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THE ANALYSIS AND COSTING OF RAIL FREIGHT OPERATIONS

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Abstract:

This paper describes a model of rail freight operations and their associated costs. The model is in the form of a suite of computer programmes called RAILCOST.

RAILCOST comprises two sub-models: a linehaul sub-model and a terminal sub-model. The linehaul sub-model loads freight flows into a network and converts these flows into trains, reflecting real life operations. The terminal cost sub-model is based on an inventory of sidings and goodsheds in the system, to reflect as closely as possible the actual pattern of terminal operations such as shunting and goods handling.

RAILCOST has so far been applied to three projects and two different rail networks. It has identified the avoidable and joint costs of handling different commodities, and has been used to examine strategies to improve the profitability of various traffics. It has also been used to simulate the operations and estimate the operating costs associated with an electrification project.

INTRODUCTION

In the past, the typical railway carried primary produce from country areas to ports, and manufactured and retail goods in the reverse direction. Under the protection given by regulation, there was no real pressure to identify the costs of particular traffics, nor would these costs have been of any relevance had they been established as they were historically only a minor consideration in railway rate-setting. A much greater consideration was 'what the traffic would bear'; and, under regulation, this was closely related to the value of the traffic.

In recent years, however, the role of Australia's railways has been changing with the advent of deregulation, increasing competition from road transport and rapidly growing mineral traffics.

All Government railways, to a greater or lesser degree, are currently faced with levels of deficit which are giving rise to public concern and to criticism from competing modes that rail rates are unfairly subsidised.

In addition, railways have become increasingly aware of the many conflicts between their commercial prerogatives and the implicit welfare obligations of the Governments which control them.

There is thus an increasing need for analytical tools which can be used to assess railway operations, both to determine the costs of the various existing traffics(1) and to examine alternative operating policies.

This paper describes one such tool, known as RAILCOST, developed for the (then) Public Transport Commission of New South Wales, in order to estimate the avoidable costs of the various traffics currently carried in NSW. It has also been designed to enable various operating and marketing strategies to be tested e.g. the effect of replacing branch-line services with road services, or the effect of abandoning all low-volume wagon-load traffics.

SCOPE OF THE MODEL

The principal objective of RAILCOST is to provide a tool which can be used to:

i) estimate the cost of carrying various traffics; and
ii) examine the impact of changes in operating polices.

Before further describing the scope of the model, it is pertinent to consider the broad structure of railway operations, costs and traffics.

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1. In this paper, a traffic is defined as a particular commodity carried between a specific origin and a specific destination.

In general, the movements of rail freight traffic can be dissected into the following activities:

- (i) a wagon is loaded, either by the railway or the consignor, with a particular commodity at a siding, station or yard;
- (ii) it is collected and taken to a central marshalling yard (variously known as trip train, pick-up train, pilot or shunting workings);
- (iii) it is marshalled into a branch-line or main-line train; which then proceeds to another yard;
- (iv) it may be remarshalled on a number of occasions en-route into different main-line or branch-line trains;
- (v) it is distributed from a central marshalling yard (trip train or pick-up train working, etc.); and
- (vi) it is unloaded at a siding, station or yard, either by the railway or consignee.

It is convenient to group together wagon loading, unloading, and distribution to and from sidings, as terminal activities. The remaining marshalling and train-working activities can be grouped as linehaul activities.

The costs incurred by a railway system can be broadly divided into four groups:

- (i) those connected with overhead activities such as financial control, planning and general administration;
- (ii) those connected with the maintenance of the permanent way and associated structures;
- (iii) those associated with signalling and the safeworking of trains; and
- (iv) those associated with the terminal and linehaul operations described above.

Of these four groups, the first is variable (although only slowly) with the general scale of operations and is joint to all traffics carried. The second and third groups are variable with the volume of traffic on a particular section of line; however this variation is not linear and these costs thus have a large component that is joint to all traffics on a particular line section. The model described in this paper is primarily concerned with the fourth group of costs, those associated with terminal and linehaul operations and which are often referred to as 'above-the-rail' costs.

The traffics carried by a railway can be divided into two groups: those for which the terminal and linehaul operations can be completely divorced from the other rail operations ('separable' traffics) and those others whose terminal and linehaul operations interact with each other ('non-separable' traffics). Examples of these interactions can be given by considering the consequences of the railway ceasing to carry a traffic which is normally hauled on a mixed-commodity train. If the traffic is not carried by the railway, there will be changes in the level of each of the six activities outlined above. However, these changes may or may not be directly proportional to the traffic volume. Consider, for example a branch-line with a twice-weekly service. If the traffic is not carried the service may nevertheless remain as a twice-weekly service if the traffic is relatively unimportant.

Alternatively, if the traffic is LCL, the service would probably be reduced to once-weekly. Further examples are afforded by backloaded traffics; if these ceased there would be little effect on the number of trains run as this is essentially determined by the volume of traffic in the loaded direction. Because of these interactions, 'above-the-rail' costs for 'non-separable' traffics contain significant joint elements. The level of jointness of course increases as the traffic becomes more 'general'. Traffics such as coal and wheat, which normally move in semi-train-loads in dedicated rollingstock, have no more than 10% of their 'above-the-rail' costs as joint; wagon load traffics such as meat and oil which also use dedicated rolling-stock have about 20% of these costs as joint, whilst wagon-load traffics such as fruit and LCL which use general rollingstock in which other traffics can be backloaded have about 50% of their costs as joint.

Such jointnesses cannot be calculated by considering a particular traffic in isolation but emerge by comparing the difference in cost to the railway between when it is carried and when it is not(1). Consider a railway which only carries two traffics, apples and beans. Let the operating cost when both traffics are carried be T; when only apples are carried be A, and when only beans are carried be B. Then the avoidable cost of apples is T-B, the difference between the cost when they are carried and when they are not. Similarly the avoidable cost of beans is T-A. The joint cost J is the residual cost, not attributable to either apples or beans, and given by

$$J = T - (T-B) - (T-A)$$
$$= A + B - T$$

If J = 0, of course, there is no joint cost and the traffics are separable.

This is the approach used in RAILCOST, and it requires including all traffics carried by a railway (or at least all non-separable traffics) in the analysis. Experience of manual analysis of this type for comparatively small parts of the system convinced us that a system-wide analysis could only be accomplished with the aid of computer techniques.

RAILCOST is therefore designed to estimate the 'above-the-rail' operating costs attributable to particular traffics by calculating the difference in system-wide operating costs between when it is carried and when it is not. The following section now discusses the structure of the model.

STRUCTURE OF THE MODEL

Railway operations, although simple in concept, in practice are characterised by considerable complexity because of the multitude of operating options available. Any model which is to contribute effectively to the strategic planning of a railway must accurately

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(1) For a more complete exposition see JOY, S., "Pricing and Investment in Railway Freight Services", in Journal of Transport Economics and Policy, 1971 (pp 231 - 246).

represent the main elements of railway operations, without being submerged in this complexity. For example, it is neither practical nor in most cases necessary to reproduce the level of detail represented by the working timetable. However it is necessary to accurately model the movement of trains and the handling of the different commodities and considerable effort has been made to ensure the model described in this paper is operationally realistic. Two distinct sub-models have been developed within RAILCOST:

(i) a linehaul sub-model for determining the resources and costs of moving wagon loads of commodities through a railway network; and

(ii) a terminal sub-model for determining the costs of loading and unloading, shunting, and collecting and distributing different commodities at different places within a railway network.

Linehaul Sub-Model

This model estimates the costs of linehaul operations between marshalling yards, including the en-route marshalling of trains. It considers each of the following costs separately:

(i) loco repairs;
(ii) crew;
(iii) oiling and examination of wagons;
(iv) wagon maintenance;
(v) fuel;
(vi) motive power staff; and
(vii) shunting staff employed in train marshalling.

It does not estimate the capital costs of wagons and locomotives, although the latter can be easily calculated from other model outputs.

The model estimates these costs by:

(i) estimating the resources used in a particular operation or group of operations; and
(ii) applying unit cost rates to this resource usage.

The resources estimated are :

(i) loco kilometres (by loco type);
(ii) loco hours (by loco type);
(iii) train kilometres;
(iv) train hours;
(v) trailing tonne-kilometres;
(vi) gross tonne-kilometres;
(vii) vehicle kilometres; and
(viii) wagons marshalled.

The model then applies the appropriate cost rates to each of the resource parameters to achieve total operating costs.

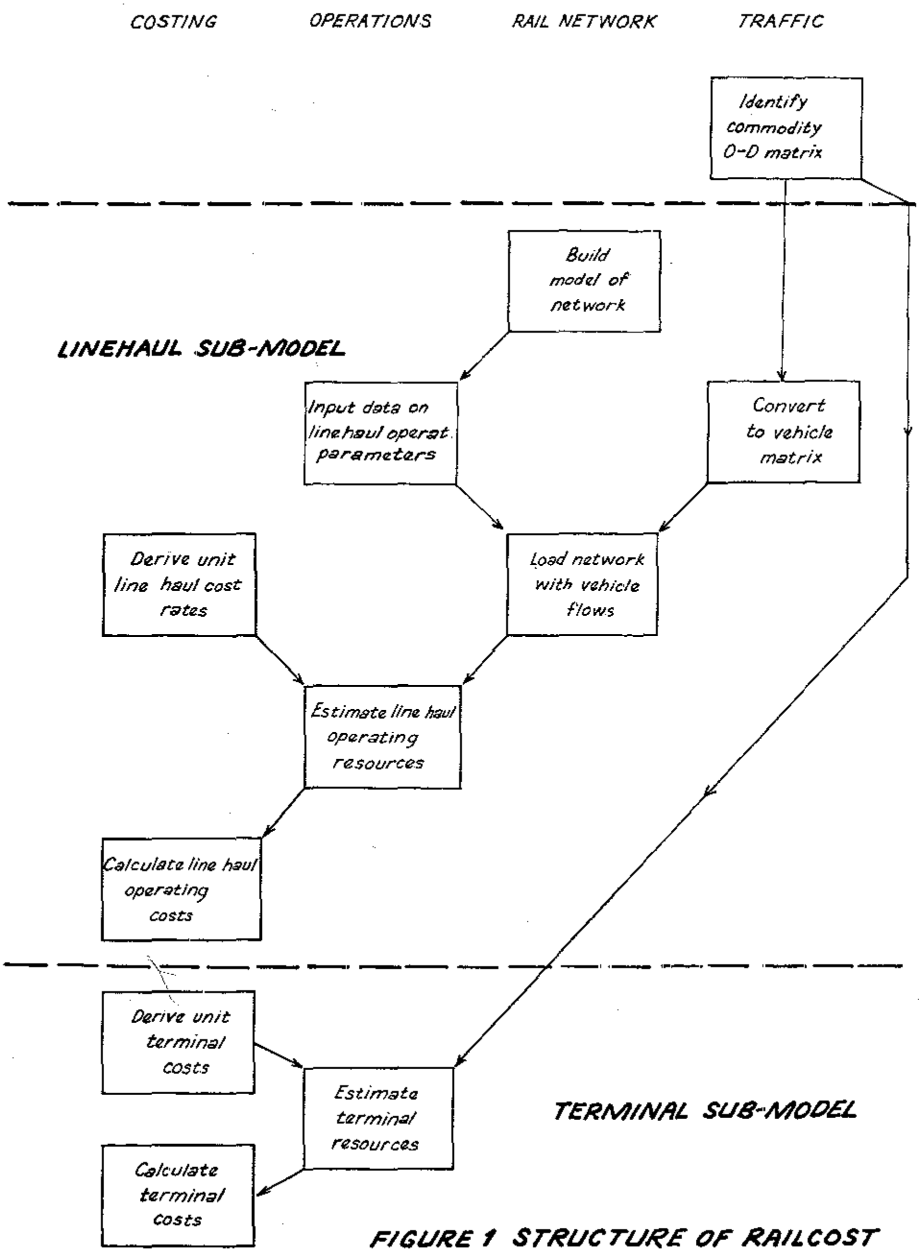

FIGURE 1 STRUCTURE OF RAILCOST

A simplified representation of the model structure is shown in Fig. 1. The following sections deal in turn with the various components of the linehaul model; the examples given are from the original NSW freight costing study mentioned above.

Build Model of the Rail Network

For this type of model, a railway has to be represented either wholly or partially as a network, so that standard transport modelling techniques of building, skimming, loading and reporting networks can be applied. Fig. 2 shows the NSW rail system, and Fig. 3 a network representation of it.

Each link in this network represents a particular physical activity; thus link 107-108 represents train operation between Cootamundra and Junee, whilst link 104-213 represents train marshalling for traffic passing from the main-line at Goulburn to and from the Cooma line.

The several thousand origins and destinations on the NSW rail system were amalgamated into 75 zones, represented by the 75 zone centroids in Fig. 3. Each zone centroid is connected to the linehaul network by a centroid connector; the terminal operations represented by these connectors are included in the terminal cost model. Comparison of Figs. 2 and 3 shows that the complexity of an area such as Sydney is greatly reduced by this approach. Those familiar with the NSW system will also notice the absence of nodes in the Hunter Valley where the bulk of the coal traffic originates. This traffic operates in unit trains and is thus a separable traffic which can be costed outside the model independently of other traffics.

Commodity Matrix

This matrix provides the basic data on the volume, revenue, origins and destinations of the various traffics carried on the railway under analysis. In the NSW project it was generated from an analysis of consignment notes, which give the origin, destination, commodity and revenue for each consignment. The basic model required that the origins and destinations be compressed to the 75 zones adopted, and the commodities similarly reduced to a manageable number for strategic planning purposes. In the NSW study, the number of commodities were reduced to 23, listed in Table 1.

A more difficult task was to divide certain traffics which were treated by the railway as one commodity, but which have different handling characteristics e.g. normal retail merchandise (LCL), and van-load consignments handled by the consignor/consignee. The general principle was to distinguish between those traffics which have particular wagon requirements, different movement characteristics, and/or different terminal handling needs.

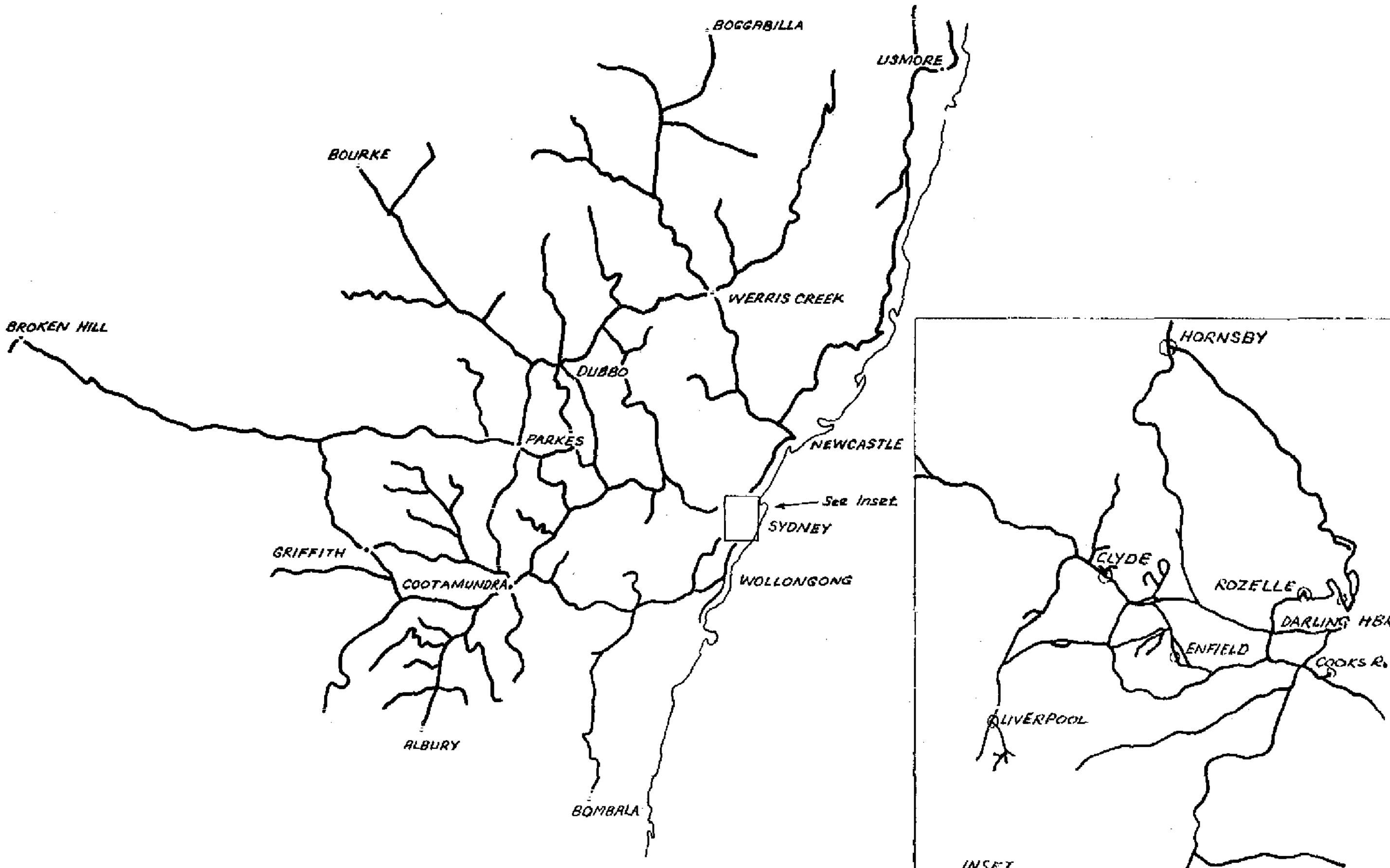

FIGURE 2 N.S.W. RAILWAY NETWORK

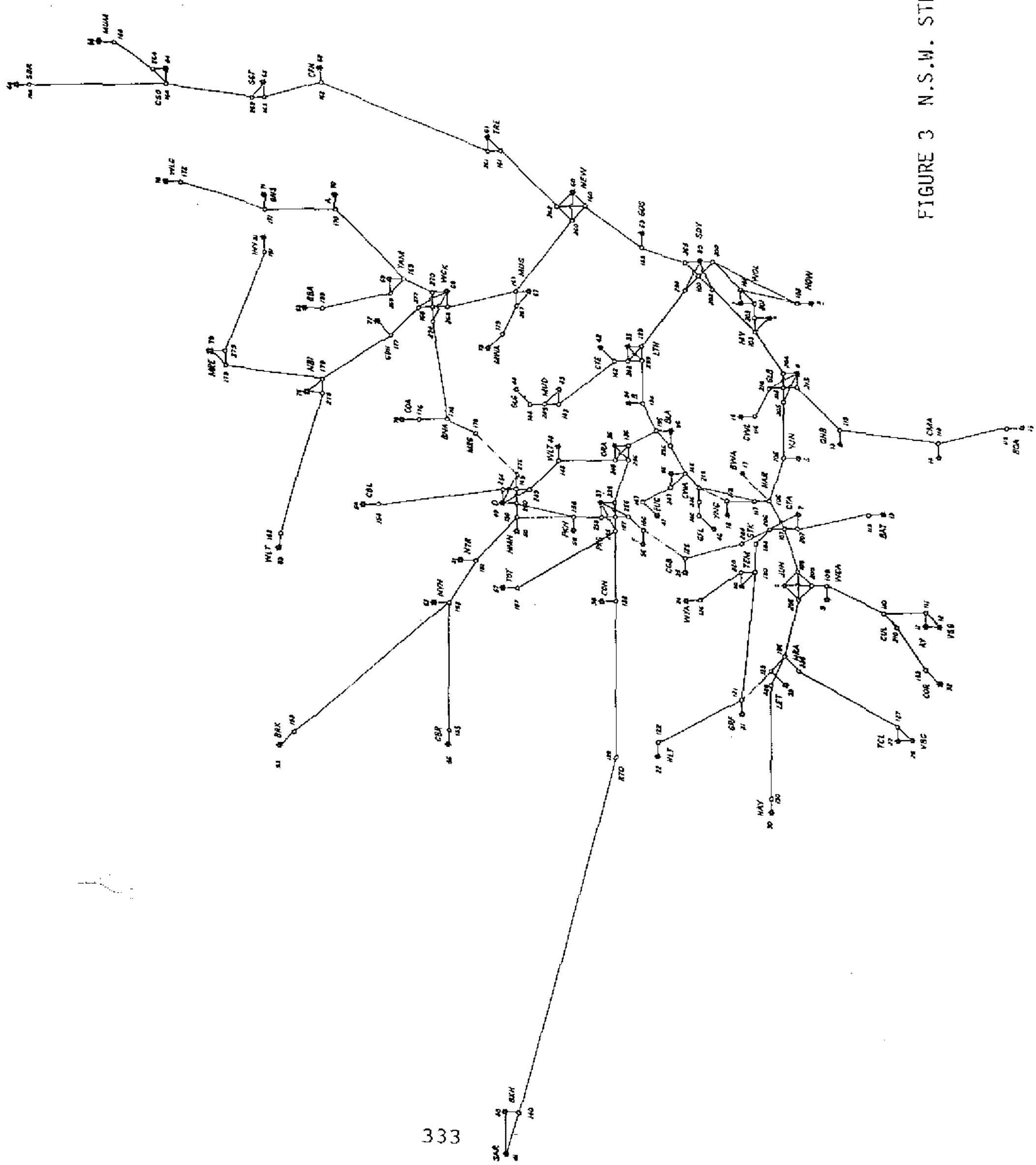

FIGURE 3 N.S.W. STRATEGIC RAIL NETWORK

TABLE 1 : COMMODITY GROUPS USED IN RAILCOST

Number	Name	Number	Name
1	Wheat and Grains	13	DBL, Beer, Retail etc.
2	Flour	14	Steel
3	Hay, Straw and Chaff	15	Scrap
4	Rice	16	Cement
5	Fruit	17	Petroleum Products
6	Meat	18	Motor Vehicles
7	Wool and Cotton	19	Concentrates
8	Milk	20	Industrial Goods
9	Timber	21	Fertiliser
10	Coal and Minerals	22	Capital Works
11	Containers	23	Livestock
12	Freight Forwarders		

RAILCOST has the capability to reorganise commodity flows for different investigations. Thus various sub-sets of the full commodity flow data can be extracted to investigate such issues as:

(i) the costs of handling particular commodities;
(ii) the costs of operating particular divisions of the railway network; and
(iii) combinations of (i) and (ii) above.

Conversion of Commodity Matrix to Vehicle Matrix

The commodity matrix is then converted to a corresponding vehicle matrix, using representative payloads. In the NSW costing, the vehicle fleet was reduced to thirteen basic wagon types, listed in Table 2. A 'loadability matrix' was then constructed, converting each of the commodities into a particular vehicle or vehicles. RAILCOST also has the facility for this system-wide matrix to be overridden for specific traffics with particular loading characteristics.

TABLE 2: BASIC WAGON TYPES USED IN RAILCOST

Vehicle	Average tare mass (tonnes)	Average gross mass (tonnes)	Average length (1)
Grain hoppers	19.9	71.8	2.1
Mineral hoppers	19.3	73.3	2.0
Tank cars	28.8	58.5	2.0
Refrigerated vans	27.4	59.6	2.0
Container flats	22.4	72.8	3.0
General flats	20.9	66.4	2.3
Concentrates wagons	19.2	72.1	1.8
Stock wagons	20.3	33.1	2.0
Car carriers	19.9	34.9	3.4
Louvre vans	25.7	67.3	2.3
Open wagons	19.0	59.7	2.1
General wagons	20.0	61.0	2.3
Brake van	21.7	-	2.0

(1) Average length is in 4 wheel wagon equivalents.

Network Loading

The vehicle matrix is then loaded onto the network using standard assignment programs. Because of their relatively simple structure, Australia's railways individually do not pose any major problems in determining the shortest paths between zones. In practice, within NSW, it was necessary to disconnect a small number of nodes to route rail traffic in accordance with actual railway operations: for example, there are no regular freight workings between Hillston and Roto in the far southwest of the State. It was also necessary to simplify one or two parallel routes, rather than try to model very specific route choices. For example, the multiple routes between Orange and Dubbo in Fig. 2 are treated as one in Fig. 3. (In practice these virtually operate as a one-way couplet).

Estimation of Operating Resources

There are three steps in the estimation of operating resources:

(i) the estimation of empty vehicle running;
(ii) the formation of the wagon flows into trains; and
(iii) the subsequent calculation of resources such as train hours, vehicle kilometres etc.

In order to estimate empty vehicle running, the freight wagons are divided into three categories:

(i) dedicated vehicles which return empty (grain and mineral hoppers, tank cars and refrigerated vans);

(ii) backloadable vehicles which can be backloaded with any commodity which uses the same vehicle type: the balance then return empty (container flats, general flats, stock wagons and car carriers);

(iii) substitutable vehicles, which are not only backloadable but which for some commodity types may be substituted for each other (louvre vans, open wagons and general wagons).

In addition, for backloadable and substitutable vehicles, an extra seasonal imbalance of empty vehicles is calculated to allow for the practical difficulty of maintaining balances over a short-term period.

These wagons are formed into train types with different characteristics (for example unit trains such as wheat or steel, or general freight trains). The train characteristics such as loads, lengths and number of locomotives are link-specific and can be derived from either the working timetable or by analysis of actual movements. Each train type is subdivided into trains of full wagons, which are calculated as weight loads, and trains of empty wagons, which are calculated as length loads. In practice, most trains carry both full and empty wagons but experience shows that the above method gives a very good approximation of total resource usage.

These calculations will give different numbers of trains and locomotives in the two directions on any one link, and these are then balanced. In addition, on certain links, such as branch-lines, there are minimum frequency constraints based on service-level considerations and these are also considered on a link basis.

The resources required in the network can then be calculated on a link-by-link basis.

Derivation of Unit Cost Rates

Unit costs were obtained from a cost attribution exercise using the PTC's 1978/79 Abstracts of Expenditure, supplemented by a considerable amount of background data. This had been obtained in previous exercises in which information was gathered on:

(i) staff disposition throughout the railway network;
(ii) operational data on average train loads, sizes and motive power, etc; and
(iii) shunting movements, times and resources, etc.

These costs were related to operating parameters with which they vary directly, although not necessarily instantaneously. In general, although cost increases arising from an increase in 'above-the-rail' operations will materialise very quickly, it often takes up to two years for a corresponding cost decrease to be achieved following a reduction in activity.

Calculation of Operating Costs

The model then calculates the total 'above-the-rail' operating costs of the system by multiplying the various resources estimated earlier by the appropriate unit cost.

Terminal Sub-Model

The terminal sub-model encompasses all operations performed by the railways between the marshalling yard and the origin or destination siding. It thus includes:

- (i) freight handling where relevant;
- (ii) accounting (i.e. clerical tasks);
- (iii) shunting and distribution, (trip trains, pilot working etc); and
- (iv) miscellaneous activities such as road delivery.

The basic data source is an inventory of each siding and goods shed in the system, together with the commodity and tonneage handled and the annual number of shunts. These sidings are formed into groups (120 in NSW) which are served by specific shunting locomotives and crews. The hours spent shunting each group of sidings can be calculated from operating records or by analysis of rosters, allowing a cost for shunting each group of sidings to be calculated. This is further distributed to particular sidings on the basis of the number of shunts. This procedure overlooks any jointness in trip-train working but experience indicates the degree of jointness is generally only between 10% and 20% and does not warrant more detailed treatment.

The inventory also contains data on the freight handling, accounting and miscellaneous staff at each location and this is likewise used to calculate the appropriate costs.

The terminal costs are then aggregated on a zonal basis and unit terminal costs calculated for each commodity in each zone. These are then multiplied by the appropriate row and column totals of the commodity matrix to estimate total terminal costs.

Summary

The outputs from the terminal and linehaul models are then combined to calculate the total 'above-the-rail' operating costs associated with a particular commodity matrix.

RAILCOST'S physical features currently are:

(i) 5 programs dealing with network representation;
(ii) 2 programs dealing with the linehaul operations sub-model;
(iii) 2 programs dealing with the terminal sub-model; and
(iv) sundry system-specific programs dealing with various aspects of commodity flows and data preparation.

APPLICATION OF RAILCOST

The model outlined above has been used to calculate the avoidable cost of the following:

(i) all movements of a particular commodity (for example, LCL traffic in NSW);
(ii) specific commodity movements (such as timber from the NSW North Coast);
(iii) alternative marketing strategies for particular commodities (for example, the introduction of regional LCL freight centres);
(iv) specific operating Divisions (for example, all traffics on the Batlow branch-line);
(v) particular operating strategies (for example electrification of the Sydney-Melbourne railway); and
(vi) combinations of the above.

Using the revenues for individual commodity origin and destination movements, it is possible to perform a contribution analysis by comparing traffic revenues and the corresponding avoidable costs.

The initial development of RAILCOST was designed for the PTC to examine the state-wide freight operations at a strategic level, and to estimate the avoidable costs of the various traffics carried in NSW. This permitted the construction of the simplified network shown in Fig. 3, together with the use of the 23 commodity groups and 13 vehicle types given in Tables 1 and 2, and system-wide average costs. Although the model represents a simplification of real life operating procedures it nevertheless gave a very good approximation in this study to the overall resources employed in the railway operation. Comparison of synthesised resources with actual railway operating statisitics showed an agreement for the various resources to within 2-4 percent for the system as a whole, and to within 5 percent for individual links. The greater variation on a link basis can be mainly attributed to temporary rerouting of trains for operational reasons during track upgrading programs.

Using the same network and commodity list, RAILCOST was also used to test operating strategies designed to improve the profitability of particular wagon-load and 'LCL' traffics in NSW.

A third application of RAILCOST was in the analysis of the Sydney-Melbourne electrification proposal, to simulate the operations and to estimate the cost savings of electrification. For this application a small network was used, containing 24 zones only, while the number of commodities totalled 18. However, the more specific nature of the study necessitated the use of more detailed cost functions.

Once set up, RAILCOST is not expensive to run. The most expensive part of the model is the conversion of the commodity matrix to a vehicle matrix, requiring the manipulation of a matrix whose dimensions are (number of zones) x (number of zones) x (number of commodities). Nevertheless, in the case of the PTC avoidable costing, each commodity only cost about $100 to analyse. In the Sydney-Melbourne electrification study, the corresponding cost was about $20.

POSSIBLE DEVELOPMENT OF RAILCOST

RAILCOST is currently based on the network representation of a railway similar to that used in Highway modelling techniques, with traffic being carried from marshalling yard to marshalling yard by general freight trains. Whilst this is a realistic representation for the majority of wagon-load freight, it is less realistic for traffics which travel in semi-train loads such as steel, wheat or containers, and which are not shunted at intermediate locations. This is currently overcome on an ad-hoc basis by specifying certain flows as 'through' movements which are not shunted en-route.

Although the current approach avoids major distortions, a better alternative would be the application of Transit modelling techniques, in which a geographic network is overlaid with lines or routes over which particular trains could run. This kind of model could also be extended to cover the trip train/pick-up train portions of the terminal sub-model.

The strategic nature of the model would still have to be preserved by some control over the variety of freight train types that could be adopted. On the other hand the number of motive power options could also be expanded from the current two. This would be most useful if any mainline electrification schemes come to fruition as such schemes are likely to require a number of isolated fleets of electric locomotives.

ACKNOWLEDGEMENTS

RAILCOST is the culmination of several years work in the PTC in the planning and costing of freight operations. Its development would not have been possible without the active advice and assistance of several officers of the Commission, in particular we would like to acknowledge the contribution of Geoff Callingham, Ian Arthur, Alan Hansen and Harry Johnson.