rail/Sea

In general, both sea and road compete with interstate rail, but because the freight forwarders' interstate operations are centred around either road or rail we have been able to ignore sea as a competitor for this traffic in the short term.

On the other hand, movement of steel between Port Kembla and Melbourne/Westernport is closely associated with the pattern of industrial development in these two coastal locations. Ships for the carriage of steel tend to be specialised "lumpy" items of plant and the decision to invest takes into account many detailed aspects of the industrial processes of which it is part, including, possibly, deliberate policy to avoid commitment to one mode only. To avoid this complexity, we postulate a range of freight transport forecasts corresponding to a greater or lesser level of steel traffic on rail. Generally speaking, different freight projections affect timing rather than the choice of upgrading option. Both rail and sea require similar lead times to increase capacity, so both modes are approximately equally responsive to changes in timing. For these reasons, we have ignored rail/sea interactions in this paper.

Rail/Road

Our approach to the road/rail interaction for interstate freight is based on the idea of rail "capacity" to carry growing traffic. The ultimate capacity of a railway line is that level of traffic beyond which congestion delays increase indefinitely. A useful analogy is provided by queuing theory; so long as the rate of arrivals at a facility does not exceed its servicing rate, the queue of waiting arrivals is stable with time to the extent that its mean length is finite. Only if the arrival rate exceeds the service rate does the queue length increase indefinitely (or for as long as the high arrival rate is maintained). From the railways point of view, the capacity will generally be somewhere below this ultimate value, because the increasing cost of congestion delays will eventually reduce the marginal net revenue to zero before ultimate capacity is reached. From a resource point of view, the railway should go on accepting traffic until the total rail resource cost, including delays, exceeds the additional cost of using road. This distinction will become clearer in the analytical section of the paper. Suffice to say at this stage that under either the commercial or resource cost criterion, growth traffic beyond the relevant capacity point is treated as spilling over on to road. Thus, one of the resource benefits of rail upgrading is avoiding this additional cost of spill-over traffic (see Annex).

In addition to the increased line haul cost by road, we also argue that the spill-over traffic would cause delays to other road users and, ultimately, could lead to a requirement for an earlier increase of road capacity. As part of its task to advise on the application of the Commonwealth Aid Roads Act, Bath, Thompson and Lack (1972) - at the Commonwealth Bureau of Roads have developed procedures to evaluate the resource costs and benefits of road upgrading and it should be possible to apply a similar analysis to assessing the significance of spill-over traffic. This work is still in its early stages; some of our results will be discussed in the final section.

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 a 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 ton-mile 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 and we have therefore considered a range of revenues per ton mile.[1]

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1. For the Melbourne-Sydney evaluations the range was 1.0 to 1.3 cents per ton mile, at 1973 prices.

RAILWAY COSTS

General description

The railways' assessment capacity 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 centralised traffic control. 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 incremental cost:

- fuel and crew
- motive power and rolling stock maintenance
- track maintenance
- motive power and rolling stock capital requirements
- traffic congestion costs.

Track maintenance

Following research at the BTE into track maintenance costs, it appears that these costs are essentially usage dependent, expressed, say, in dollars per gross[1] tonne kilometre. By including all components of track in the maintenance function, and treating existing earthworks, bridges,

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

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.

Motive power and rolling stock capital requirements

We visualise that, under steady traffic conditions over the long term, average annual mileages 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.

Traffic congestion delay costs

This can be conveniently divided into two parts - direct delay costs, i.e. crew, and indirect delay costs resulting from degraded utilisation of equipment. The former are straightforward; by aggregating equipment costs we have simplified the latter. There are two bounds to the effect of traffic delays. At one extreme, there is the situation in which delays do not lead to loss of motive power and rolling stock utilisation - as would be typified by, say an infrequent service to a remote railhead. Other than additional crew costs, the only cost to the railway may be idle manpower cost at the terminal. At the other extreme, we have delayed arrivals at a busy terminal, working 24 hours per day, and turning trains around continuously. In this situation, transit delays would be predominantly reflected as reduced utilisation of wagons and locomotives, in terms of annual mileage. 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. These are treated in exactly the same way, but with discretion, because, as discussed earlier, wagon utilisation is relatively insensitive to transit delays for some traffics. Some allowance is also made for delays to long distance passenger trains; country and suburban services are ignored.[1] Long distance passenger trains are generally typified by low frequency and rolling stock that can be treated as unique to the service.[2] Passenger coaches tend to operate in sets, travelling in each direction on alternate days; for a typical intercity transit time of about 15 hours, then, a delay of one or two hours would not directly affect utilisation of rolling stock. Some time between trips is required for carriage cleaning etc. but it has been assumed that adequate tolerance

1. Interference between long distance freight trains and suburban services can be significant, during peak hours on heavily used shared lengths of track. This requires analysis in its own right, generally as part of an urban transport study.
2. The Southern Aurora and The Overland would typify this situation.

is available to absorb delays. Passenger time delay cost is ignored because of lack of definitive estimates of its value for this type of traffic-see Walker and Jones (1975). This leaves motive power as subject to delay costs; the locomotives used on passenger trains are generally not unique to that traffic - and transit delays will therefore lead to a degradation of utilisation. Delay costs for train crews are treated in the same way as for freight trains, noting that passenger trains carry conductors and catering staff.

ESTIMATION OF DELAYS TO TRAINS

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 restraints, not least of which are those associated with the terminals at the end of the journey. Overnight express passenger trains for instance would leave round about 7 pm and arrive 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 impracticable for line upgrading investigations involving significant and numerous changes to the configuration of the line, composition and volume of traffic. For this reason computer simulations of train operation have been developed both by NSW railways and jointly by Rudd and Storry (1974). Essentially, these simulations take the operating characteristics and train departure schedule as given and develop a timetable according to the appropriate signalling rules and train priorities. The synthetic timetables so produced are imperfect to the extent that the flexibility inherent in a manual system is lacking and no explicit attempt is made to optimise the train schedules; however, Jones and Walker (1973) have verified that reasonably realistic schedules can be produced at traffic intensities typical of those currently on main lines.

At traffic intensities approaching the ultimate capacity of the line, however, we have found that the synthetic schedules become sensitive to small timetable changes and the inflexibility of the simulation process becomes apparent in its failure to resolve train crossing conflicts in a realistic way. For example, the simulation may fail to resolve conflicts at a high traffic volume, while at a higher volume, because of some fortunate combination of train crossings, all conflicts are once more resolved.

Another problem associated with identifying the ultimate capacity of the line is that, in practice, train departures and transit times are subject to random variation, usually in a way detrimental to the overall performance of the system. Thus, while our simulations are realistic at traffic volumes being realised currently on main lines, with some congestion being experienced, their validity becomes uncertain as saturation is approached. For this reason, our imputed values of ultimate capacity are probably too high. This will tend to understate the resource benefits from upgrading.

RAILWAY LINE CAPACITY - A GENERAL APPROACH

Description

First consider the simple case of homogenous traffic.

Defining our nomenclature:

C_M	=	Capital cost of motive power, per train, expressed as annuity.
C_R	=	Capital cost of rolling stock, per train, expressed as annuity.
A_M	=	Annual mileage of locomotives under datum conditions.
A_R	=	Annual mileage of 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 mile.
δT_x	=	Delay per trip, at a traffic intensity 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.

Annual mileage of locomotives under delayed conditions

$$= \frac{A_M \cdot T}{T + \delta T_x}$$

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

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

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

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

Use of this improved formula would, however, only have a small effect on the final results.

Similarly, annual mileage of rolling stock under delayed conditions = $\dfrac{A_R}{1 + f(x)}$

Therefore annual capital component of train cost at traffic volume x = $x.D.\left(\dfrac{C_M}{A_M} + \dfrac{C_R}{A_R}(1 + f(x))\right)$ (2)

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

This annual capital component (equation 2) of train cost is identical to the sum of motive power/rolling stock capacity cost and traffic congestion delay cost as defined in later sections.

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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 $\dfrac{i(1 + i)^n}{(1 + i)^{n-1}}$ where i is the discount rate and n the life. Clearly, as either i or n increase it tends to i.

Other costs are given by:

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

Maintenance and fuel: xDm

Therefore annual net revenue

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

This will be a maximum when

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

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 of the form

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

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

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

$$+ \sum_{\text{all } j} n_j \left[R_j - \left\{ D_j \left(\frac{C_{Mj}}{A_{M_j}} + \frac{C_{Rj}}{A_{R_j}} \right) + H_j T_j \right\} (1+f_j(x_1, x_2 \ldots x_K)) - D_j m_j \right] \quad (4)$$

Clearly, for all but the simplest cases, the combined traffic volume corresponding to maximum annual net revenue would be deduced numerically. However, 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 3).

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

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

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

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

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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.

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.

Summary of implications of analysis

(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.

A graphical illustration of these capacities is shown on Figure 1.

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, with the addition of:

suffix 1 to indicate a cost parameter after upgrading
I = Capital cost of upgrading, expressed as annuity
S = Annual manpower saving after upgrading

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

$$P_1 = x\left[R - \left\{D\left(\frac{C_{M1}}{A_M} + \frac{C_R}{A_R}\right) + HT\right\}(1+f_1(x)) - Dm_1 - I + S\right]$$

and upgrading is justified providing

$$\left\{D\left(\frac{C_{M1}}{A_M} + \frac{C_R}{A_R}\right) + HT\right\}(1+f_1(x)) + Dm_1 + I - S - \left\{D\left(\frac{C_M}{A_M} + \frac{C_R}{A_R}\right) - HT\right\}(1+f(x))$$

$$- Dm < 0$$

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:

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

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

The upgrading decisions are illustrated graphically on Figure 2.

Two upgradings are shown to illustrate the reasoning determining their introduction points. It is interesting to note that a resource costing approach could lead to an earlier introduction of upgrading compared to a commercial approach - e.g. if the resource capacity is greater than V_3 as indicated on Figure 2.

Now consider the situation illustrated on Figure 3. Suppose there is a choice of upgradings which could be introduced sequentially. Clearly, upgrading (1) should be introduced at traffic volume V_1, followed by upgrading (2) at V_3. Now suppose that, in upgrading from (1) to (2), a significant proportion of the first investment becomes redundant long before its life would normally expire. The question could now be one of postponing upgrading until some grander scheme becomes justified - say doubling the line. With an approach using annuity based capital cost we would need to apply an iterative procedure to allow the lives of earlier investments to be reduced if necessary. The problem of scheduling investment is not unique to railways and we have developed general procedures based on dynamic programming which can account for capacity constraints, prescribed upgrading sequences and premature scrapping of earlier investments. These are briefly described in the next section.

SCHEDULING UPGRADING

It may be shown that an investment problem involving n options which may be scheduled in any way over m decision periods has $n(n-1)^m$ solutions. Thus, with 5 options and 10 annual decision periods, there would be over one million possibilities. In order to keep the computational task within practical limits, the dynamic programming technique may be applied to this problem. This effectively decomposes the problem to comparing n options n times for each of the m periods, i.e. mn^2 computations - a factor of about four thousand down on the example given above.

The technique is formulated and validated by Nemhauser (1967). Briefly, the procedure calculates the costs and benefits of selecting any one of the options available for a given decision period. Providing the costs and benefits incurred during a decision period are only determined by the change of state of the system during that period and are independent of preceding or following changes, it is possible to select an optimum decision path year by year, moving backwards in time. "Optimum" in this context would be leading to the maximum value of the difference between benefits and costs, although other criteria, to be maximised or minimised, could be used providing they are additive. To illustrate the approach, a simple example is shown on Figure 4.[1] The sample problem involves four options to be selected during a five year period; essentially, an option is a transition from one state to another (or remaining in the same state). For each year of the study period each transition incurs a "score", analogous to, say, net benefit; these are shown as five transition tables on the figure.

This data is subjected to a dynamic programming procedure for three sample problems. Firstly, unconstrained to the extent that any option may be selected at any time; secondly only options of equal or higher state number may be selected and thirdly, only two options are available; remaining in the current state, or proceeding to the state with a state number equal to the current state number plus one. State number 1 is the starting state in all three cases. The results are shown

1. For a detailed discussion of dynamic programming and the use of transition tables see Nemhauser (1967), p.67onwards. For a less technical discussion omitting the use of transition tables, see Wagner (1969), Chapt. 8.

on Figure 4 in the form of optimum paths through the time/state network. The cumulative score at each point[1] of the network is the total for an optimal path, from that state in that year, to a state at the end of the study period. These three simple examples illustrate the power of the procedure in being able to handle constraints.

Returning now to our railway investment problem, the following lists the requirements and constraints that would need to be incorporated in a dynamic programming procedure:

- costs and savings (or benefits) discounted year by year,
- finite capacity of some upgrading configurations,
- spill-over of traffic assigned to other
- prescribed modes when capacity is reached on the railway, including its cost,
- pre-determined sequences of upgrading,
- applicable to both commercial and resource criteria,
- premature withdrawal of earlier investments.

This last requirement, which is incompatible with the step by step dynamic programming procedure, can be met by an artifice. This takes the form of specifying an upgrading likely to be prematurely scrapped as several mutually exclusive upgradings each having a specific year of introduction. Thus, the cash flows corresponding to any year of scrapping can be calculated. We have incorporated all of the requirements listed above in a generalised computer procedure.[2]

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1. Each point corresponds to one state in a particular year.
2. To be published.

SOME RESULTS

Commercial criteria

Figures 5 to 10 inclusive are a sample of results from a current BTE study of the Melbourne-Sydney rail link. The results take the form of graphs of annual net revenue against time, calculated as outlined in previously. We have divided the link into a Victorian section and a New South Wales section; implied here are the separate commercial interests of the State railway systems.

Consider first the Victorian standard gauge line from Albury to Melbourne. This is a relatively new line for interstate traffic only, single track with centralised traffic control (CTC). Figure 5 shows, that for the operating and cost parameter indicated, commercial capacity will be reached in year 4; adding six crossing loops provides sufficient capacity till year 17. Adding a further four or twelve loops extends capacity beyond the twenty year study period. The graph also shows that the optimum strategy, for the parameter assumed, would be to introduce the first six additional loops in year 1, with some benefit from reduced delays, followed by another four loops in year 13, with another eight loops between years 16 and 17. The restricted number of alternatives do not require a dynamic programming procedure.

Figure 6 shows the effect of train weight on line capacity. Increasing train weight from 800 tons to 1100 tons would delay onset of commercial capacity by about six years; a further increase to 1400 tons would delay it by another 3 to 4 years. The diminishing returns to net revenue from an increase of train weight occur because 1400 ton trains require double heading, with consequent increase of locomotive maintenance costs. Figure 7 shows that commercial capacity with 6 loops is not reached during the study period if train weight is increased to or beyond 1100 tons. Again, diminishing returns from further increase of train weight is evident.

Turning now to the NSW portion of the line, the critical section is that between Albury and Junee. It is single track and mechanically signalled. The upgrading examples shown on Figures 8, 9 and 10 are two CTC schemes and selective line doubling. The first figure shows that the existing line would be expected to reach commercial capacity by about year 10; CTC1 would last until about year 17, CTC2 to beyond the end of the study period as would also selective doubling. CTC2 is, in fact, an extension of CTC1 and the graphs show it should be introduced in year 16. If 800 ton trains were retained, it would be economic to introduce CTC1 in year 1; selective doubling is inferior to CTC2 at any time in the study period. The dominance of CTC schemes over doubling (and other schemes not shown on graph) enable the optimum upgrading schedule to be identified without recourse to dynamic programming.

We also examined the effect of train weight on the NSW section. Again, heavier trains are superior for both the existing and upgraded line (Figures 9 and 10) and the trend of diminishing returns from increase of train weight beyond 1100 tons is re-emphasised. The gradients on the NSW side are such that 1400 ton trains become excessively penalised by the increased number of locomotives required to traverse the Great Divide.

<u>Resource criteria</u>

As outlined earlier, a resource cost approach needs to consider the interaction between road and rail. The idea of a resource capacity of a railway line beyond which further traffic spills over on to road has already been developed

As an example, we consider the case corresponding to resource capacity being reached on the existing Melbourne-Sydney line in year 14 of the planning period. Applying the parameters derived in the Annex, we have calculated the cost of transporting the spill over on road including the additional costs caused to this traffic and to other road users by this increment of traffic. To estimate the delay costs we applied the procedures developed by the Commonwealth Bureau of Roads (CBR) for evaluating road improvements to two configurations of the Hume Highway - namely its present configuration maintained indefinitely and an upgraded condition equivalent to two lanes in each direction over its whole length. These would represent the lower and upper bound of highway development, differing in capital cost by over $100 million. When resource capacity is reached on the railway line, we suppose that the NSW section is upgraded by introducing CTC and Victorian section by the addition of 6 loops, for a total track and signalling capital cost of under $5 million. The resource costs are summarised in Table I (road costs) and in Table II (totals and benefits for various combinations of road and rail configurations).

The main features of Table I are highlighted by the results for year 20. By that time, the spill-over traffic amounts to about 250 trucks per day, if rail is not upgraded. The "basic" cost of this traffic (defined as a footnote to the table) is about $16M. The "additional" cost (also defined) amounts to about $6½M, giving a total resource cost of about $22½M for the existing road compared to about $14M for an upgraded road. Note that the upgraded road leads to a reduction of basic cost because it leads to lower truck operating costs. The first row of Table II enumerates the resource costs of interstate freight rail traffic on the existing line; these remain constant over the seven year period because resource capacity has already been reached by year 14. The next row shows the same costs for the upgraded line; in this case there would not be any spill over on to road and these costs would be the total resource cost for the interstate freight that would go by rail. The next two rows are the sums of the rail resource costs for the existing line and the road resource costs given in Table I. The last two rows are the differences between the preceding two rows and the rail resource costs for the upgraded line, i.e. the rail upgrading benefit. These results indicate a rate of return from rail upgrading investment of at least 30%, even if the Hume Highway is upgraded to the point that the effect of spill over traffic on additional road costs (defined in Table I) is insignificant.

If present trends towards unit trains and containers were accelerated to the point that a significant shift of modal split away from road would occur, leading to a possible order of magnitude increase in rail upgrading requirements, then the road/rail interaction would become important. It is possible that accelerated investment in rail could be traded-off against a lower rate of investment in road. These possibilities are currently being examined.

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TABLE I

RESOURCE COSTS OF SPILL-OVER ROAD TRAFFIC ON EXISTING AND FOUR LANE HUME HIGHWAY

Melbourne-Sydney
1100 ton trains,
existing railway line.

Year of Study Period		14	15	16	17	18	19	20
Overflow 20 ton truck trips per day		15	48	83	120	160	203	248
Basic [(a)] line haul cost of overflow truck traffic.	$M	0.96	3.08	5.33	7.71	10.28	13.04	15.93
Additional Cost [(b)] to overflow and existing road traffic, existing road.	$M	0.20	0.71	1.38	2.26	3.38	4.75	6.44
TOTAL	$M	1.16	3.79	6.71	9.97	13.66	17.79	22.37
TOTAL for four lane highway.	$M	0.90	2.90	5.02	7.26	9.68	12.30	14.06

(a) Basic line haul cost is as calculated from the parameters derived in the Annex and does not include any additional costs caused by the greater volume of truck traffic. (b) Additional cost is the increase in vehicle operating resource cost, including time cost of drivers, resulting from the heavier truck traffic.

TABLE II

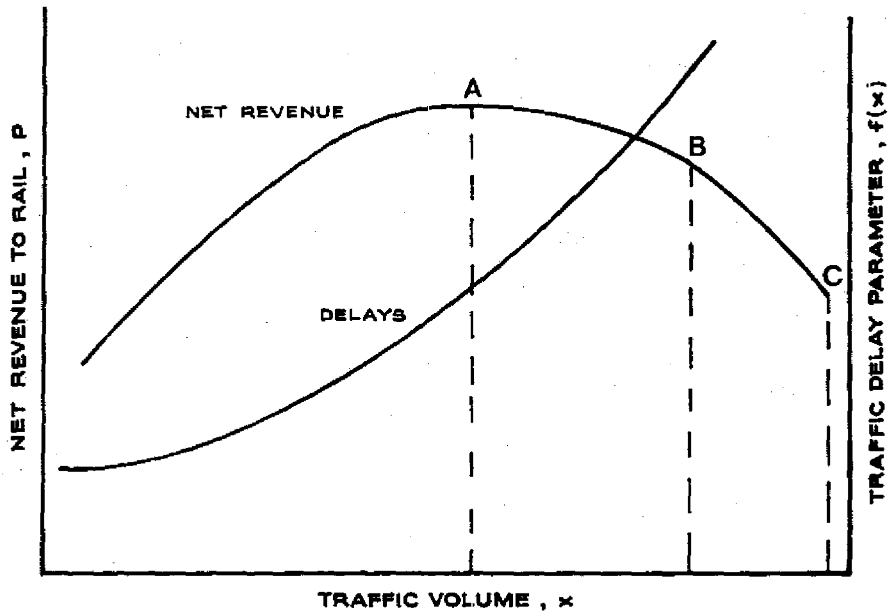
TOTAL RESOURCE COSTS AND BENEFITS OF INTERSTATE FREIGHT WITH VARIOUS COMBINATIONS OF UPGRADED RAIL AND ROAD

Melbourne-Sydney: 1100 ton trains
Upgraded Road: Equivalent to 4 lanes all the way.
Upgraded Railway: 6 additional loops in Victoria, CTC1 in NSW.

Rail capital converted to an annuity at 10% discount rate. No road capital included. Road resource costs from Table I.
No spill-over to road with upgraded rail.

($ million)

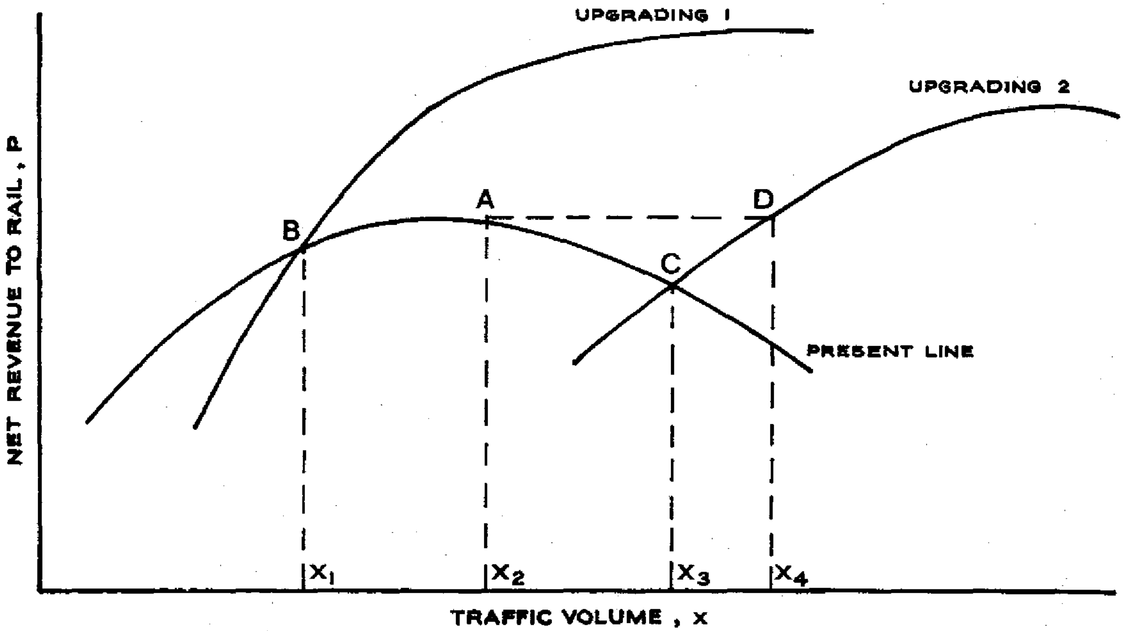
Year of Study Period	14	15	16	17	18	19	20
Rail resource cost, existing line	26.11	26.11	26.11	26.11	26.11	26.11	26.11
Rail resource cost, upgraded line	24.86	26.53	28.14	29.77	31.40	33.98	35.75
Total resource cost, existing road, existing rail	27.27	29.90	32.82	36.08	39.77	43.90	48.48
Total resource cost, upgraded road, existing rail	27.01	29.01	31.13	33.37	35.79	38.41	40.17
Total resource cost, benefit from rail upgrading							
. existing road	2.41	3.37	4.68	6.31	8.37	9.92	12.73
. upgraded road	2.15	2.48	2.99	3.60	4.39	4.43	4.42



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

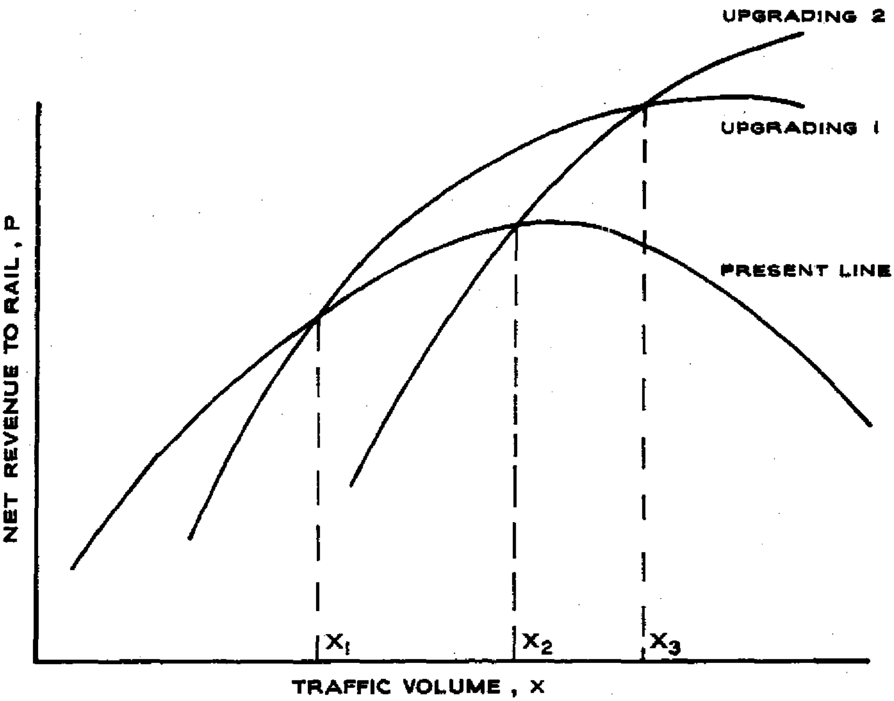
NOTE : B MAY LIE ANYWHERE BETWEEN A AND C

FIG. 1 VARIATION OF NET REVENUE TO RAIL AND DELAYS WITH TRAFFIC VOLUME



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

FIG. 2 INTRODUCTION OF UPGRADING FROM COMMERCIAL AND RESOURCE POINTS OF VIEW



X_1 : TRAFFIC VOLUME AT WHICH UPGRADING 1 SHOULD BE INTRODUCED

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

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

FIG.3 CHOICE BETWEEN UPGRADINGS , COMMERCIAL CRITERIA

↓ current state next state →

Year 1	1	2	3	4
1	6	7	2	8
2	9	6	2	5
3	6	8	3	6
4	2	4	7	2

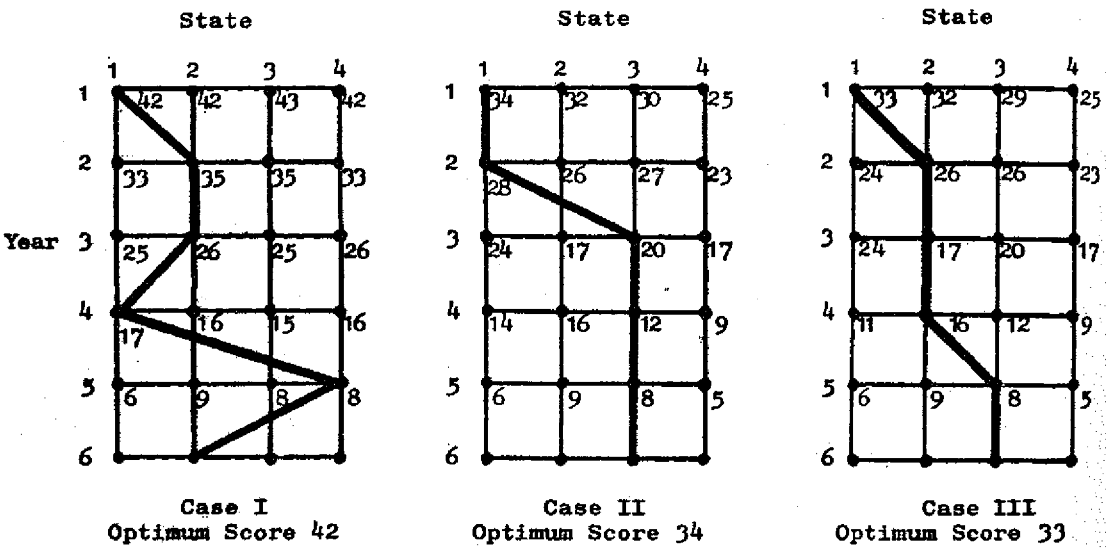
Year 2	1	2	3	4
1	0	3	8	5
2	4	9	2	4
3	0	5	6	9
4	6	4	8	6

Year 3	1	2	3	4
1	0	8	1	9
2	9	1	2	1
3	8	5	8	6
4	9	4	7	8

Year 4	1	2	3	4
1	3	2	5	9
2	5	1	8	2
3	8	6	4	3
4	7	3	8	4

Year 5	1	2	3	4
1	4	5	6	0
2	8	9	5	7
3	0	6	8	7
4	0	8	1	5

TRANSITION TABLES



Case I - unconstrained

Case II - only options of equal or higher serial may be selected

Case III - only options of equal or higher by one serial may be selected.

All schedules constrained to start from state 1.

FIG. 4 WORKED EXAMPLE OF DYNAMIC PROGRAMMING

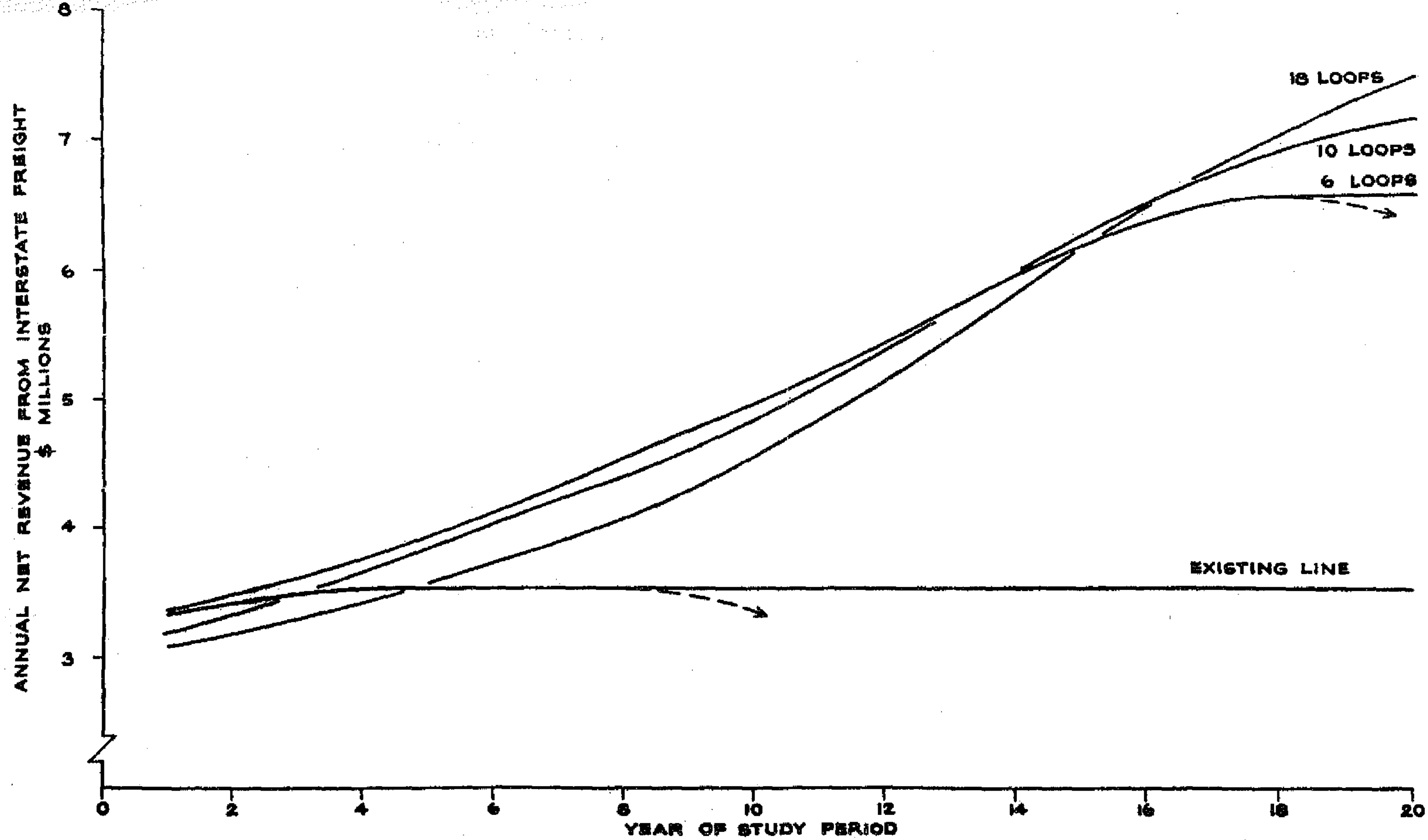


FIG. 5 ALBURY-MELBOURNE. VARIATION OF NET REVENUE FROM INTERSTATE FREIGHT FOR VARIOUS LINE UPGRADINGS

800 TON TRAINS
HIGH FORECAST. REVENUE AT 1·3 ¢/TON MILE
10 % DISCOUNT RATE
SMOOTHED CURVES

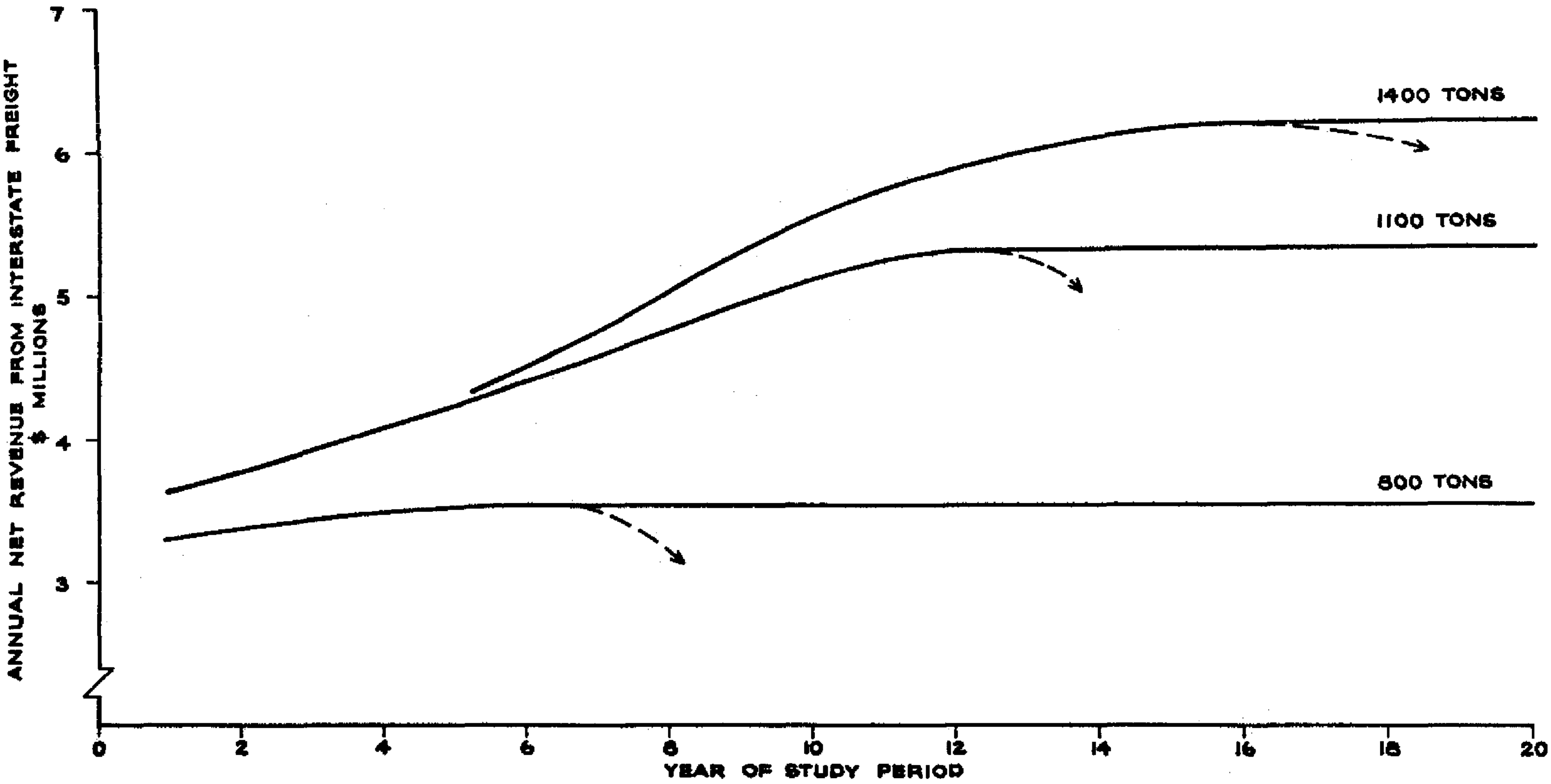


FIG. 6 ALBURY - MELBOURNE . VARIATION OF NET REVENUE FROM INTERSTATE FREIGHT FOR VARIOUS TRAIN WEIGHTS

EXISTING LINE
HIGH FORECAST . REVENUE AT 1·3 ¢/TON MILE
10 % DISCOUNT RATE

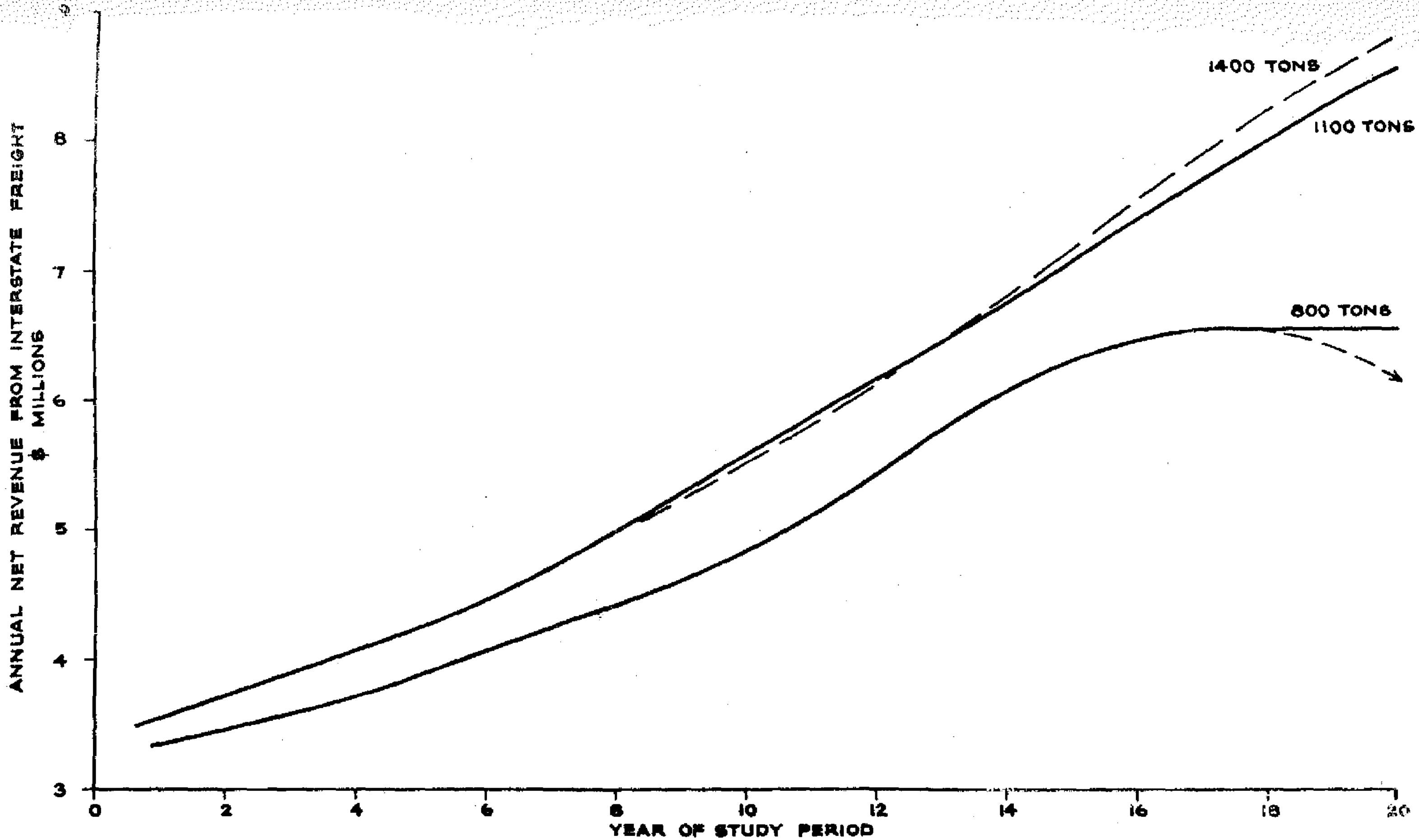


FIG. 7 ALBURY - MELBOURNE. VARIATION OF NET REVENUE FROM INTERSTATE FREIGHT FOR VARIOUS TRAIN WEIGHTS

6 ADDITIONAL CROSSING LOOPS
HIGH FORECAST. REVENUE AT 1·3 ¢/TON MILE
10 % DISCOUNT RATE

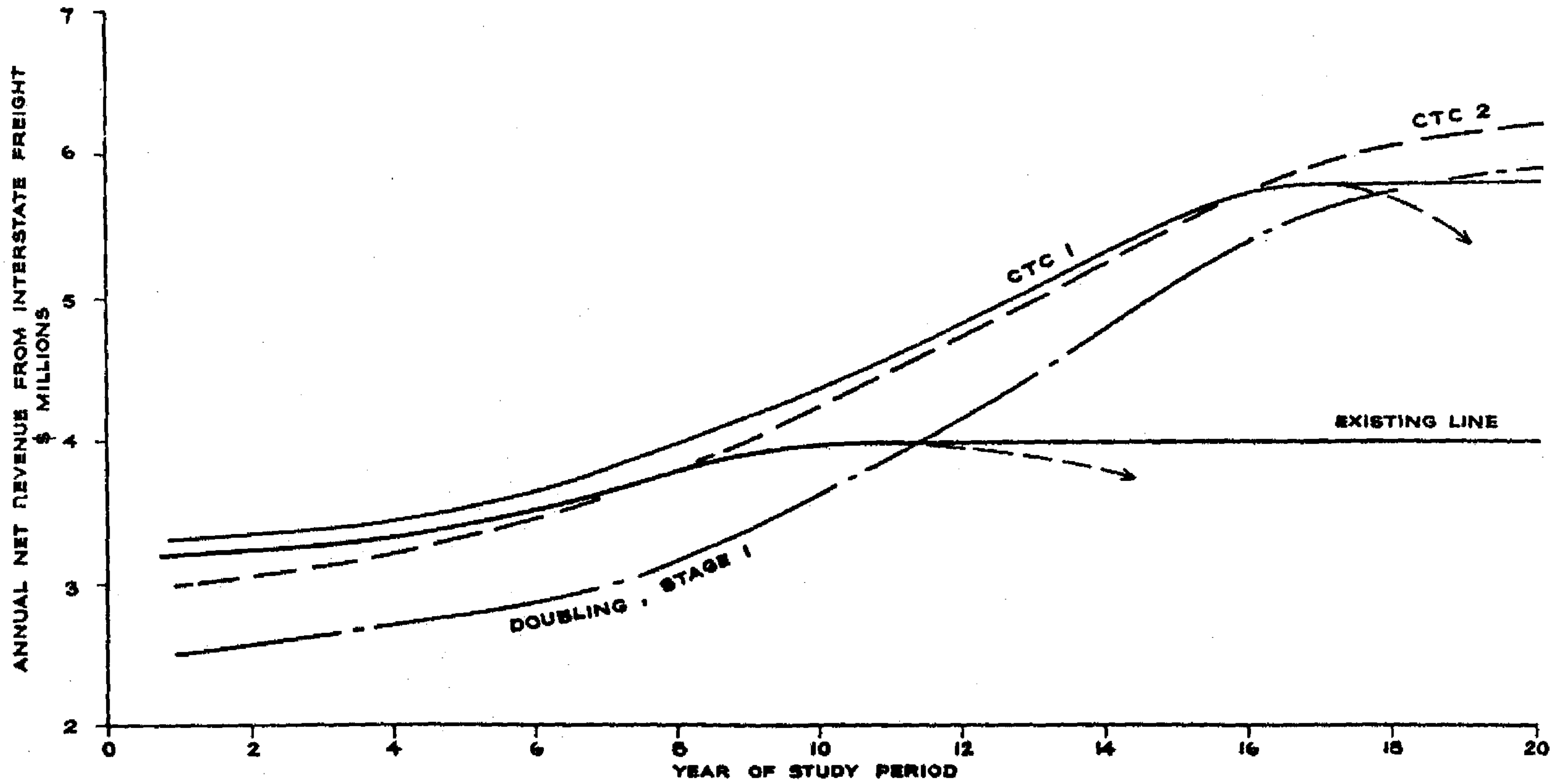


FIG. 8 ALBURY – SYDNEY. VARIATION OF NET REVENUE FROM INTERSTATE FREIGHT FOR VARIOUS LINE UPGRADINGS

800 TON TRAINS
HIGH FORECAST. REVENUE AT 1·3 ¢ / TON MILE
10 % DISCOUNT RATE

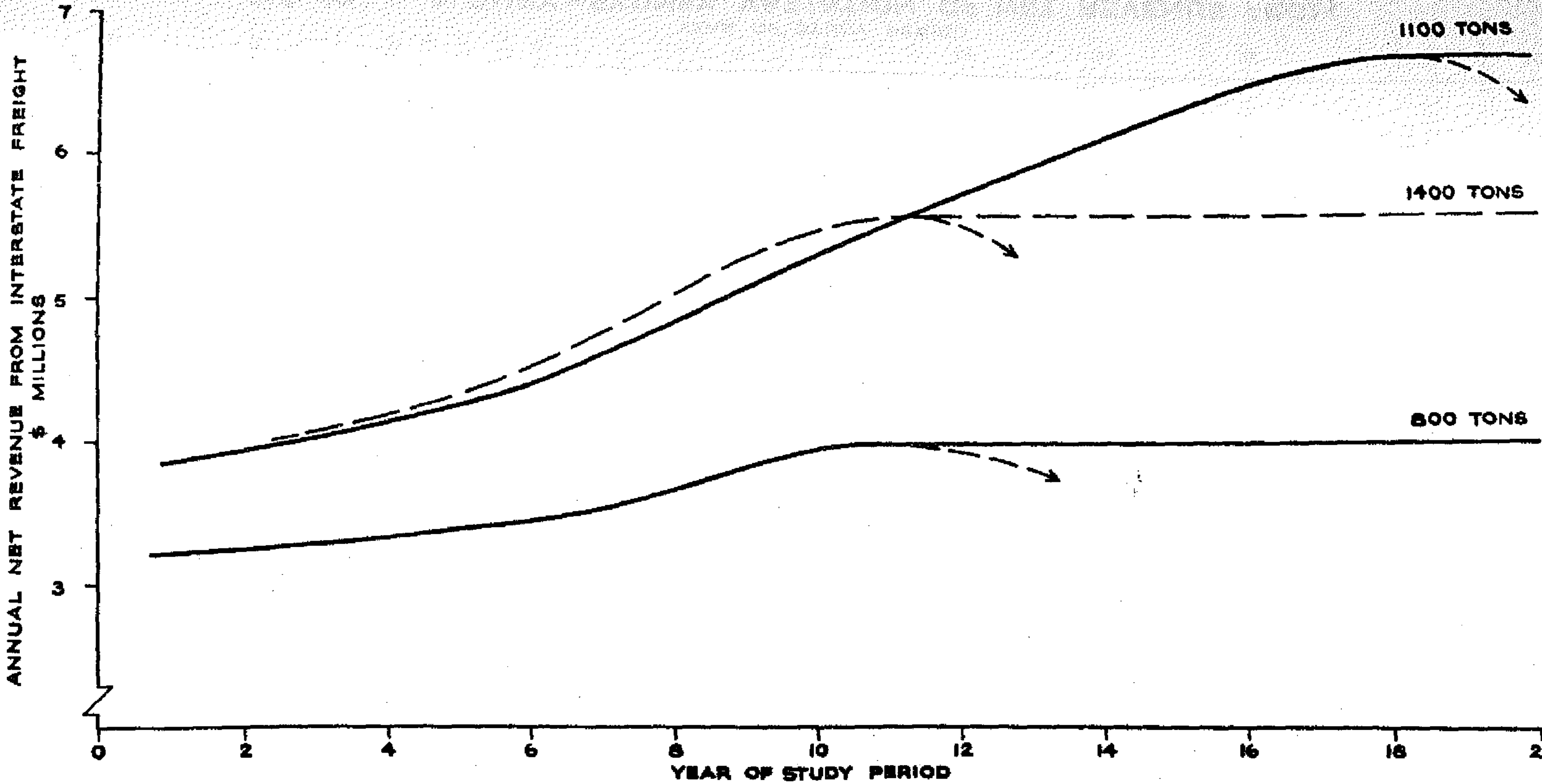


FIG. 9 ALBURY – SYDNEY. VARIATION OF NET REVENUE FROM INTERSTATE FREIGHT FOR VARIOUS TRAIN WEIGHTS

EXISTING LINE
HIGH FORECAST. REVENUE AT 1·3 ¢ / TON MILE
10 % DISCOUNT RATE

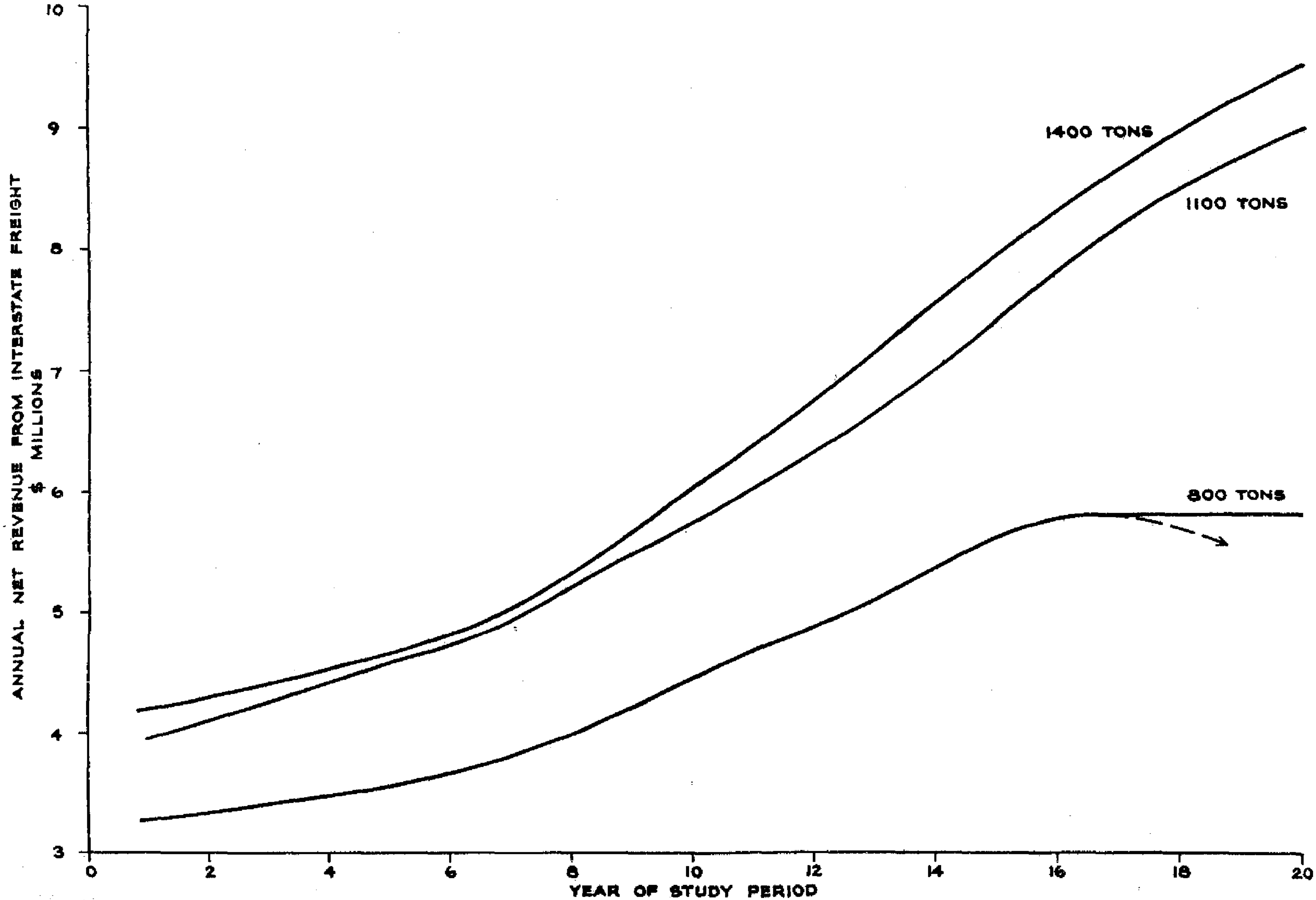


FIG. 10 ALBURY – SYDNEY. VARIATION OF NET REVENUE FROM INTERSTATE FREIGHT FOR VARIOUS TRAIN WEIGHTS

CTC 1 . HIGH FORECAST . REVENUE AT 1·3 ¢/TON MILE , 10 % DISCOUNT RATE

ANNEX

COMPARISON OF THE COSTS OF CARRYING CONSOLIDATED GENERAL GOODS BETWEEN SYDNEY AND MELBOURNE BY ROAD OR RAIL

Availability of data has restricted this comparison to the Melbourne-Sydney link, which will reflect the characteristics of the Hume Highway, the Sydney-Melbourne rail link, and a line haul length of the order of 600 miles.

The total general goods traffic (excluding overseas containers) can be broken up into two types:

- general goods traffic which needs consolidating usually by freight forwarders,
- 16-20 ton consignments, door to door unit loads.

Currently available estimates indicate that the total traffic is evenly split between the two types described above. Rail's share of the total general goods traffic appears to be between 30% and 40%. Discussions with major freight forwarders have indicated that about 80% of the traffic requiring consolidation is carried by rail; this suggests that rail's share of door to door unit load consignments is small. We therefore assume that the growing interstate general goods rail traffic will be predominantly consolidated and will be marketed by freight forwarders as at present.[1] Our model will be based on the Mayne-Nickless and TNT operations between Sydney and Melbourne,

1. This approach is probably conservative because as the container/unit train system is developed, it is likely that rail will capture an increasing share of the door to door unit load traffic. This is the basis of the Railways of Australia Container Express Service (RACE).

essentially unit train operations between gantry cranes at each end. Containers are loaded directly from road vehicles on to flat-top wagons and consolidation is carried out at central depots.

A graphical representation of consolidated freight forwarders' traffic is shown on Figure A1. We assume that:

(a) On the average the consolidating depots are equidistant from the railhead and the start of the highway at the edge of the city. Thus the road transport task from depot to railhead or to start of the road line haul proper will be the same and may therefore be ignored. To be consistent, the road line haul distance between the centres of Sydney and Melbourne are reduced by about 50 miles.

(b) The distribution of shippers about the depots is the same for rail and road consignments.

Given these assumptions, comparison of road and rail can ignore links 1, 3, 4 and 7 on Figure A1. For rail consignments, however, an intermodal transfer cost is added; this is based on current gantry capital and operating costs. The line haul costs, links 2 and 6, are derived as follows.

ROAD, LINK 2, FIG. A1

The following costs (1973) relate to 5 axle, 20 ton trucks operating on a shuttle service between Sydney and Melbourne.[1]

1. Truck cost elements were obtained from the BTE reports "A study of intersystem railway rating practices with particular reference to the Riverina area of NSW" (to be published), "Liquefied petroleum gas as a motor vehicle fuel" (April '74). All taxes were removed from the above cost elements. The ARRB Road User Manual (1970) gives similar truck costs to those obtained by the BTE when adjusted for 1973.

	cents/mile
Operating costs (includes road maintenance)	11.3
Wages	14.3
Truck capital	10.92
Total	36.52

Road Costs: 37 cents per mile or 1.85 cents/ton mile.

RAIL, LINK 6, FIG. A1

The following costs (1973) relate to trains operating between Sydney and Melbourne and having an average weight of 1000 gross tons (500 net tons).[1]

	cents/mile
Crew	50.00
Rolling stock capital	49.92
Motive power capital	56.98
Fuel	30.00
Track maintenance	69.00
Loco maintenance	75.5
Rolling stock maintenance	80.0
	410.8
Adding intermodal transfer[2] costs at $0.5 ton/lift	494.1

Rail costs: $4.94 per mile or 0.99 cents/ton mile.

The above estimates indicate that on the average the transport cost of consolidated general goods by rail amounts to about half the cost of carrying the same goods by road.

1. Rail costs were obtained from the New South Wales Public Transport Commission and from Victorian Railways, and where conditions differed in the two states, a length weighted average was used.

2. The growth traffic, i.e. freight forwarders' traffic, was assumed as being entirely handled by gantry in large containers or flexivans.

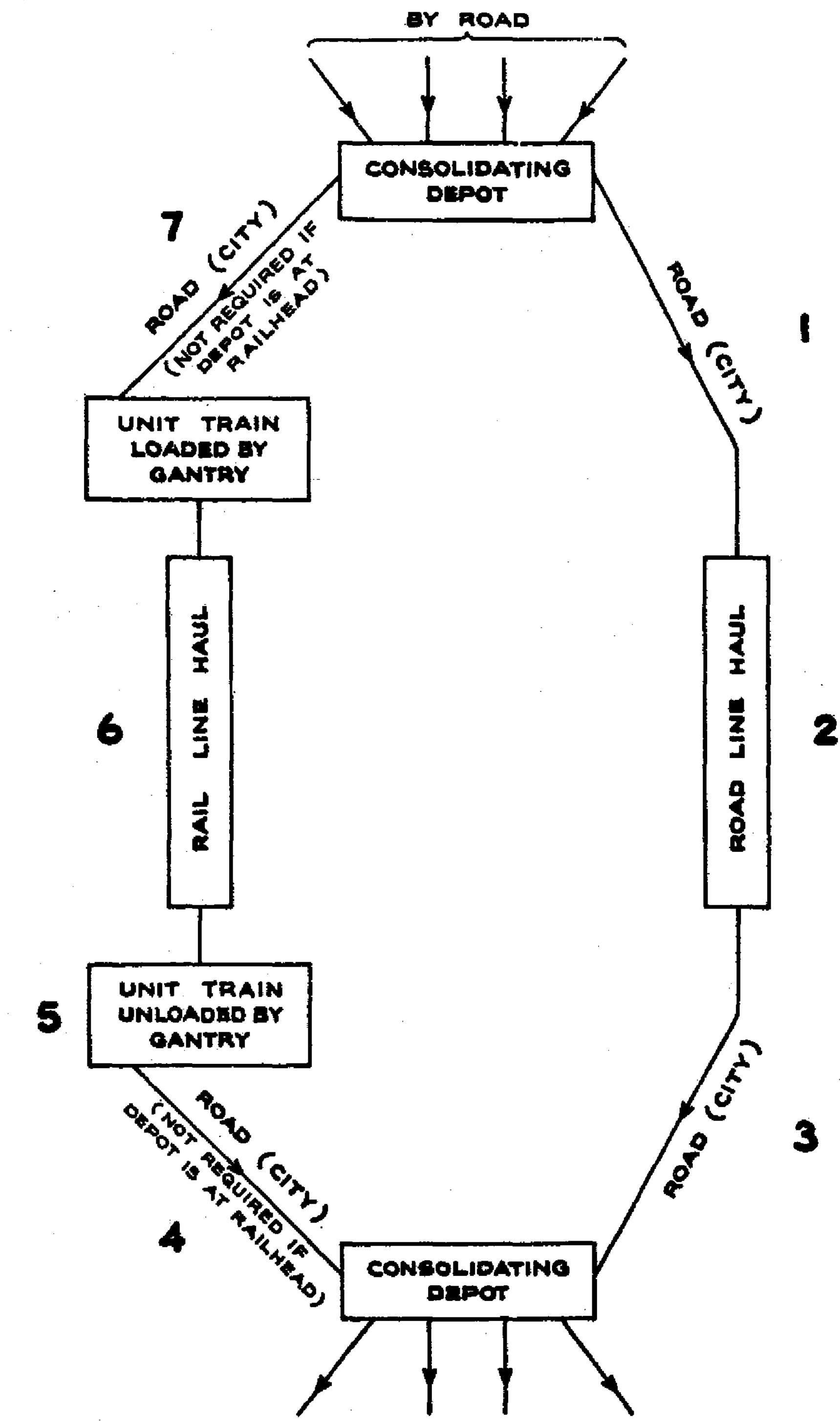


FIG. A1 OPERATIONS REQUIRED FOR TRANSPORT OF GOODS WHICH NEED CONSOLIDATION