Freight Transport Energy Consumption: A Comparison Between the Efficiency of the Modes in the Non - Bulk Task

Occasional Paper

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Freight Transport Energy Consumption:

A Comparison between the Efficiency of the Modes in the Non-Bulk Task

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FOREWORD

The work reported in this paper has been undertaken because of a concern for a general tendency in the transport community to make sweeping statements about the desirability of diverting traffic from one mode to another in order to save fuel. Such pronouncements can be misleading when applied to any particular case, so a need exists to establish the proper basis for examining and comparing the energy performance of alternative modes of transport.

The paper attempts to clarify the issues by examining the energy consumption characteristics of the three main freight modes (road, rail and sea) when undertaking comparable tasks. This appears to be the only valid basis for comparisons of energy efficiency - if such comparisons must be made.

This work shows that there can be no generalisations about modal efficiency but it provides a basis for more robust estimates to be made in particular circumstances, especially when data are lacking. Neither does the work provide a definitive answer to questions of relative fuel efficiency, since the data base requires further improvement, but it does present a substantial advance on previously available information.

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SUMMARY

This paper looks at the Australian domestic freight task to determine what parts of the task are suitable for the purpose of making comparisons between the modes, and then examines the energy efficiency of road, rail and sea freight when undertaking comparable tasks.

Existing information on freight movements in Australia is reviewed, from which it is deduced that the non-urban non-bulk component, which is considered to be the main area where significant potential for modal transfer exists, represents approximately 19 per cent of the total tonne-kilometres carried by all modes. This sector is at present shared between the modes in the proportions road 62 per cent, rail 30 per cent and sea 8 per cent.

The general characteristics of energy consumption by transport are then discussed in the context of the overall liquid fuel supply, and it is found that transport as a whole consumes 57 per cent of total oil supplies. All non-urban freight (including bulk movements) consumes 8.3 per cent, with the non-bulk component difficult to estimate accurately, but almost certainly consuming less than 4 per cent of total supplies. Thus it is seen that the fuel conservation potential of intermodal transfers of non-bulk freight is small in percentage terms (probably less than 1 per cent) although the effect measured in terms of numbers of truck or train movements along trunk routes could be very significant.

From these preliminary considerations of the freight task and fuel usage in aggregate terms the paper then turns to a detailed examination of the energy efficiency characteristics of road, rail and sea transport in the non-bulk task.

Particular prominence is given to the rail systems, as these are found to be the most variable in their characteristics. From data supplied by the State rail authorities it is found that a set of energy efficiency curves can be derived which indicate the energy efficiency of rail as a function of net tonnes of freight per locomotive, taking account of the influence of other operating conditions. It is not possible to determine reliably whereabouts on these characteristic curves typical operating points for all

systems would lie, since the data on net freight tonnes per locomotive are inadequate. It is clear, however, that railways certainly have the capability in their present form to be significantly more energy efficient than either road or sea transport in the general freight role, and for heavily utilised main lines they are probably more efficient as currently operated.

Because of the very rapid decline in the efficiency of rail as the net load per locomotive falls below 300 tonnes, and the adverse effects of route circuity, terrain and shunting which are likely to affect branch lines more severely than main lines, it is also probable that branch line operations are less energy efficient than road transport.

The disparity between the efficiencies of different parts of the railway system suggests that there is also considerable potential for lifting the maximum attainable efficiency of some railways by improvements to grading and alignment, although this is not examined in detail.

CHAPTER 1 - INTRODUCTION

This paper has been written because of widespread general interest and concern over the energy used for transport in Australia, the importance of freight transport to the national economy, the possibilities which may exist for conservation and the relative efficiencies of the competing modes. Much has been written and said about the latter point. Unfortunately previous examinations of this issue have frequently failed to take the fundamental precaution of ensuring that they are comparing like with like. It is perfectly obvious that no meaningful comparison can be made between the transport of passengers and parcels. It is equally obvious that a comparison between the bulk shipment of oil by sea between Barrow Island and Perth cannot sensibly be made with the distribution of frozen food by road from a Melbourne factory to centres throughout Victoria. Unfortunately, because of the way in which many freight and energy statistics are assembled, a comparison based on modal aggregate statistics is often all that has been possible, and this implies precisely the sort of comparison referred to above.

It is also important to stress that energy consumption is only one aspect of modal performance. It would be quite wrong to assume that, because an energy saving would result from a particular modal transfer, that the modal transfer is therefore desirable. There might be many other adverse aspects of the transfer that would result in a net disadvantage to the community if it were implemented. It is not disputed that the efficient use of energy is a desirable objective, but it must be pursued in the proper context of overall efficiency and economy.

There is basically only one good reason for making a comparison between modes, and that is to see if a particular job might be better done a different way. The emphasis here should be placed on 'particular job'. If a comparison is being made with a view to transferring a particular task to a different mode it is essential that the comparison should be made on a task specific basis.

For a considerable proportion of the total freight movement in Australia there is no realistic alternative to the present modes used. This paper does not attempt to look at all possible situations where modal transfers are feasible, but concentrates on that part of the freight task which gives rise to the greatest interest in modal efficiencies, namely the general distribution of non-bulk freight outside urban areas.

It is also necessary to consider carefully the external factors (such as weather and other traffic) which may influence the performance of a particular mode, and the way in which the performance may vary when carrying out the same task but under different circumstances.

Because of these considerations, and the considerable variability of previous estimates of modal fuel efficiencies, this paper places considerable emphasis on developing a suitable presentation of modal characteristics to enable the performance of a mode to be viewed in the context of the varying conditions which affect it rather than giving a single average figure which, even when related only to a particular type of task as discussed above, will tend to obscure the nature and causes of variations in performance.

CHAPTER 2 - THE AUSTRALIAN DOMESTIC FREIGHT TASK

CHARACTERISTICS OF THE FREIGHT TASK

The movement of freight within Australia is not a single homogeneous activity, but a collection of activities as diverse in character as in geographical location. In order to make any sensible comparisons between different parts of the freight task it is therefore clearly essential to have an appreciation of the characteristics of its different components.

The Australian freight task has previously been identified (Quinlan 1977) as having three main segments. These are:

a) The movement of raw materials for industry, the most important of which are inputs to the steel making industry, oil to refineries and coal. These travel mainly by sea and involve long haul operations of bulk commodities.

b) The movement of primary products for export, which like the first category involves large bulk and considerable distance, but does not involve transport within Australia by sea. They are moved, mainly by rail, from the point of production to the port of export. Thereafter, of course, their movement is by sea, but is not classed as domestic freight.

c) The distribution of goods for consumption within Australia (and to a much smaller extent to ports for export to other countries). This segment is essentially non-bulk in character, and takes place extensively within the major urban areas as well as involving long distance transport between major centres and from the major centres to all other parts of the nation.

The magnitude of a freight task may be measured either by the number of tonnes consigned or by the tonne-kilometres of output. The way in which the Australian freight task is shared by the different modes is shown in Table 2.1 with the shares being shown both according to tonnes consigned and tonne-kilometres of output. Since this study is concerned with the energy usage by the different modes it is the second measure which is of most significance, but it is nevertheless informative to see how the breakup of the task changes in character when measured according to the two alternative yardsticks. The very large volume of freight consigned over short distances in urban areas causes the urban freight category to dominate the tonnes consigned statistics. Conversely the very short distances involved in urban freight and the very long hauls for which bulk domestic sea freight is used cause sea to provide the major share of tonne-kilometres of output. Air freight is included for completeness at this stage but is clearly a very small and specialised segment of the market. Since it is not really relevant to consider air freight as a possible candidate for modal transfer for energy conservation purposes it is not included henceforward. Pipeline transport is also deleted from further consideration since it is an unknown quantity at this stage for anything other than bulk gases, liquids and slurries, and data is very sparse for the latter case.

TABLE 2.1 - ESTIMATE OF AUSTRALIAN DOMESTIC FREIGHT TASK, 1975-76

Component	Consignments		Output	
	10^6 tonnes	per cent	10^9 t-km	per cent
NON-URBAN FREIGHT				
Road	100	7.9	23	11.7
Rail: government	85	6.7	31	15.7
non-government	117	9.2	26	13.2
Sea	47	3.7	101	51.3
Air	0.1	*	0.1	*
Pipeline	18	1.4	4	2.0
SUBTOTAL NON-URBAN	367	29.0	185	93.9
URBAN	900	71.0	12	6.1
TOTAL ALL TYPES	1 267	100.0	197	100.0

* Less than 0.1

Source: Derived from Quinlan (1977).

It is already clear that a very large proportion of the tonne-kilometres of output is provided by those modes which are known to be most energy efficient when moving large bulk over long distances. It can also be seen that since urban freight is predominantly handled by road and therefore represents a large proportion of the road tonne-kilometres, then a large proportion of the road output is provided under conditions which are highly energy intensive (trucks and delivery vans operating under urban traffic conditions). Thus the aggregate energy intensiveness of each mode is heavily influenced by its major activity which in the case of rail and sea occurs under the most favourable possible conditions for energy efficiency, whereas the opposite is true for road. Moreover, those parts of the tasks which exert such a strong influence on the aggregate energy intensiveness of each mode involve activities where competition between modes is generally not possible. Rail and sea clearly cannot undertake a significant role in urban freight movement and road haulage is not a practical alternative for the long haul bulk traffic undertaken by sea and rail. There is, of course, a limited area of potential competition between rail and sea, and pipeline transport is certainly a technically feasible alternative to rail or road for some bulk traffic. However, to compete with rail a pipeline has to be considered as an alternative at the initial installation stage. Once a railway has been provided with the capacity to handle a particular bulk traffic, the construction of a pipeline as an alternative cannot at present be economically justified.

The freight movements which are of interest for comparing modal efficiency are only those for which competition is feasible. These are primarily those rail and sea movements classed as non-bulk (from the third segment identified above) and all categories of non-urban road transport. The total non-urban road transport task includes a certain amount of traffic conventionally classed as bulk liquid and bulk solid. For the purposes of this study, however, this is lumped together with general freight since any road traffic is at least in principle capable of being moved as general freight by either rail or sea where the route is served by these modes.

Detailed estimates of interregional freight consignments are provided in three previous BTE publications (BTE 1977, BTE 1978, BTE 1979), which provide an analysis of freight movements by type of freight (bulk, non-bulk) as well as by mode and type of haul. A summary of the estimates is reproduced here as Table 2.2. This table, however, does not provide any information on intraregional movements, or on the number of tonne-kilometres performed, and in order to obtain estimates of these quantities (which are shown in Table 2.3) it is necessary to note some of the characteristics of the transport system and make certain assumptions.

Firstly it should be noted that non-government railways are involved only in the bulk movement of primary products (most of it in the north west of Western Australia) and can therefore be omitted from further consideration. They are also intraregional and therefore do not appear in Table 2.2. Government railways, however, undertake both bulk and general freight, and their task requires further analysis.

Turning now to Table 2.3 in which estimates of the freight movement in Australia are developed for each mode, it will be seen that in the road section of the table the interregional and total tonnes consigned correspond to figures in Tables 2.1 and 2.2, the intraregional figure being obtained by difference.

Average haulage distances for each category are then assigned so that the total tonne-kilometres matches the figure shown in Table 2.1 and the tonne-kilometres for each category thereby estimated. In the case of road (but not rail or sea) part of this data is available (Australian Bureau of Statistics 1978), and the assigned haulage distances are therefore chosen to match this data. Exactly the same procedure is followed for the rail all categories data. For the rail non-bulk data, the interregional figure is built up from the detailed tables of freight consignments in a previous BTE Information Bulletin (BTE 1979). The same average haulage distances as were assigned to the 'all categories' data are then applied to obtain the tonne-kilometre statistics.

TABLE 2.2 - ESTIMATES OF INTERREGIONAL FREIGHT CONSIGNED WITHIN AUSTRALIA, 1975-76

(Million tonnes)

Mode	Type of freight			Total
	Bulk liquids	Bulk solids	Non-bulk	
	INTERSTATE			
Road	1.1	2.2	17.9	21.3
Rail	0.4	1.4	5.8	7.7
Sea	13.3	14.8	5.5	33.7
Air	-	-	0.1	0.1
All modes	14.9	18.5	29.4	62.8
	INTERREGIONAL WITHIN STATES			
Road	2.6	7.3	35.5	45.4
Rail	1.8	30.3	9.8	42.0
Sea	4.8	7.4	0.4	12.7
Air	-	-	-	-
Pipeline	20.5	2.1	-	22.6
All modes	29.7	47.2	45.8	122.7
	TOTAL INTERREGIONAL			
Road	3.7	9.5	53.5	66.7
Rail	2.2	31.8	15.7	49.7
Sea	18.2	22.3	6.0	46.4
Air	-	-	0.1	0.1
Pipeline	20.5	2.1	-	22.6
All modes	44.6	65.7	75.2	185.5

NOTE: Certain figures may not add to totals due to rounding.

<u>Source:</u> BTE 1978.

TABLE 2.3 - ESTIMATE OF NON-URBAN FREIGHT MOVEMENT IN AUSTRALIA, 1975-76

Mode	Intra-regional	Interregional		Total
		Intra-state	Inter-state	
ROAD				
All categories (classed as non-bulk)				
Consignments (10^6t)	33.3	45.4	21.3	100
Assumed average haul (km)	80	269	380	-
Output (10^9t-km)	2.7	12.2	8.1	23
RAIL				
All categories				
Consignments (10^6t)	35.3	42.0	7.7	85
Assumed average haul (km)	30	530	1 000	-
Output (10^9t-km)	1.1	22.2	7.7	31
Non-bulk freight				
Consignments (10^6t)	0.9	9.8	5.8	16.5
Assumed average haul (km)	30	530	1 000	-
Output (10^9t-km)	0.03	5.2	5.8	11
SEA				
All categories				
Consignments (10^6t)	0.7	12.7	33.7	47.1
Assumed average haul (km)	100	520	2 800	-
Output (10^9t-km)	0.07	6.6	94.4	101
Non-bulk freight				
Consignments (10^6t)	0.1	0.4	5.5	6.0
Assumed average haul (km)	300	500	500	-
Output (10^9t-km)	0.03	0.25	2.75	3

Source: BTE 1977, BTE 1978, BTE 1979 and Table 2.1.

In a similar way the sea all categories tonnes consigned data is obtained from Table 2.2. Detailed tabulations of freight movements in the previous Information Bulletin (BTE 1977), and values of average haulage distance are then assigned to match the known characteristics of coastal shipping and the total tonne-kilometre figure from Table 2.1. For the non-bulk component tonnes consigned and average haulage distances are again obtained in the same way. These estimated distances differ substantially between 'all categories' and 'non-bulk' principally because the former involves some very short intraregional movements, mostly of bulk liquids (eg petroleum from Botany Bay to Clyde refinery) and a substantial proportion of very long interstate hauls from the north west. The non-bulk traffic, however, is made up mainly in the intraregional category of movements from Darwin along the coast of Arnhem Land, and in the interstate category of movements from Melbourne to Tasmania.

Thus using available statistical data and general information about the known characteristics of various freight activities, it is possible to build up an estimate of the modal shares of the non-bulk freight task. This information, developed at length in Tables 2.1 to 2.3, is summarised in Table 2.4 and presented in pie chart form in Figures 2.1 and 2.2.

IMBALANCE OF FREIGHT FLOWS

A major factor influencing the energy efficiency of any mode is the balance of loading in opposing directions. Clearly, any system which operates full in one direction and empty in the other will suffer an energy penalty as compared with a system which is fully loaded in both directions. For some types of transport operation, for example hauling minerals from an inland mine to a sea port, running one way empty is unavoidable. The amount of return freight in the form of general commodities for use in the mine area is much less than the outgoing minerals and in any case the rolling stock used is normally of specialised design and could not be used for the transport of general freight. In the case of general non-bulk freight, however, a major concern of transport management is to obtain adequate loadings in both directions. The overall balance of freight flows along a particular route is not within the control of the supplier of transport. There is a certain amount of traffic and each operator competes for the traffic according to

TABLE 2.4 - SUMMARY OF ESTIMATED NON-URBAN FREIGHT MOVEMENTS, 1975-76

a) Million tonnes (per cent)

Mode	BULK	NON-BULK			
	All movements	Intra-regional	Interregional		Total
			Intra-state	Inter-state	
Road	0 (0)	33.3 (27)	45.4 (37)	21.3 (17)	100 (81)
Rail	185.5 (82)	0.9 (*)	9.8 (8)	5.8 (5)	16.5 (13)
Sea	41 (18)	0.1 (*)	0.4 (*)	5.5 (4)	6.0 (5)
TOTAL	226.5 (100)	34.3 (28)	55.6 (45)	32.6 (27)	122.6 (100)

b) Thousand million tonne-kilometres (per cent)

Mode	BULK	NON-BULK			
	All movements	Intra-regional	Interregional		Total
			Intra-state	Inter-state	
Road	0 (0)	2.7 (7)	12.2 (33)	8.1 (22)	23 (62)
Rail	46 (32)	0.03 (*)	5.2 (14)	5.8 (16)	11 (30)
Sea	98 (68)	0.03 (*)	0.25 (*)	2.75 (7)	3 (8)
TOTAL	144 (100)	2.76 (7)	17.7 (48)	16.7 (45)	37 (100)

* indicates less than 1 per cent.

NOTE: Some totals do not agree due to rounding.

Source: Table 2.3.

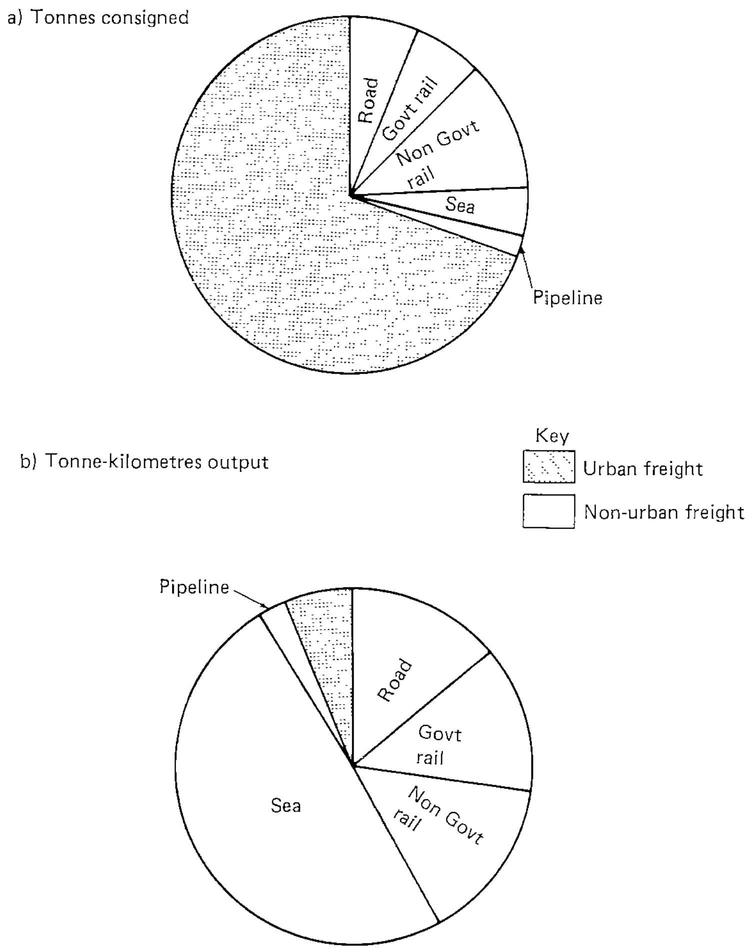
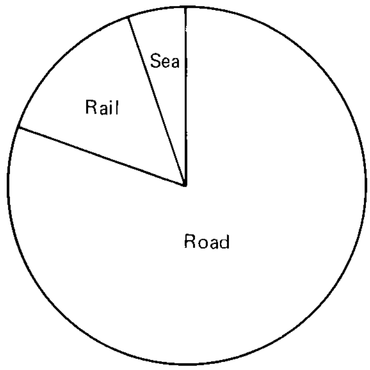


FIGURE 2.1
THE AUSTRALIAN DOMESTIC FREIGHT TASK 1975-76

Source: Table 2.1

a) Tonnes consigned



b) Tonne-kilometres output

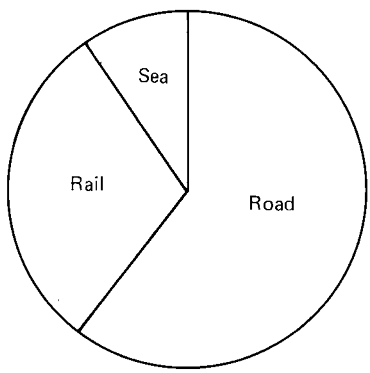


FIGURE 2.2
MODAL SHARES OF THE NON-URBAN NON-BULK FREIGHT TASK 1975-76

Source: Table 2.4

his available capacity. If there is an overall imbalance of traffic between two centres, as there is between Sydney and Brisbane for example, where road, rail and sea all transport more from Sydney to Brisbane than they carry in the reverse direction, there is little that transport operators can do to balance the system loads, although they can, of course, compete with one another for return loadings and one operator may therefore be able to raise his load factor above the system average at the expense of another. One particular form that this competition takes between road and rail highlights the greater operational flexibility and adaptability of road transport. A truck operator who has obtained a contract to take a load from, say, Melbourne to Sydney will endeavour to obtain return loading from Sydney. If he is unable to obtain any primary contract he can offer his services to a major freight-forwarder as a sub-contractor. Since the freight-forwarders are naturally concerned to keep the loadings on their own vehicles balanced in both directions (which they do very effectively) they are unlikely to offer a sub-contractor a cargo which would unbalance the loadings on their road fleet. If, however, they have a consignment destined to be transported by rail they may offer this to the truck sub-contractor at rail freight rates. Thus the truck operator gets a return load, albeit at a relatively poor rate, the freight-forwarder gains a door to door service at no increase in cost, and the railway loses the load.

In theory this sort of competition should at least enable one mode to improve its balance of loading, even if at the expense of another mode, and if there is a net imbalance of flow then the imbalance on all modes should be in the same direction. In practice this is not always the case. Although on some major routes, principally from Brisbane to other capital cities, all modes show a net imbalance in the same direction (surplus capacity out of Brisbane), on a number of other routes the competing modes have net imbalances in opposing directions. In such a case, the possibility appears to exist for an intermodal transfer which will improve the load factors of both modes involved.

This situation has been examined briefly for the Sydney-Melbourne, Melbourne-Adelaide, Sydney-Adelaide and Adelaide-Perth corridors and the results shown in Table 2.5. In this table, based on 1975-76 data (BTE 1978) the freight flows in each direction are compared for each mode and the results shown as an excess or deficit in the direction specified in the column headings. This excess or deficit is shown both as thousands of tonnes (at a) and as a percentage of the two-way total for each mode (at b). Feasible intermodal transfers for each route are then determined (from a) and tabulated in the next section (c). Thus for the Sydney to Melbourne route it can be seen that road carries 301 000 tonnes more in this direction than in the return direction, whereas rail and sea carry respectively 49 000 and 16 000 tonnes less from Sydney to Melbourne than in return. It therefore appears that if 49 000 tonnes of Sydney to Melbourne freight were transferred from road to rail, and 16 000 tonnes from road to sea then the rail and sea loads would be balanced in both directions, and the imbalance for road would be reduced by 65 000 tonnes. The situation after intermodal transfers have been carried out to bring loadings as near as possible into balance is shown in the last two sections of the table.

Two caveats must be noted in connection with Table 2.5. The first is that no account has been taken of the commodity types which account for the imbalance, and this may well inhibit balancing intermodal transfers. If the imbalance occurs in commodity types requiring specialised vehicles which cannot be backloaded with other commodities then intermodal transfers will not be feasible. The second caveat is that the purpose of the table is only to indicate the magnitude of the imbalance and the implied inefficient use of resources. The feasible intermodal transfers shown are not a prescription since balancing can also be achieved by transfers which are complementary to those indicated. Thus in the Sydney-Melbourne example discussed, the rail and sea modes could just as readily be balanced by transferring Melbourne to Sydney freight from rail and sea to road.

TABLE 2.5 - IMBALANCE OF NON-BULK FREIGHT MOVEMENTS BETWEEN MAJOR CENTRES, 1975-76

	Quantity	Sydney to Melbourne	Sydney to Adelaide	Melbourne to Adelaide	Adelaide to Perth
(a)	Excess (or deficit) '000 tonnes				
	Road	301	69	76	(4)
	Rail	(49)	(28)	(72)	47
	Sea	(16)	-	89	6
(b)	(a) Expressed as percentage of total consignments both ways for mode				
	Road	7	8	8	(5)
	Rail	(6)	(30)	(11)	(24)
	Sea	(30)	-	100	75
(c)	Feasible balancing intermodal transfer				
	Road	-65	-28	-72	+4
	Rail	+49	+28	+72	-4
	Sea	+16	-	-	-
(d)	Excess (or deficit) after transfer (c)				
	Road	236	41	4	0
	Rail	0	0	0	43
	Sea	0	-	89	6
(e)	(d) Expressed as percentage of total consignments both ways for mode				
	Road	6	5	4	0
	Rail	0	0	0	(21)
	Sea	0	-	100	75

NOTE: Entries at (a) and (d) of this table are the consignments in the direction shown in the column headings minus the consignments in the reciprocal direction.

MODAL CHOICE

Any consideration of the prospects for intermodal transfer of freight, whether for energy conservation or any other reasons, must consider the reasons for the current market place decisions about modal choice. These decisions are made independently by individual shippers, and are based on many factors. Energy consumption as such does not enter into the consideration, and whilst it may be possible to show that a particular intermodal transfer is feasible and would save energy, there is little point in doing so if the transfer is for some reason unacceptable to the shipper. It is therefore appropriate to give some consideration to the factors on which modal choice decisions are based.

In April 1980 Transport Australia organised a workshop on 'Modal Choice for Intercity Freight', with participants drawn from a wide range of transport users and suppliers. The discussion at this workshop indicated that there is a widespread practice of using transport facilities as a mobile warehouse or pipeline and keeping static inventories to a minimum. This is part of the strategy of distribution management to minimise the sum of transport and inventory costs which is often referred to as the logistics cost. Given this strategy, it is therefore not surprising that the qualities of a transport service which the user of that service values most highly are the qualities which enable him to trim his logistics costs. On the inventory cost side these are reliability of delivery time, frequency of service, speed of response to particular demands, and accountability (that is the readiness with which it is possible to identify and contact someone who is responsible for safe delivery of a consignment and who can take some action if problems arise). On the transport cost side the relevant items are the door to door price and other direct costs such as packaging and insurance. Speed as such is not seen as being particularly important to most users of transport, although it can be critical to the supplier of the transport service in order to obtain satisfactory utilisation of equipment. Nevertheless, speed of transport does affect the total length of time for which goods are held in inventory, and it is interesting to note what sort of figures are involved. A single truck load of a moderately high value commodity such as small electrical appliances could well have a total value of $100 000. If a company is obtaining a 20 per cent rate of return on employed capital then the daily opportunity cost of the $100 000 tied up in that consignment is in the vicinity of $50. If this is compared with a typical rail freight rate from Sydney to Melbourne of $25 per tonne or $500 for a 20 tonne consignment it can be seen that one extra day can make a significant difference to the total logistics cost.

SUMMARY

This chapter has briefly reviewed the Australian freight task, some of the more important factors which influence its characteristics and the way in which the task is currently shared between modes. It is not possible to identify precisely what components are captive to a particular mode, although it is clear from the proportion of bulk and non-bulk freight in Table 2.4 and the proportion of urban and non-urban freight in Table 2.1 that only a relatively small proportion of the total freight task is potentially suitable for modal transfer. This question will be considered further in Chapter 3 where fuel usage is discussed.

CHAPTER 3 - TRANSPORT ENERGY CONSUMPTION

GENERAL CONSIDERATIONS

Concern over energy consumption by transport has a twofold aspect. On the one hand there is concern for the impact on transport costs of increasing fuel prices, and their effect in turn on overall inflation. On the other hand, there is concern over the actual availability of suitable fuels to enable transport to continue to function, and the contribution which transport could and should make to conservation in a situation of decreasing fuel supplies. Both of these considerations naturally direct attention to possible ways of continuing to perform the transport task whilst using less energy.

FUEL COST

Until comparatively recently fuel costs have been a small part of total transport costs. In some cases, particularly railways, it has represented such a very small part of total costs that the railways' management felt that it was simply not worth while extracting and recording any detailed statistics about fuel usage, and consequently there is a comparative lack of data available. Table 3.1 shows the proportion of total costs which are attributable to fuel and it will be seen that for rail the proportion is very small and rising slowly, for sea it is rather larger and shows a much stronger upward trend, whereas for road, although the proportion is substantially higher, there was actually a declining trend from 1969 to 1979 although this has since been sharply reversed. The figures for road transport represent average values for the industry within NSW, and within the industry there are large variations according to the type of operation. For urban and suburban short haul operators fuel may well represent less than 10 per cent of total costs, whereas for a 6-axle articulated truck travelling 150 000 kilometres per year fuel may now be as much as 30 per cent of the total costs. These varying results, and the apparent anomaly of road transport showing a declining proportion of fuel costs whilst other modes were experiencing rising fuel costs, can be explained if some of the characteristics of fuel pricing and cost structure are noted.

Figure 3.1 shows, for the period 1950-1980, how the wholesale price of automotive distillate has varied relative to the average weekly earnings, taking a base index figure in 1950 of 100. Average weekly earnings have been chosen as the deflator rather than, say, the consumer price index, because a major part of a transport operator's costs are either direct wages or are closely linked to wages. It can be seen from this that, relative to wages, fuel prices showed a continuous decline from 1950, falling to 43 per cent of the 1950 level by 1977. Since 1977 there has been a sharp rise and the price has now risen to the 1966 level on a relative basis. It is therefore not surprising that fuel costs represented a declining proportion of total costs to the road transport industry, at least up to 1978.

TABLE 3.1 - FUEL COST AS A PERCENTAGE OF TOTAL COSTS FOR FREIGHT TRANSPORT

Year	1969	1974	1979
Road (a)	18	17	14
Rail (b)	1.6	1.3	2.4
Sea (b)	4.7	4.8	11

Sources: (a) McDonell 1980.
(b) Annual reports ANL, NSWGR (1969), NSWPTC (1974 and 1979).

For rail the circumstances are rather different. Railways do not pay excise duty on diesel fuel and they also have to identify in their accounts all the overhead costs associated with their infrastructure. The road transport industry also pays a share of its infrastructure costs but this is at least in part obtained via the fuel excise and therefore appears in fuel costs. Additionally, the railways have, during the last decade made substantial changes in their method of operation particularly in respect of cargo handling at terminals. The rising proportion of fuel costs may therefore be due more to reduced costs in other areas rather than increased fuel costs.

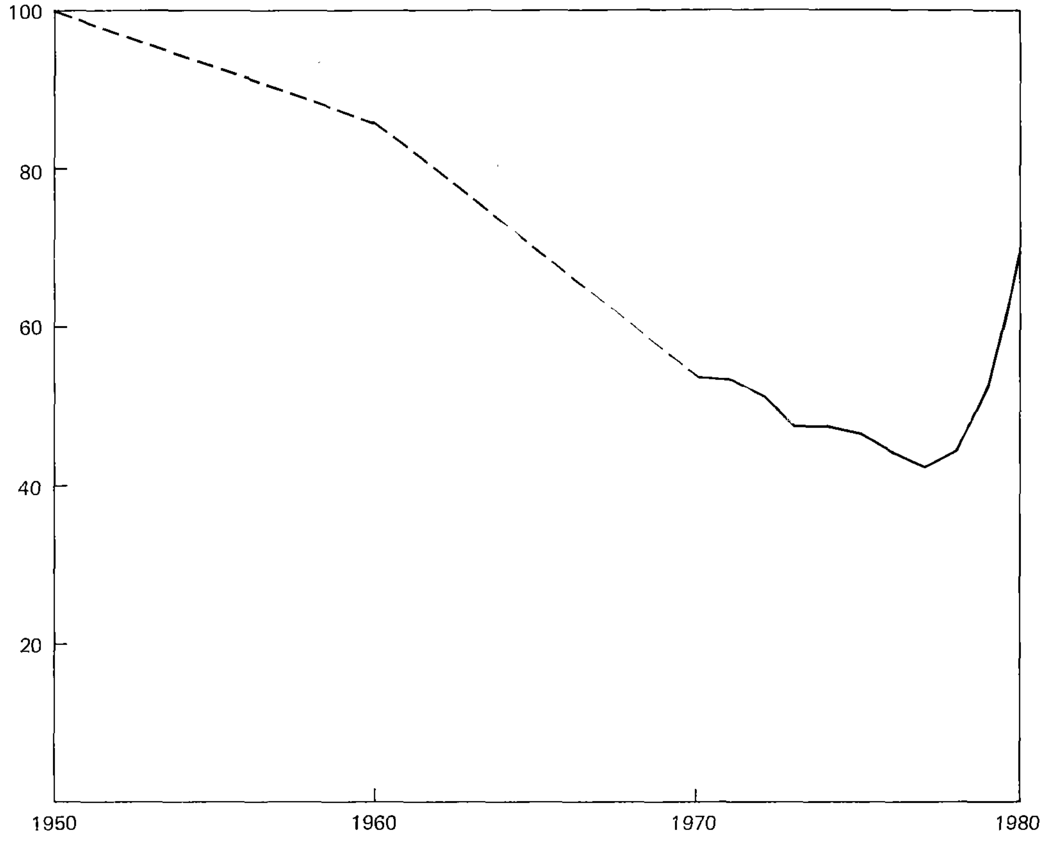


FIGURE 3.1
WHOLESALE PRICE OF AUTOMOTIVE DISTILLATE RELATIVE TO AVERAGE WEEKLY EARNINGS PER MALE EMPLOYED UNIT: BASE 1950 = 100

Source: Australian Bureau of Statistics and Australian Institute of Petroleum

The much sharper rise in the proportion of fuel costs in sea transport is largely attributable to the nature of the fuel used and its much greater sensitivity to the well-head price of crude oil. Figure 3.2 shows the typical cost structure of road transport fuels in 1980, and it will be seen that the well-head price constitutes only 15 per cent of the final price paid by the consumer.

Thus for these fuels a 100 per cent increase in the well-head price of crude oil from present levels would, if other cost components remained unchanged, result in an increase in the price to the end user of only 15 per cent, or slightly more if allowance is made for the concomitant increases in refining and distributing costs. Ships' bunker fuel, however, originated virtually as a waste product from the refining of the heavy Arabian crudes to produce distillate and gasoline for automotive use, and was sold at a price lower than the price of the crude oil supplied to the refinery. With the introduction in 1968 of the Gippsland crude oil which is much lighter, bunker fuel was no longer so freely available as a by-product of Australian refineries and had to be imported in increasing proportions. Thus, whereas total petroleum consumption rose by 44 per cent from 1968 to 1978, imports of fuel oil rose by nearly 400 per cent during the same period, and the price of this imported fuel oil kept very much in step with the increases in the price of OPEC crude oil. Thus, ships' bunker fuel has risen in price by a much greater proportion than the fuels used by other modes, even though it is, of course, still a relatively cheap fuel in absolute terms.

It should be noted then that fuel cost as a percentage of total costs cannot be used to indicate the relative efficiencies of energy use by different modes because of totally different cost structures both of the modes and of the fuels they use. They do serve, however, as a useful introduction to the significance of fuel costs as a whole.

FUEL CONSUMPTION

Transport as an economic activity is a very intensive user of energy. In 1976-77 transport, storage and communication contributed approximately 7 per cent of the gross domestic product but used approximately 26 per cent of the primary fuels. Although these figures suggest that transport as such is a

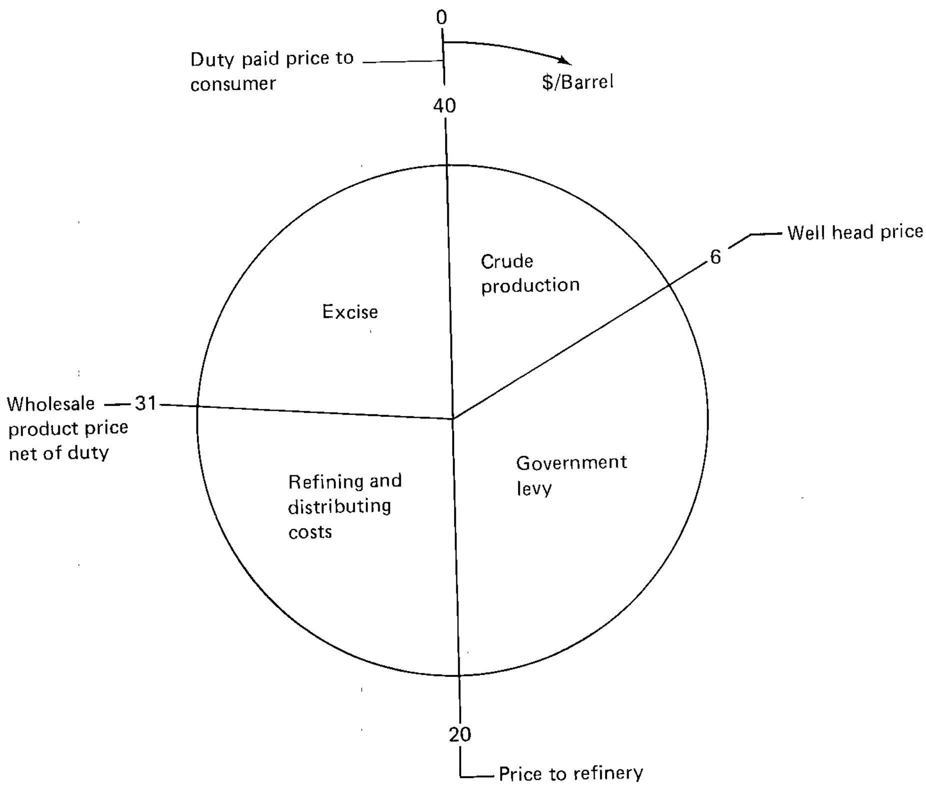


FIGURE 3.2
THE STRUCTURE OF ROAD TRANSPORT FUEL COSTS,1980

Souce: Australian Institute of Petroleum 1979 relatively small part of the nation's economic activity, it is a vital input to nearly all other activities. Without transport most industrial activities would soon stop, and it is interesting to note that the experience of transport operators during disruptions to fuel supplies which have recently occurred in Australia leads to the general conclusion that the most critical activity of all is transporting workers to their place of work. It seems that at least in a short-term shortage situation industry is more likely to be halted because staff cannot get to work than because commercial transport cannot move the necessary raw materials and finished products. Thus the relative efficiencies of the different modes is of interest primarily for long-term conservation strategies rather than for the tactics of combating short-term contingencies.

As mentioned above the consumption of energy by the transport sector amounts to 26 per cent of primary fuel usage. Nearly all of the fuel used in the transport sector, however, is petroleum and so transport's share of petroleum consumption is substantially larger: in fact about 57 per cent of all petroleum consumption in Australia goes to the transport sector. The way in which the various petroleum products are applied to different end uses is shown in Table 3.2. Particular points to note from this table are the very large proportion of total transport fuel use which is accounted for by motor spirit, much of which is used in private cars, and the substantial proportion of automotive distillate (diesel fuel) which is consumed by non-transport activities. Although described as non-transport because of the industrial classification, much of this use is in fact for transport type activities. For example, the haulage of coal by dump truck from an open cast mine to the rail head is just as much a transport activity as the subsequent movement by rail to a sea port, but the former is classed as 'mining' not 'transport'. No reliable estimates are available of the proportion of this non-transport use which can be regarded as a legitimate transport activity. It should also be noted that the figures in Table 3.2 do not include the large quantities of fuel supplied at overseas fuelling points to international shipping serving Australia. It has been estimated (Lawlor and Brown 1980) that overseas shipping is supplied with six times as much fuel from overseas bunkering as from domestic bunkering, and it is therefore important that the data of Table 3.2 should not be applied to the totality of transport activities affecting Australia without making an adjustment for this factor.

TABLE 3.2 - FINISHED PRODUCT/END USE SUPPLY TABLE: PER CENT OF TOTAL AUSTRALIAN OIL CONSUMPTION

Fuel type	Non-transport uses	Transport uses				Total
		Air	Road	Rail	Sea	
Transport fuels						
Avgas		0.3				0.3
Avtur		5.3				5.3
Motor spirit			38.0			38.0
Automotive distillate	9.8		4.0	2.0	0.4	16.2
Industrial diesel fuel	3.7				1.6	5.3
Fuel oil	12.0				5.3	17.3
Other products	17.6					17.7
TOTAL ALL PRODUCTS	43.1	5.6	42.0	2.0	7.3	100.0

Source: Derived from Australian Institute of Petroleum, 1979; Australian Bureau of Statistics, 1978; Department of National Development and Energy, 1979.

In order to obtain an indication of the significance of non-urban freight as a consumer of petroleum fuel two further steps are necessary. Previous estimates (Lawlor and Brown 1980) of the energy consumption in transport by mode and purpose are reproduced in Table 3.3, and show the shares as percentages of transport energy consumption. By combining these data with those of Table 3.2 it is possible to obtain estimates of the petroleum fuel used in non-urban domestic freight transport, expressed as a percentage of total Australian petroleum consumption. This is shown in Table 3.4, with the addition of the actual quantities in megalitres based on 1977-78 consumption. Thus it will be seen that for all non-urban domestic freight movements (including bulk operations which occur mainly by rail and sea), road transport is the largest consumer of fuel, using 4.1 per cent of our oil supply; sea is next with 2.0 per cent followed by rail with a consumption of 1.7 per cent and air with 0.5 per cent.

TABLE 3.3 - AUSTRALIAN ENERGY CONSUMPTION IN TRANSPORT BY MODE AND PURPOSE, 1975-76, PER CENT

Mode		Non-urban freight	Other transport	Total
Road		7.3	66.0	73.3
Rail		3.0	2.0	5.0
Sea:	Coastal	3.6	-	3.6
	Overseas	8.8	-	8.8
Air:	Domestic	0.8	4.9	5.7
	International	-	3.5	3.5
TOTAL		23.5	76.0	100.0

Source: Lawlor and Brown 1980.

TABLE 3.4 - AUSTRALIAN PETROLEUM CONSUMPTION IN ALL NON-URBAN DOMESTIC FREIGHT BY MODE, 1975-76

Mode	Percent*	Megalitres
Road	4.1	1 464
Rail	1.7	607
Sea	2.0	714
Air	0.5	179
TOTAL	8.3	2 964

* Per cent of total petroleum consumption for all purposes.

Source: Tables 3.2, 3.3 and Australian Institute of Petroleum, 1979.

SUMMARY

It is useful at this stage to take stock of the situation and consider the size of the problem being addressed. The question at issue is whether or not there would be any benefit to Australia, by way of petroleum conservation or improved transport efficiency, economy or security, by inducing a shift of the freight task from one mode to another. It must be remembered that much of the freight is assigned to a particular mode because there is no alternative. Much road freight goes to or from places where there is no railway line or sea port, and much of the general freight moved by coastal shipping is between Tasmania and mainland Australia.

Table 2.4(b) showed non-urban domestic freight movements, giving separate estimates for bulk and non-bulk categories. Fuel usage cannot be strictly matched to freight movements, since the relative efficiencies of the modes varies according to circumstances. If, as a first approximation, however, it is assumed that in non-urban freight the fuel usage rate is the same for both bulk and non-bulk traffic, then the petroleum consumption in the non-bulk component of non-urban freight appear as in Table 3.5. If it is further assumed that at the most a half of the non-urban non-bulk freight currently carried by road could be transferred to rail, then this represents a reduction of 11.5×10^9 tonne-kilometres in the road task (50 per cent of 23) and an equal increase in the rail task, which is an increase of 105 per cent on present levels. If these percentages are applied to the fuel usage figures in Table 3.5 this results in a reduction of 732 megalitres in road fuel use and an increase of 224 megalitres in rail fuel use, giving a net reduction of 508 megalitres per year or 1.4 per cent of Australia's total oil consumption. This quantity is probably a considerable overestimate since it is based on a shift of 50 per cent of the non-urban road freight task to rail, and the assumption about equal fuel usage rates in the bulk and non-bulk components almost certainly understates the rail usage figure. It should therefore be regarded very much as an upper limit, and it is probable that actual fuel savings which could be achieved would not exceed 1 per cent of Australia's current total oil consumption. Although small in percentage terms it is interesting to note that this quantity of fuel is enough for 1000 large semitrailer trips each way each day continuously between Sydney and Melbourne.

Even the 1 per cent saving referred to above as an upper limit appears from other estimates to be a very generous figure. A recent Railways of Australia report (Railways of Australia 1980) estimated the total feasible fuel saving which could accrue from diverting freight from road to rail at 84.6 megalitres which is 0.24 per cent of Australia's total oil consumption. These figures serve to indicate the scale of the task and the potential benefits. In the following chapter the actual performance of the modes when undertaking comparable tasks will be examined in more detail.

TABLE 3.5 - AUSTRALIAN PETROLEUM CONSUMPTION IN NON-URBAN NON-BULK DOMESTIC FREIGHT TRANSPORT BY MODE, 1975-76

Mode	Percent*	Megalitres
Road	4.1	1 464
Rail	0.6	214
Sea	0.06	21
TOTAL	4.76	1 699

* Per cent of total petroleum consumption for all purposes.

Source: Bureau of Transport Economics estimates.

CHAPTER 4 - INTERMODAL COMPARISONS

GENERAL CONSIDERATIONS

Over the last decade there have been numerous attempts by researchers around the world to quantify the differences in energy consumption rates between the modes. These attempts have embraced a wide variety of assumptions, circumstances and even purposes, since many of the published results have arisen from an attempt by one particular interest group to promote the merits of one form of transport. Although it is not proposed to make a detailed survey of estimates in this report, it is of interest to note the spread of results which have been obtained, and in Figure 4.1 some of these estimates are presented in diagrammatic form. It is immediately clear from this figure that not only does the energy consumption of each mode vary considerably according to the task, but that the ranges for each mode overlap considerably. As already indicated in Chapter 2, rail and sea modes are used extensively for the long distance movement of bulk loads, and their aggregate energy consumption rates are influenced accordingly. It would therefore be quite inappropriate to apply such statistics to a totally different task simply because it was undertaken by the same mode.

It has become common practice to measure the energy consumption rate, or energy intensiveness, of a freight transport operation by comparing the energy consumed (either in litres of fuel or in megajoules) with the quantity of transport provided in tonne-kilometres. This practice is followed here but it is necessary to note a warning about the validity of this convention. There is no fundamental reason why the output of a transport system should be measured in tonne-kilometres rather than any one of a number of alternative units. Many freight operators have found that with typical cargoes the limiting factor is volume not mass and this has long been recognised in the shipping industry by the adoption of the 'cargo tonne' which takes account of volume. The cubic metre kilometre may therefore be a more pertinent measure. The customer purchasing a transport service is purchasing the service as a total entity not just a certain number of tonne-kilometres, so the dollar value of the service to the customer may alternatively be considered the most appropriate measure of the output. In some cases (as for example with an express parcels service) it is the speed, frequency and

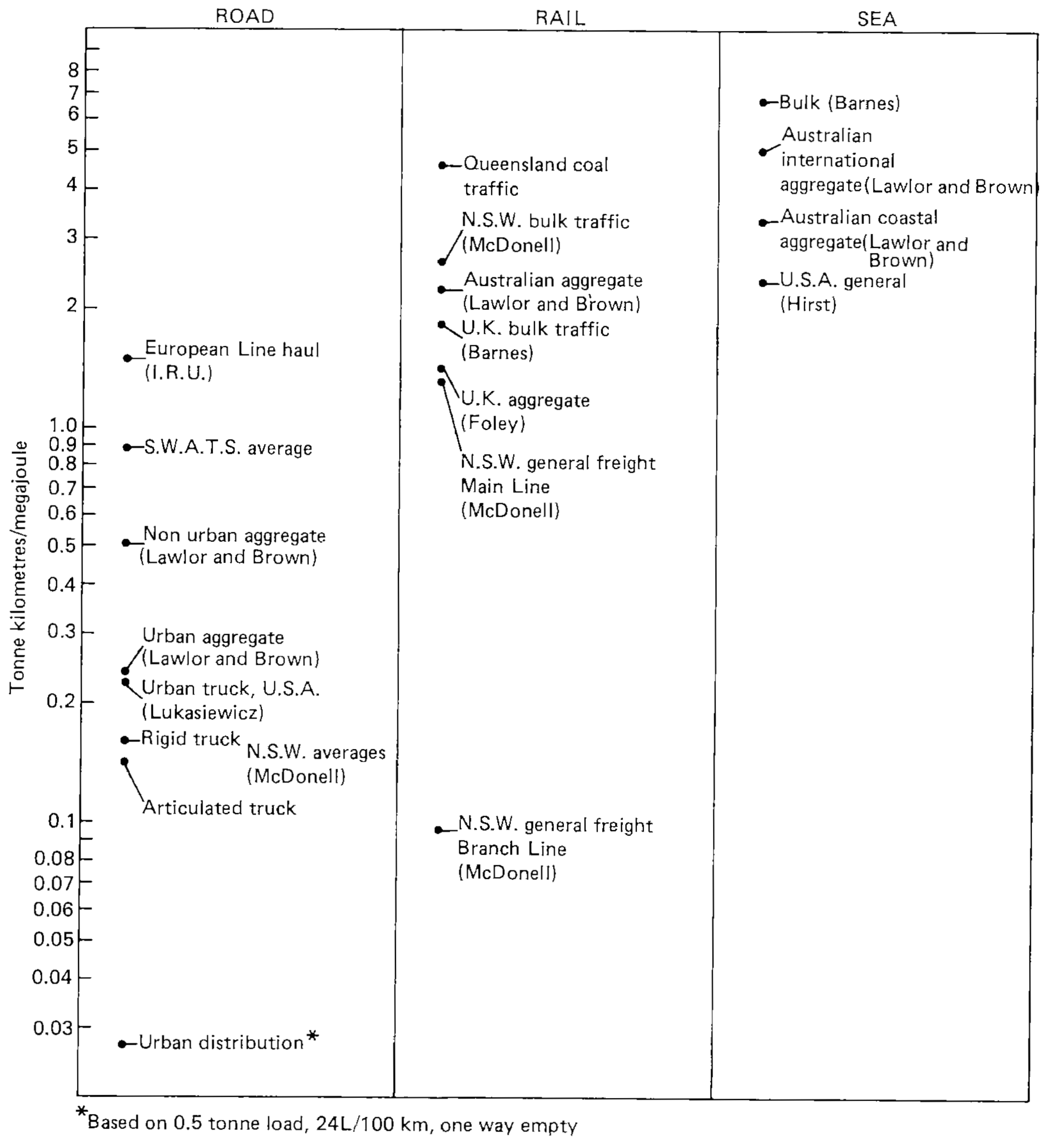


FIGURE 4.1
ESTIMATES OF ROAD RAIL AND SEA ENERGY EFFICIENCY

Sources: References shown and BTE estimates reliability which are essentially the services which the customer is buying. Although he may be charged on a tonne-kilmetre basis, the tonne-kilometres are valueless unless complemented by these other properties, and for the operator in such a business it might well be that the simple number of runs between A and B is the quantity which best measures the output of the system. Having noted these considerations, the fact remains that most freight statistics are related to tonnages, and most physical or institutional limits to carrying capacity are expressed in terms of mass. Thus the maximum permissable gross combination mass of a truck is directly limited by regulation, whereas the volumetric carrying capacity is only indirectly constrained by limits on the overall dimensions of the vehicle and what the vehicle designer can achieve within those limits. Similarly, the total mass of freight trains is limited by the ruling gradient on any particular line, which is a physical limitation of the locomotive's performance, whereas the train's volumetric capacity is variable between wide limits. Thus although the tonne-kilometre is not necessarily the ideal measure of the quantity of transport, it is adopted throughout this report as the best available, with the caution that it should never be used as the basis for comparison without also giving attention to the particular circumstances of the operation.

There are many factors which influence the energy intensiveness of a transport mode, but they can be broadly grouped into two categories. Firstly, there are those factors which affect the linehaul energy intensiveness in megajoules per net tonne-kilometre travelled, and secondly there are those factors which determine the relationship between the linehaul performance and the overall origin-destination performance.

The first group will include such considerations as cargo type and consolidation, design of vehicle affecting the gross/net ratio and the system dynamics (in the widest sense) which determine the amount of energy required to move a gross tonne-kilometre. These system dynamics considerations involve rolling resistance, aerodynamic resistance, type of propulsion system and such factors as gradients and interference from other traffic which demand braking and acceleration. The way in which these factors will affect performance is not always obvious. For example, increasing speed is usually considered to increase energy consumption because of the increased power required to drive a vehicle at higher speeds. On the other hand restricting speed to a certain level may, in the case of a train in particular, necessitate braking on downhill segments and increased powering on uphill segments thereby actually increasing fuel consumption. Also to be included in this group of factors are the route alignment causing disparity between the shortest distance between terminals and the actual route distance, the overall load factors as determined by the extent of return load imbalance and dead running or positioning journeys, and those ancillary activities such as shunting, handling and storage at terminals which can be regarded as part of the linehaul operations.

The second group of factors relate to supplementary transport activities for collection and distribution at either end of the linehaul operation. Since these are primarily dependent on the actual task rather than the mode used it is appropriate to deal with them separately and at this stage discussion relates specifically to the linehaul component.

Although it is now recognised that the energy consumption of a particular mode can vary widely and that there are many factors (most of which have been identified) which contribute to this variation, the influence of each factor individually cannot be predicted accurately, nor is there any established methodology for dealing with these effects. The determination of energy consumption by transport is still very largely empirical and so, if reliable data are to be obtained for comparisons and planning purposes, it is necessary to undertake a task by task evaluation of modal energy consumption. Even though it is recognised that the use of modal aggregate data is unsuitable for specific task comparisons a problem still arises over the appropriate level of disaggregation to apply. Since the purpose is to make a reliable estimate of the energy used by alternative modes when moving the same item of freight between the same origin and destination, and since it is known that there are variations even between individual journeys on the same route by the same mode, the ideal information for planning purposes would be the probability distribution functions of the energy intensiveness for each mode and route. This, however, would be quite impractical since it is unlikely that sufficient individual trip data would be collected. At the other extreme a single observation cannot be used reliably because it would not be known whether the observation was typical or not. In theory, the direct energy consumption in the linehaul can be dealt with by obtaining data on a representative sample of operations on the route in question. This should yield reasonably well clustered data which would indicate both a typical figure and the likely extent of variation caused by the various random effects. In practice, it has been found that disaggregate data on individual operations is not always readily available; some truck operators for example only maintain fleet average fuel consumption figures. Even so a sample of data taken from a number of different operators is a great deal better than national aggregate data since it is specific to a certain type of traffic and may also be specific to a particular route. Other considerations raise problems of principle quite apart from the practical question of availability of data. For example, although it is easily seen that 'overhead' energy costs such as rail shunting and empty running should be taken into account when determining the performance of the revenue movements, the basis on which they should be allocated is less obvious. It has already been determined that the measure of output should be the tonne-kilometre, but all types of terminal handling costs are physically related to the tonnes consigned through the terminal rather than to the tonne-kilometres performed by the system, and it is therefore best to treat terminal energy separately. Another consideration is the difference in principle between the average energy intensiveness for freight actually moved and the marginal energy intensiveness for additional freight which might be carried, particularly if the additional freight either takes up spare capacity on an existing journey or alternatively necessitates an additional journey at low load factor. A further related question is whether all cargo in one movement should be charged in proportion with the total energy consumption or whether an attempt should be made to establish different rates for different parts of the consignment. Thus a goods train may be made up of a string of wagons which individually have different gross/net ratios: should all the freight be regarded as contributing equally to the consumption of energy? A truck might leave Sydney with a consignment of freight for Albury and Melbourne. The Albury to Melbourne sector will be run at an inferior load factor, but should this energy penalty be borne by the Melbourne consignment or the Albury consignment?

It rapidly becomes clear that to identify a specific consumption of energy which is physically related to the movement of a specific tonne of freight is an impossible objective except where an entirely homogeneous cargo is moved from a single origin to a single destination. Moreover, in many cases it is not even relevant since in the case of a mixed freight train, for example, one particular wagon will be moved only when there are a number of other wagons which have to go to the same destination, and each wagon load depends on the existence of all the others (including empty returns) for its movement to occur.

From examination of these issues it is considered that the most rational approach is to regard the total output (measured in tonne-kilometres) of a particular operation or series of similar operations as a joint activity, and to share all the movement energy costs equally over each unit of output. Given the adoption of this approach, the objective is therefore to try and determine for each mode on each of the selected routes the amount of general freight moved and the amount of fuel consumed in the process, in all cases aggregating over a balanced movement of vehicles in both directions. The emphasis on general freight applies mainly to rail and sea modes, where bulk movements have a markedly different character and are therefore excluded. In the case of road transport, freight movements classified as bulk liquid or bulk solid are still effectively single vehicle loads carried on vehicles of fundamentally similar characteristics to those used for general freight movements. Moreover, this type of load is, in principle, just as plausible a candidate for transfer to alternative modes (whether by piggy-back, roll-on roll-off or container) as those types of freight classed as general, and it is therefore not appropriate to try and segregate this class of operation. Three types of operation which it is considered appropriate to exclude, however, are parcels express service (the tonne-kilometre is not a suitable measure of the service in this case), livestock transport and abnormal loads (overweight or over dimension) because of their own special characteristics.

SELECTION OF ROUTES FOR STUDY

The selection of appropriate routes to be studied was based on several considerations of which the most important were the existence of substantial movements of freight on competing modes (to ensure a reasonable data base and feasibility of intermodal transfer) and the need to get a representative sample of types of route not restricted only to the major trunk routes. The final selection of routes is shown in Table 4.1 together with the flows of general freight (where these statistics are available) expressed both in tonnes and as a percentage of the total movement of general freight between all origins and destinations. It will be seen that this selection includes not only the most heavily trafficked routes between capital cities, but also some shorter routes from capital cities to nearby centres and one long haul route between comparatively small centres.

Although data was sought for all of these routes it was not always available. The actual information obtained is discussed in Chapter 5.

TABLE 4.1 - CITY PAIRS SELECTED FOR STUDY AND CORRESPONDING NON-BULK FREIGHT FLOWS

City pair	'000 tonnes per year	per cent*
Townsville-Mt Isa	-	
Brisbane-Rockhampton	-	
Brisbane-Toowoomba	-	
Brisbane-Sydney	1 325	1.8
Brisbane-Melbourne	775	1.0
Sydney-Melbourne	4 850	6.4
Sydney-Newcastle	-	
Sydney-Canberra	742	1.0
Sydney-Orange	-	
Melbourne-Albury	333	0.4
Melbourne-Bendigo	-	
Melbourne-Adelaide	1 718	2.3
Melbourne-Perth	515	0.7
Adelaide-Perth	285	0.4
		14

- indicates freight flows for these routes not separately available.

* percentage of total non-bulk freight between all origins and destinations.

Source: BTE 1978.

CHAPTER 5 - RESULTS

CONVENTIONS USED

It was stated in Chapter 4 that the convention of measuring the output of a transport system in tonne-kilometres is followed in this study, although it was noted that some discretion needs to be exercised in applying this to different situations.

Two other conventions also need to be established. Energy supplied can be measured either in terms of the quantity of fuel (eg, litres of distillate) or in absolute energy units (megajoules). Although the former is a perfectly satisfactory method for use within one system, it makes intersystem comparisons difficult because different fuels (eg, distillate and heavy fuel oil) have different energy contents. In this study all energy usage is therefore expressed in megajoules. Having established the units of measurement for the input and the output there remains a choice in the method of comparing them. Energy intensiveness (energy consumption per unit of output) is widely used, but this method has the disadvantage that the inherent characteristics of the system as a function of load factor are less readily perceived, and the problems of relating the efficiencies of rail based on net and gross loads are also less easily managed. The alternative of expressing the efficiency of the system as output per unit of input offers advantages in these respects and is therefore used here.

The following conversion factors may be noted:

1 litre of motor spirit (super)	=	34.4 MJ
1 litre of automotive distillate	=	38.4 MJ
1 litre of fuel oil	=	42.0 MJ

1000 MJ is equivalent to 29.1 litres of motor spirit
26.0 litres of automotive distillate
23.8 litres of fuel oil

Since very little motor spirit is used in freight transport the following conversions are quoted for automotive distillate (used by road and rail) with figures for fuel oil (ships) given in parentheses.

1 t-km/MJ	=	38.4 t-km/litre	(42.0)
	=	2.6 litres/100 t-km	(2.38)*

* note this is an inverse relationship.

LINEHAUL CHARACTERISTICS

Sea

Sea transport, if considered globally, spans a very wide range of ship type, size and performance. For coastal movements of general freight, however, the smaller container vessel is the appropriate type to consider, and for this purpose the Motor Vessel *Melbourne Trader* was used as the source of data. The principle characteristics of the MV *Melbourne Trader* are as follows:

Class and type	Vehicle deck container vessel
Length overall	140 metres
Deadweight	5132 tonnes
Service speed	18.4 knots
Machinery	2 x Pielstick 12 PC2V diesels
	8830 kW total at 520 revs/min
Screws	Two, controllable pitch
Fuel type	Heavy oil and marine diesel

Data on fuel consumption and cargo carried were obtained for 18 separate voyages between east coast ports. It was not possible to obtain data relating specifically to the coastal city pairs selected for study as these were not all included in the ship's regular trading pattern. The data obtained, however, provided a satisfactory indication of the ship's characteristics, and can be taken as representative of what would be achieved on other routes since the relative values of speed, consumption and cargo carried would be similar. In Figure 5.1 these data are plotted together with a regression curve

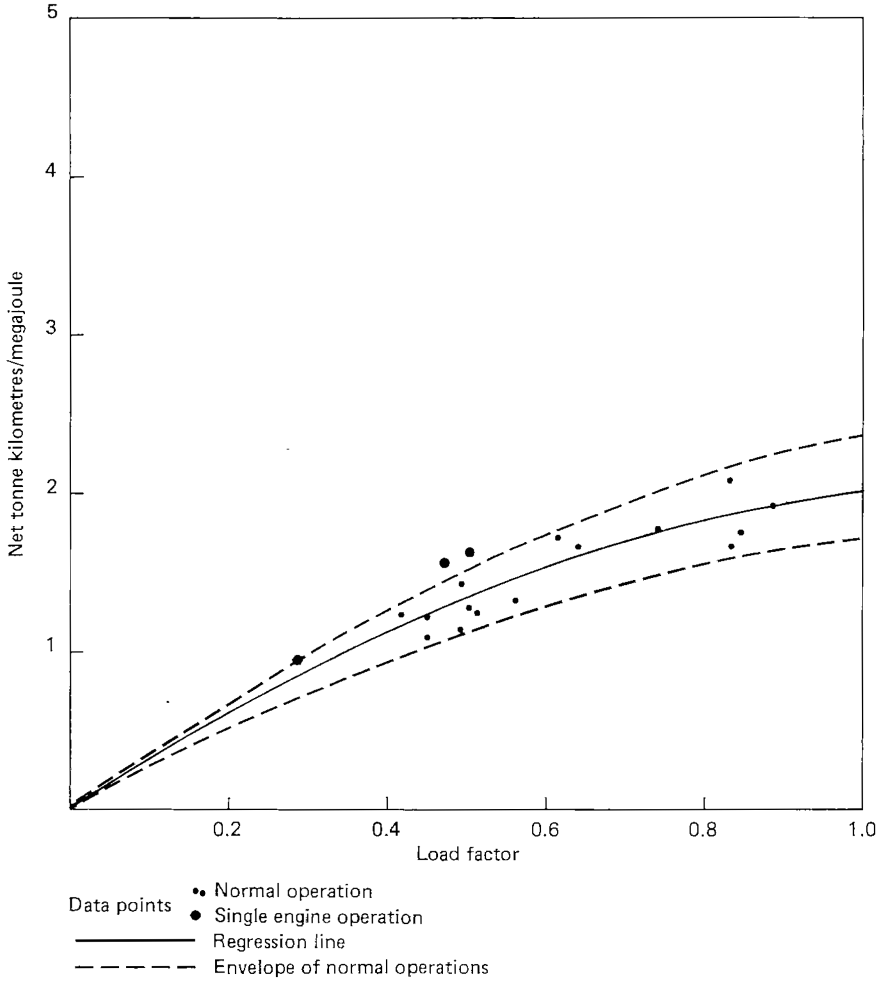


FIGURE 5.1
SEA FREIGHT ENERGY EFFICIENCY DIAGRAM
FOR M.V. MELBOURNE TRADER

and upper and lower boundaries to the data set. The boundaries are defined as curves having the same form as the regression curve, but with all the ordinates increased in a constant proportion for the upper boundary (and decreased for the lower boundary) so as to include all data points for normal operation. The regression equation is given in Appendix I.

The *Melbourne Trader* was selected for study because it was considered typical of ships used in the general cargo coastal trade. This is in accordance with the purpose of this study to try and determine the current realities (as distinct from theoretical possibilities) of the relative modal energy efficiencies. It is nevertheless of some interest to know what sort of improvement might be achieved if the flow of cargo was such as to exploit the full capacity of a larger ship. An assessment was therefore made of the performance which would be achieved by the *Anro Australia* if it were operated between Melbourne and Fremantle and it was possible to utilise the full pay load capacity of this ship (which is 23 000 tonnes). Given these assumptions it appears that *Anro Australia,* operating at a load factor of 1.0, could achieve an efficiency of 5.0-6.0 tonne-kilometres per megajoule when operating at its designed service speed.

A further issue which calls for some comment is the question of slow steaming. The power required to drive a ship varies approximately as the cube of the speed, and over a limited range of speeds the fuel consumption varies in the same way(1). It can therefore be claimed that by slow steaming a ship can substantially improve its energy efficiency. Whilst this is true it must be remembered that similar considerations can also apply to the other modes, and it would not be a valid comparison to set a ship's slow steaming performance against normal operations of the other modes. Moreover all modes have to operate in the world of commercial reality in which consignors make a modal choice on the basis of the service offered. A change in procedure such as slow steaming would cause a reduction in the level of service, and the consequences of this (eg, reduced load factors) would have to be considered.

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(1) If the speed deviates too far from the design speed, changes in the efficiency of the propulsion system have a significant effect on fuel consumption and the cube relationship is not valid.

Road

The characteristics of the long distance road haulage industry have been reported on in an earlier publication (BTE 1979). The main feature of relevance to this study is that the industry is made up of a large number of independent operators, the great majority of whom operate only one or two trucks. Thus there is no single organisation which can provide operating data on the system as a whole, and it was therefore decided to seek the necessary data by means of a questionnaire directed to a sample of major road haulage operators. The assistance of the Australian Road Transport Federation and its affiliated State associations was obtained to identify suitable operators to approach for data and also to advise on the type of data which the industry would be able to provide. The questionnaire, a sample of which is reproduced in Appendix II, was divided into two parts. The first part, which was common to all questionnaires, contained general questions to provide a profile of the respondent. This was considered necessary to put in the proper context the data provided in the second part of the questionnaire. The second part sought specific numerical data on freight movements and fuel consumption on a number of specified routes, and therefore varied in detail from State to State. Since it was by no means certain that respondents would have statistical data in the particular form which was requested, they were invited to provide relevant data in any other alternative form if this was more convenient.

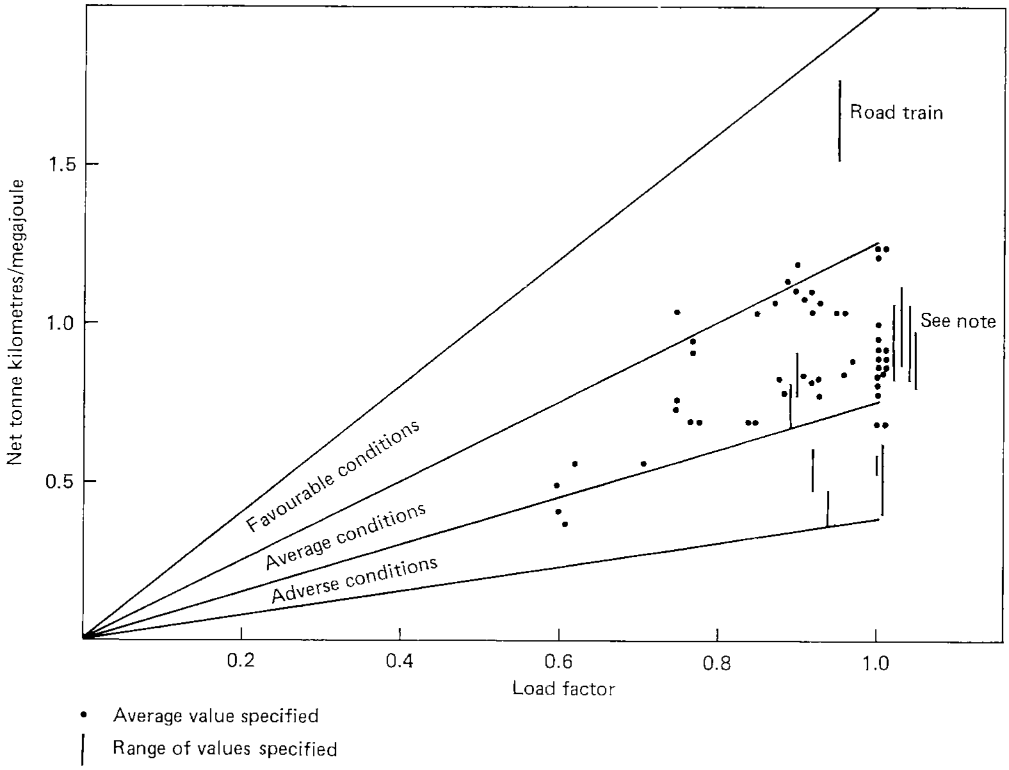
A total of 88 questionnaires was sent out to all States. A substantial number of these failed to yield usable data, mainly because the respondent either did not operate on the routes specified or alternatively used sub-contractors to provide prime movers and therefore had no data available. Usable replies were received from 18 respondents, and although this was a smaller response than was originally hoped for it yielded data on 47 operator-truck combinations on the various routes being examined and was considered adequate. A majority of respondents were able to provide only fleet or route average fuel consumption, but nonetheless there were enough responses which included details of the range of fuel consumption (best to worst) obtained on a particular route and truck type to provide a useful indication of the variation which occurs.

The data supports the view that the efficiency of trucks increases with size. Generally speaking 36 and 38 tonne semi-trailers produced more tonne-kilometres per megajoule than 32 tonne semi-trailers, which in turn were better than lighter rigid trucks. Road trains appear significantly more efficient than ordinary semi-trailers.

Those returns which did provide best and worst figures as well as averages show that for one truck type on one route the variation between best and worst fuel consumption is typically about 20 per cent but can be substantially higher. This variation may be attributed to many factors including differences between individual vehicles of the same type, differences between drivers and variability of weather and traffic conditions en route. What is of particular interest is that this apparently random variation in actual fuel consumption appears to be substantially greater than any systematic variation between routes or due to changes in loading. In other words the actual fuel consumption of a truck (in litres per 100 kilometres) does not appear to be much influenced by the route on which it is operating or the amount of load which it is carrying, but it is moderately affected by the way it is driven. It is also clear from the responses that the larger freight forwarding organisations are able to consolidate loads so that load factors better than 85 per cent are achieved on the great majority of their operations. It appears that smaller operators serving smaller centres are more likely to operate one way at low load factors, though it is not known whether this is due to an inherent imbalance in traffic between the large cities and smaller centres or to lack in the organisational ability of small firms to secure adequate return loading.

In Figure 5.2 the individual results obtained from the questionnaire are plotted, with results giving only an average value and those supplying a range of values being separately indicated. In view of the conclusion mentioned above that actual fuel consumption is not much influenced by load, it is assumed as a first approximation that efficiency is directly proportional to load factor. This is indicated by the straight lines radiating from the origin which define the areas of operation described as favourable, typical and adverse conditions.

More detail on truck fuel consumption characteristics is given in Appendix I.



NOTE: The large number of data points occurring at load factor = 1.0 have been separated laterally for clarity.

FIGURE 5.2
ROAD FREIGHT ENERGY EFFICIENCY DIAGRAM

Rail

The structure of the long distance rail haulage industry is the complete antithesis of the road haulage industry since in each State only one organisation is responsible for all the rail freight activity (apart from the specialised private rail systems which are not included in this study). Thus all the data are held by a small number of government owned or statutory bodies and accordingly there is no difficulty in identifying sources of information. There are, however, a number of difficulties associated with the varying character of the different State railway networks and the nature of the data available from each one. For example, the parts of the West Australian Government Railway (Westrail) and Australian National Railway (AN) networks relevant to this study are virtually a single line. Such branches that do exist are small in number and there is no difficulty in identifying related wagon flows and fuel consumption for actual traffic. In contrast, the network of track operated by the New South Wales State Rail Authority is complex with many branches, and there are relatively few general freight goods trains which operate as a unit from end to end of a trunk route. Instead trains are assembled and broken up at intermediate points where freight is directed along different branches, and it becomes impossible to obtain simple empirical data on freight movement and energy consumption between, say, Sydney and Brisbane. However, the NSW State Rail Authority has undertaken extensive simulation work to predict the speed and fuel consumption which can be achieved on each section of track with a given trailing load. These results contain an element of idealisation, in that speeds, acceleration rates and braking points are all optimised, and clearly the actual performance would be expected to fall short of the simulated performance. No indication of the extent or variability of this difference was available. Similarly, the net to gross ratios for the different types of traffic are simulated and based on total commodity flows throughout the system, the characteristics of the stock of wagons, and optimised loading and balancing wagon flows.

In addition to the variability of the characteristics of data available from the different systems, a freight train is fundamentally more variable in character than a linehaul truck.

The maximum allowable gross trailing load varies considerably according to the locomotive type, the ruling grade on the route and the operating schedule to be maintained, and actual trailing loads vary widely up to the allowable limit. The result is that normal mainline freight trains may operate in different parts of Australia with anything from 350 to 1750 trailing tonnes per locomotive. In addition to this already wide variation, the gross/net mass ratio varies for different wagons and different types of load, and the type of terrain exerts more influence on the performance of a train than on the performance of a truck.

Because of this great variability between States, the data obtained from the various States was initially analysed separately, and details of this are provided in Appendix I.

If the results obtained from Vicrail and Queensland Railways observations and the NSW State Rail Authority simulations are combined, however, it is possible to prepare a composite diagram for rail performance as shown in Figure 5.3. In this diagram the curves delineate three adjoining areas representing the bands in which operations are likely to occur under 'favourable', 'typical' and 'adverse' operating conditions, in a similar manner to the presentation used for road in Figure 5.2. In this case, however data were available for a far greater spread of loads, and this permitted the form of the curves to be more positively determined. Since unfavourable conditions, mainly steep gradients, also effectively limit the total trailing load which can be hauled per locomotive this lower boundary is only drawn up to a trailing load of 1000 tonnes. Many of the circumstances causing train performance to fall in this lower area are associated with ruling grade loads limited to about 600 tonnes.

It will be noted that the axes of this diagram are gross tonnes (not load factor) and gross tonne-kilometres per megajoule and this diagram cannot be directly compared with Figures 5.1 and 5.2. The necessary modifications to obtain a comparable rail diagram are discussed below.

At this stage, data relating to Westrail and AN operations are not included because these data were provided on the basis of net train loads. They are taken into consideration when the question of net performance is examined.

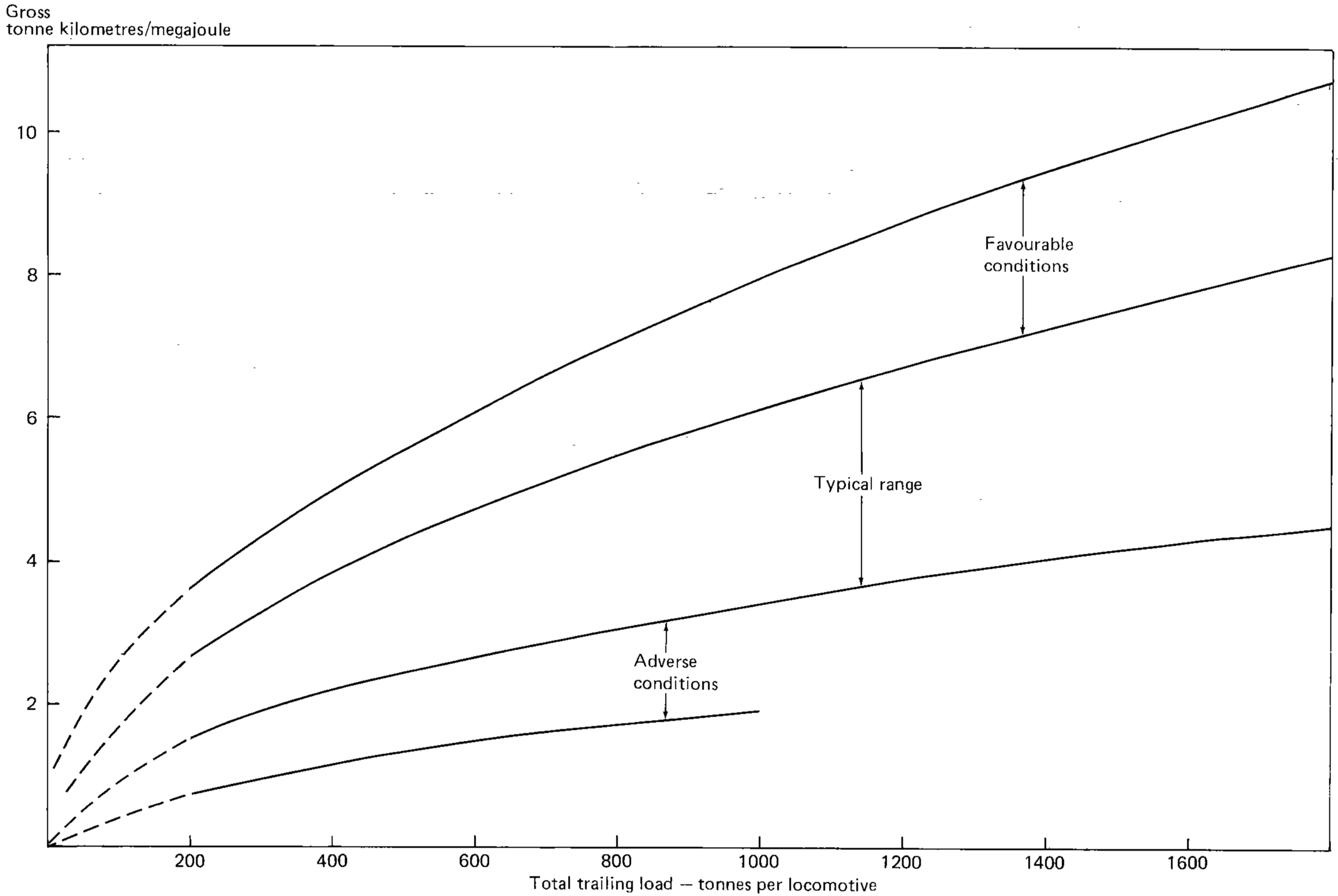


FIGURE 5.3
RAIL FREIGHT ENERGY EFFICIENCY
GENERALISED GROSS TRAIN CHARACTERISTICS

Relating rail performance to net load

The load data used to develop Figure 5.3 was based on total trailing load. The reasons for this arise from the physical constraints on railway operations. The performance of a locomotive, and therefore its ability to maintain a schedule, depends on the total trailing load. Railway operations staff therefore concentrate on the gross load, and although the net load on a wagon must be known or estimated in order to work out the gross load, this information may not be accurately estimated and is not generally recorded so as to be readily available. Information about net loads carried therefore tends to be based on assumptions, averages for particular types of traffic, and the design capacity of the various wagons. Table 5.1 lists gross/net ratios for a number of different wagons, and it will be seen from this that gross/net ratios may vary over the range 1.44 to 3.90. It would appear therefore, that in order to indicate the net performance of freight trains (and so obtain information which can be compared with that already presented for road and sea), the values of gross tonne-kilometres per megajoule represented by the curves in Figure 5.3 should be divided by the appropriate gross/net mass ratio. The difficulty with this approach is that in order to represent the spread of values caused by the varying gross/net ratios, the ordinates of the upper limit curve should be divided by the best achievable gross/net ratio (say 1.44) and the lower limit curve should have its ordinates divided by the 'most unfavourable' gross/net ratio which normally occurs. The appropriate value for this 'most unfavourable' gross to net ratio is not easily determined. It might be taken as 3.9 from Table 5.1, but this does not really take account of the situation where trains are operated with only a partial load (ie a low load factor). Even if this value of 3.9 is used, the upper and lower limit curves on the diagram will now be spread so far apart (their ordinate values will differ by a factor of nearly 12) that the diagram will be too vague to be of any real use. Clearly this approach would not be very satisfactory, and a more useful approach is to relate net tonne-kilometres per megajoule to net freight tonnes on the train. The procedure for obtaining this relationship is explained below with reference to Figure 5.4.

TABLE 5.1 - GROSS/NET MASS RATIOS FOR TYPICAL NON-BULK RAIL FREIGHT WAGONS

WAGON TYPE	GROSS/NET	BASIS OF ESTIMATE
NSW Container flat	1.44	System simulation using
NSW General flat	1.45(a)	actual commodity flows
NSW Car carrier	2.33	and including balancing
NSW Louvre van	1.61	vehicle returns for louvre
NSW General wagon	1.49	vans and open wagons
AN VFX	1.67	
AN Louvre wagon	1.46	
		Vehicle specification
VR VP	1.69	
VR VHX	1.52	
VR typical 4 wheel wagon	1.71	
VR Freight forwarder van	2.19	
VR Freight forwarder		Traffic Branch estimates of
open wagon	2.53	average values for traffic
VR steel traffic	1.55	type on Melbourne-Albury
VR Container traffic	1.81	standard gauge line
VR Motor vehicle	3.90	

(a) Mainly steel traffic.

In Figure 5.4, the upper line represents a train characteristic based on gross tonnes. Consider the point A on this curve which represents the performance of a 1600 gross tonne train (10.2 gross t-km/MJ). The performance of this train when expressed in terms of net tonnes will be represented by a point on the straight line joining A to the origin, the position of the point along the line depending on the gross/net ratio of the train. The ordinates of A, representing gross tonnes per locomotive and gross tonne-kilometres per megajoule, are both divided by the gross/net ratio to obtain the corresponding net tonne values. In the diagram the point A' represents the performance of a 1600 gross tonne train with a gross/net ratio of 1.6.

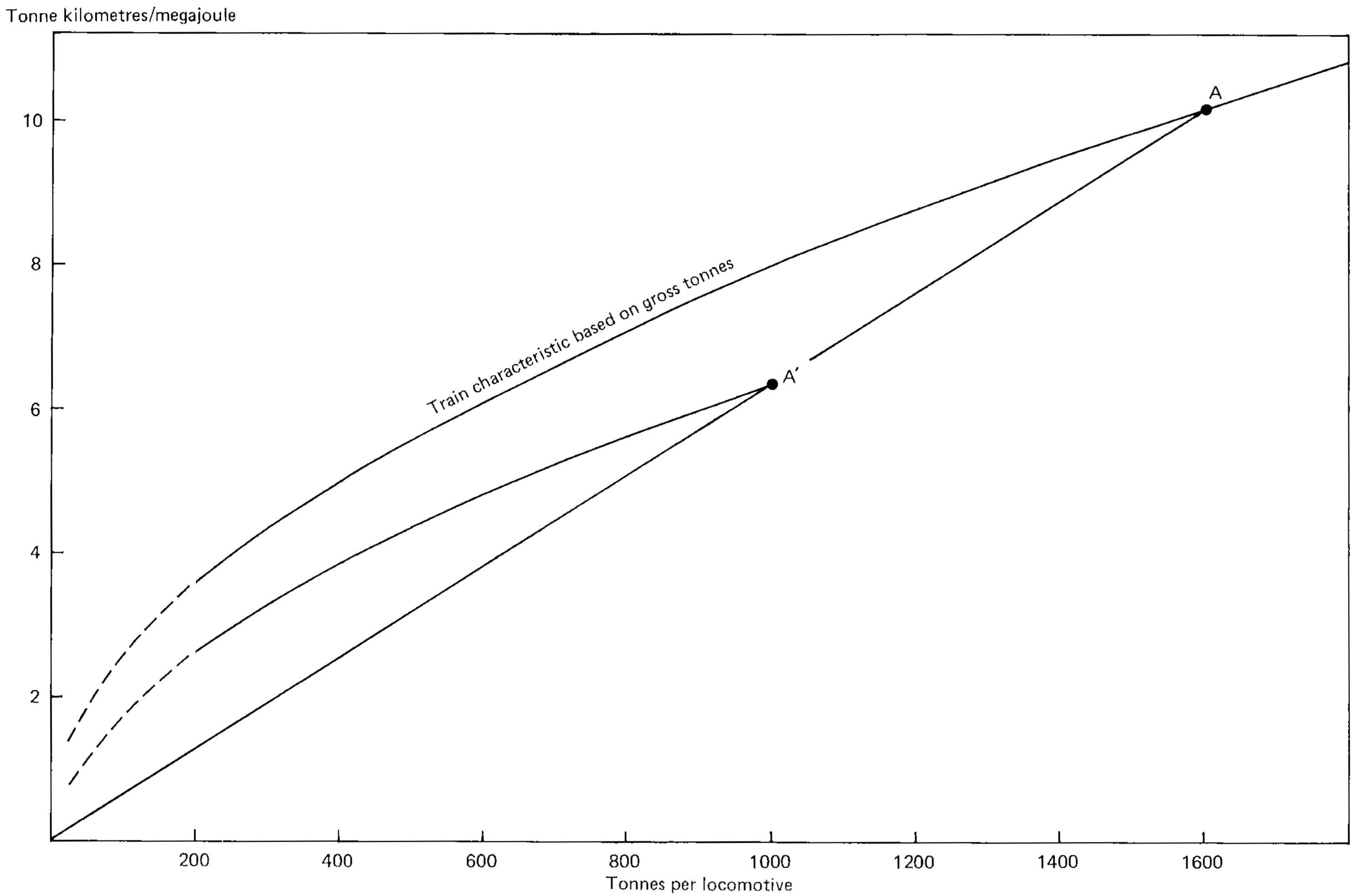


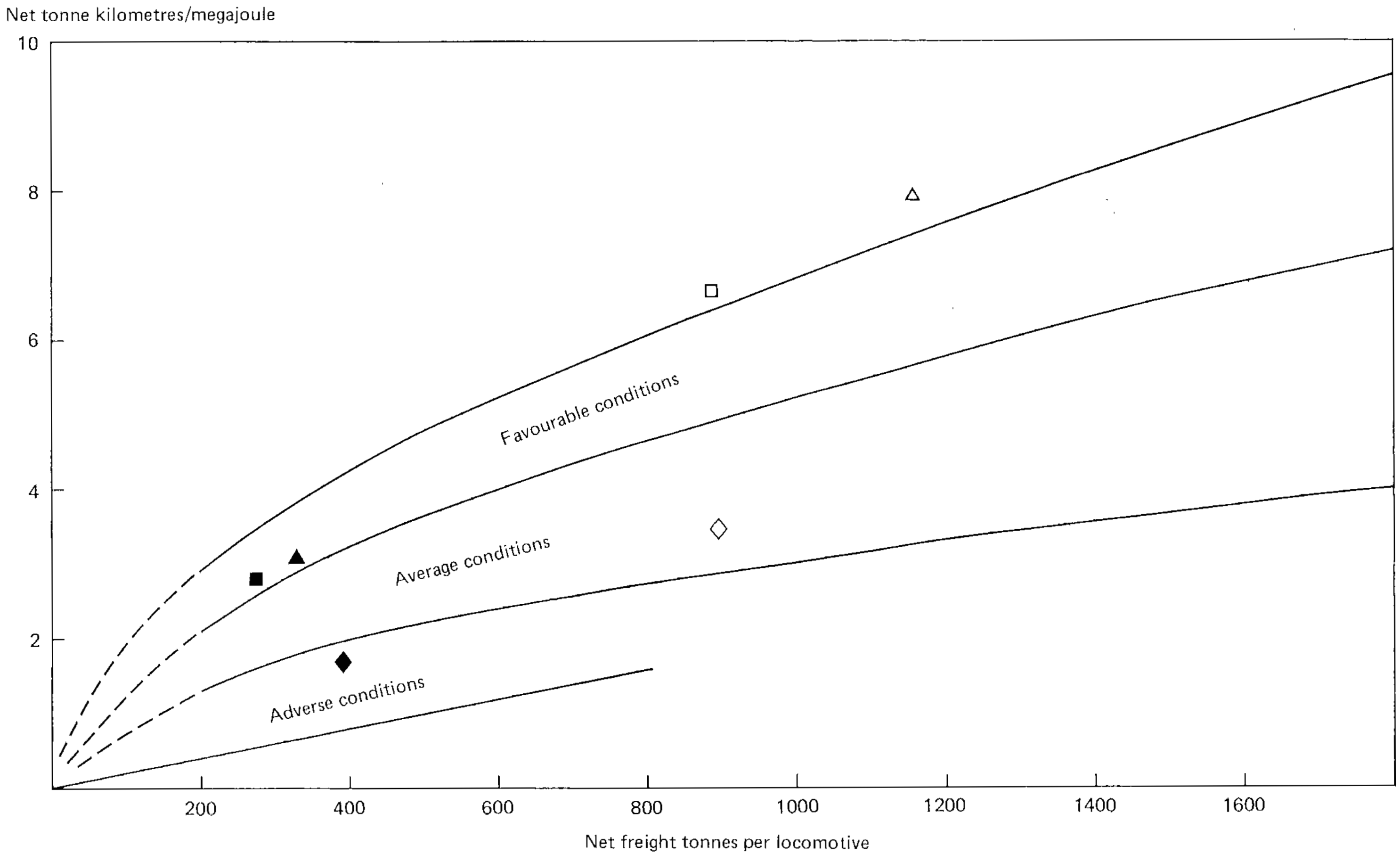
FIGURE 5.4
CONVERSION OF RAIL ENERGY EFFICIENCY DIAGRAM FROM GROSS TONNAGE BASIS TO NET TONNAGE BASIS

If this process is repeated for other points on the gross train characteristic curve the result is that a curve passing between A' and the origin can be generated to estimate the performance of trains with a gross/net ratio of 1.6. Thus for any situation in which the performance of trains expressed in terms of the gross trailing load is represented by the curve passing through A, all points representing the performance expressed in terms of net tonnes for all gross/net ratios greater than 1.6 will lie in the area between the straight line and the curve passing through A'. By applying this method to the curves shown in Figure 5.3 and assuming a minimum attainable value of 1.4 for the gross/net ratio the gross tonnage performance diagram of Figure 5.3 can be converted into the net tonnage performance diagram of Figure 5.5.

The distinction between good, average and adverse operating conditions is obviously somewhat flexible and subjective. In fact, there are not three separate categories of operation which can be classed as good, average and adverse, but a continuous spectrum of operations, and Figure 5.5 should be viewed with this in mind.

As an indication of how this diagram relates to actual experience, the points representing the operations of Westrail and AN across the Trans Australian Line are shown (data from Table I.3). The Westrail line from Kalgoorlie to Perth is regarded by railwaymen as one of the best aligned and graded sections of mainline railway in Australia, and the locomotives used are also claimed by Westrail to be outstandingly fuel efficient. The points representing their operation would therefore be expected to fall high in the favourable band.

It will be seen that the point representing single header operation in the westbound direction (which has everything possible in its favour) actually falls a little above the suggested top limit for favourable conditions in Figure 5.5, whilst the double header operations for this section and for the AN section between Port Augusta and Kalgoorlie are somewhat lower. Thus although Figure 5.5 was developed entirely from eastern States data and theoretical considerations, it seems to be reasonably consistent with actual freight movements and fuel use data obtained from Westrail and AN.



△ Kalgoorlie-Perth single header
▲ Perth-Kalgoorlie single header
□ Kalgoorlie-Perth double header
◇ Port Augusta-Kalgoorlie double header
◆ Kalgoorlie-Port Augusta double header
■ Perth-Kalgoorlie double header

FIGURE 5.5
RAIL FREIGHT NET ENERGY EFFICIENCY DIAGRAM

SHUNTING AND TERMINAL ACTIVITIES

In addition to the fuel used in the linehaul vehicle, the amount of fuel used in shunting of vehicles and other terminal activities associated with cargo handling must be considered as part of the total linehaul fuel consumption.

These terminal activities are of course related to tonnes throughput rather than tonne-kilometres. The approach taken here is therefore to consider first the fuel consumption per tonne, and then determine how this influences the total picture.

For coastal shipping, the fuel consumption and total cargo throughput at the ANL Terminal in Melbourne were estimated. The type of fuel used was predominantly automotive distillate with about 10 per cent of total fuel being represented by LPG and petrol. Although it is not strictly accurate to treat these three fuels in the same way (because of their differing energy content) the error involved is not sufficiently large to be significant in this case. With this simplification it may therefore be stated that 438 880 litres of fuel were used in handling a total of 2 592 000 tonnes of cargo, or 0.17 litres per tonne. Since each tonne of cargo carried on a ship will go through two terminal handling operations this leads to an estimate of 0.34 litres per tonne (13 MJ/t) for the total terminal energy use. This represents an adjustment of up to 3 per cent of the linehaul fuel consumption for terminal handling.

The amount of fuel used in rail shunting is influenced by many factors, which include the mix of freight and destinations combined in a single train, the layout of shunting yards and the type of locomotive and method of operation. Data on shunting fuel use provided by AN and Westrail is given in Table 5.2, and the variation in the figures for shunting fuel at different locations can be explained in part by their differing characteristics. Adelaide and Perth are both 'simple' terminal stations. Port Pirie is a more complex terminal at which trains arrive from and depart in three directions, and the consequent breakdown and makeup of trains will inevitably involve more shunting. Port Augusta is simply a way point at which very little shunting would normally be required, and the same would be true of Kalgoorlie (which is not separately identified in the Westrail data). The data available are obviously much too thin to permit any rigorous estimation of shunting fuel use but it suggests that 0.35 litres (13.4 MJ) per net tonne for an end of line terminal, 0.70 litres (26.9 MJ) per net tonne for a junction involving both train breakdown and makeup operations for the same freight, and 0.05 litres (1.9 MJ) per net tonne for a minor junction involving only the addition or removal of a few wagons from a through train would be reasonable estimates.

The effect of this shunting fuel use on the total linehaul operation will obviously depend on the stage length and characteristics of the mainline operation. Applying the data of Table 5.2 to the corresponding mainline fuel consumption has the effect of increasing the Adelaide to Kalgoorlie fuel use by 8 per cent and the Kalgoorlie to Perth fuel use by 16 per cent. If the general values for shunting fuel use suggested in the previous paragraph are applied to the Sydney to Newcastle operation the additional fuel consumption of 0.35 litres per tonne at both Sydney and Newcastle and 0.05 litres per tonne at Gosford results in 0.75 litres per tonne being used in shunting. Since the simulated mainline fuel consumption for this line segment is 1.66 litres per tonne this means that shunting adds 45 per cent to the total linehaul fuel consumption.

It is stressed that the reliabiity of data on shunting fuel use is very uncertain and the foregoing results can therefore only be treated as indicative, not definitive. Nonetheless, they give cause for concern and clearly show the need for more accurate and detailed information on this aspect of rail fuel use.

There will be a limited amount of vehicle movement in road terminals which is analagous to rail shunting. This activity will normally be carried out by the linehaul prime mover, and the corresponding fuel consumption will be embedded in the linehaul data. No separate treatment of fuel use at road terminals is therefore considered necessary.

TABLE 5.2 - FUEL USE IN RAIL SHUNTING

Rail System	Litres per net tonne Westbound	Litres per net tonne Eastbound
AN		
Shunting at Adelaide (Mile End)	0.28	0.20
Shunting at Port Pirie	0.66	0.70
Bogie exchange at Port Pirie	0.18	0.18
Shunting at Port Augusta	0.05	0.05
	1.17	1.13
Westrail(a)		
Shunting at Perth	0.45	0.45

(a) Shunting fuel consumption data provided by Westrail gave only the total to be allocated to intersystem traffic at Perth. This has been arbitrarily allocated at an equal rate to eastbound and westbound traffic.

ROUTE CIRCUITY AND FEEDER SERVICES

One of the main features of contrast between the freight modes is that in transporting a consignment from origin to destination, the use of the sea mode will always involve the use of feeder services at either end of the linehaul, rail will usually involve the use of such services, and road will frequently (but not always) avoid their use. In making an intermodal comparison of energy use it is essential that this aspect should be examined, and it is convenient to deal with this at the same time as the effect of variations in linehaul distances, or route circuity, between modes.

The number of possible combinations of origin and destination is immense, and the number of ways in which linehaul and feeder services may be combined is therefore also immense. If in addition the possible variation in shunting fuel consumption is considered it becomes clear that to attempt to make a generalised comparison between the modes based on a single parameter such as distance would be both inappropriate and futile. A tabular approach which can be applied on a case by case basis is more suitable, and some examples follow.

In Table 5.3 parameters have been selected to represent a situation in which a consignment is sent from the Melbourne area to the Sydney area. The actual pick up and delivery points are assumed to be 50 kilometres from docks and rail depot in a direction involving backtracking along the linehaul route. In terms of actual places this would be from somewhere near Wallan on the Hume Highway north of Melbourne, to Camden. It is assumed that road transport would be able to perform a direct door to door service with the linehaul vehicle, and the actual road distance is therefore 100 km less than the terminal to terminal distance of 893 km. Rail and sea modes each involve 50 km feeder service at each end, and their terminal to terminal linehaul distances are 963 km and 1100 km respectively. This is the type of situation which gives road an advantage over rail or sea. The linehaul energy efficiency is estimated (by reference to Figures 5.1, 5.2 and 5.5) to be 0.8 t-km/MJ for road, 2.8 t-km/MJ for rail and 1.8 t-km/MJ for sea. Additionally it is assumed that for rail there is a shunting requirment of 13 MJ/t at both Melbourne and Sydney and a further 2 MJ/t at each of three intermediate stations (making a total of 32 MJ/t) and that the road feeder service operates with an energy efficiency of 0.4 t-km/MJ. Using these values, Table 5.3 can be completed and for this particular operation it is found that road transport would consume 991 MJ/t, rail 626 MJ/t and sea 874 MJ/t, the last two being inclusive of the necessary road feeder service.

A second example illustrated in Table 5.4 concerns a consignment to be taken from Sydney to Shepparton. The question arises whether it would use less fuel to take it by road all the way, rail all the way or a combination of rail to Albury with a road connection to Shepparton. In the case of the all rail journey it is assumed that transhipment from standard gauge to broad gauge would occur at Albury and the consignment would then be taken via Benalla, Euroa and Seymour to Shepparton.

TABLE 5.3 - COMPARISON OF ENERGY CONSUMPTION BY ALTERNATIVE MODES UNDERTAKING THE SAME TASK: MELBOURNE HINTERLAND TO SYDNEY HINTERLAND

Component of operation		Road	Rail	Sea
TERMINAL TO TERMINAL				
Linehaul distance	(km)	793	963	1 100
Efficiency	(t-km/MJ)	0.8	2.8	1.8
Linehaul energy	(MJ/t)	991	344	611
Shunting energy	(MJ/t)	-	32	13(a)
Subtotal	(MJ/t)	991	376	624
FEEDER SERVICE				
Feeder distance	(km)	-	100	100
Efficiency	(t-km/MJ)	-	0.4	0.4
Feeder energy	(MJ/t)	-	250	250
TOTAL TASK ENERGY	(MJ/t)	991	626	874

(a) Terminal energy.

The broad gauge segment is treated in Table 5.4 as branch line operation achieving 0.8 t-km/MJ, and shunting is assumed to require 13 MJ/t at Sydney and the Albury bogie exchange and 2 MJ/t at two other intermediate points in NSW. For the rail/road combination shunting at Albury is assumed to require only 5 MJ/t because the freight does not have to be bogie exchanged or reassembled into a new train. With these figures it will be seen that the all road service uses the greatest amount of energy, and the rail/road and rail/rail alternatives are substantially more economical with little to choose between them.

TABLE 5.4 - COMPARISON OF ENERGY CONSUMPTION BY ALTERNATIVE MODES UNDERTAKING THE SAME TASK: CENTRAL SYDNEY TO SHEPPARTON (VIC)

Component of operation		Road	Rail/ road	Rail/ rail
TERMINAL TO TERMINAL				
Linehaul distance	(km)	763	642	642
Efficiency	(t-km/MJ)	0.8	2.8	2.8
Linehaul energy	(MJ/t)	954	229	229
Shunting energy	(MJ/t)	-	22	30
Subtotal	(MJ/t)	954	251	259
FEEDER SERVICE				
Feeder distance	(km)	-	170	290
Efficiency	(t-km/MJ)	-	0.4	0.8
Feeder energy	(MJ/t)	-	425	363
TOTAL TASK ENERGY	(MJ/t)	954	676	622

The final illustration is for a relatively short journey intended to be representative of the delivery of a consignment of goods to a rural property or small country town. In this case it is assumed that the road distance is 200 km and the movement by rail involves 240 km of branch line operation plus 40 km of road feeder service at the end. Both road and rail are assumed to operate at low round trip load factors equivalent in the case of train to an average net load of 100 tonnes yielding an efficiency of 0.5 t-km/MJ. The road linehaul and feeder services are assumed to have the same efficiency of 0.4 t-km/MJ. In this instance it can be seen from Table 5.5 that the use of road actually consumed 16 per cent less energy than rail.

Examples of the sort given above cannot possibly cover all types of situation, but serve to illustrate the variety of cases which may arise and the different conclusions which consequently unfold.

TABLE 5.5 - COMPARISON OF ENERGY CONSUMPTION BY ALTERNATIVE MODES UNDERTAKING THE SAME TASK: MINOR BRANCH LINE SERVICE

Component of operation		Road	Rail/road
TERMINAL TO TERMINAL			
Linehaul distance	(km)	200	240
Efficiency	(t-km/MJ)	0.4	0.5
Linehaul energy	(MJ/t)	500	480
Shunting energy	(MJ/t)	-	15
Subtotal	(MJ/t)	500	495
FEEDER SERVICE			
Feeder distance	(km)	-	40
Efficiency	(t-km/MJ)	-	0.4
Feeder energy	(MJ/t)	-	100
TOTAL TASK ENERGY	(MJ/t)	500	595

CHAPTER 6 - CONCLUSIONS

It is worth restating at this point that if meaningful comparisons are to be made between modes they must be based on comparable tasks. Also the efficiency of each mode is sensitive to the operating conditions, and no general conclusions concerning the relative efficiencies of modes should ever be applied to a particular operation without taking account of the specific operating conditions which prevail. Given that caveat, and that this paper is based on a study of non-urban non-bulk freight movement in Australia, the following general conclusions can be drawn:

- In their present form mainline railways have the potential to be more fuel efficient than either sea transport (as represented by the coastal movement of containers in the MV *Melbourne Trader*) or road haulage.

- The quantity and quality of information available on the loadings being achieved by the rail systems do not make it possible to determine to what extent that potential is actually realised.

- From the fuel efficiency characteristics of railways as estimated in this study, it is probable that long distance mainline freight trains, as they are presently operated between major cities, are significantly more fuel efficient than road or sea.

- For shorter distances and smaller train loads (branch line operations), and if quite reasonable assumptions are made about the net train load, rail appears to be less efficient than road. As net train loads fall below 300 tonnes the comparison becomes increasingly more unfavourable to rail.

- The fuel efficiency of rail transport is markedly affected by terrain, both directly by influencing the fuel required to haul a train of given mass, and indirectly by determining the maximum trailing load which can be hauled. As a consequence, the best efficiency which can be achieved on mainline rail freight operations varies considerably (by a factor of at least 4) between different routes.

- Improved alignment and grading have the potential to produce substantial improvements in the fuel efficiency of the currently less efficient mainlines. These lines include those in the busiest corridors for general freight in Australia.

- Shunting of rail vehicles and other cargo handling activities adds to the fuel used in linehaul operations by rail and sea. The proportionate increase depends on the length of the linehaul operation, but in the case of coastal shipping between capital cities it appears to be about 3 per cent, for long distance rail operations (eg Adelaide to Perth) it is about 8 per cent, and may add as much as 45 per cent to the linehaul fuel consumption on shorter routes such as Sydney to Newcastle.

- The fuel efficiency of road transport does not appear to be significantly influenced by the route characteristics, and is mainly determined by the amount of load carried on each vehicle.

- Rail and sea are generally at a disadvantage compared with road in the matter of route circuity (the ratio of actual route distance to minimum great circle distance). This factor does not negate rail's inherently greater efficiency on mainline routes, but can become very much more significant on branch lines.

- Given presently employed technology and operating practices, a net saving of fuel could in general be achieved by transferring long distance freight from road and sea to rail, and by transferring freight carried on lightly loaded branch lines from rail to road.

- The amount of fuel which could be saved by such transfers is limited (almost certainly less than 1 per cent of Australia's total petroleum consumption). Any argument seeking to encourage such transfers on the grounds of fuel saving alone is therefore not persuasive. This conclusion is based on the present situation in which both road and rail use the same fuel. Electrification of railways would of course alter the balance of considerations.

APPENDIX I - DATA ANALYSIS

GENERAL CONSIDERATIONS

The method of analysis and presentation of fuel efficiency data used in this study is a graphical display in which the output in tonne-kilometres per megajoule is plotted against some suitable measure of load (eg percentage load factor or actual net load) as in Figure I.1. Two basic assumptions are implicit in this presentation. The first is that if the load (or load factor) is zero, then clearly the output in tonne-kilometres must also be zero, and any curve plotted on the diagram to represent the characteristics of a particular system must therefore pass through the origin. The second is that as the load is reduced from its maximum permissable value, the actual fuel consumption will either remain constant (in which case the curve describing the system characteristic will be a straight line through the origin) or it will decrease in sympathy with decreasing load, in which case the former straight line will become convex upwards (but must still pass through the origin). Both of these possibilities are catered for by assuming that the characteristic curve is of the general form:

$$y = ax^b$$

where y is the value of t-km/MJ and x is the selected measure of load.

Sea Data

The set of data points obtained for the MV *Melbourne Trader* are well spread over a range of load factors from 0.3 to 0.8. Regression analysis of this data yields:

$$y = 2.072\ x^{0.615}$$

with a mean value of 0.58 for load factor (x). Estimated upper and lower bounds which contain all points are:

upper bound	$y = 2.53\ x^{0.615}$
lower bound	$y = 1.62\ x^{0.615}$

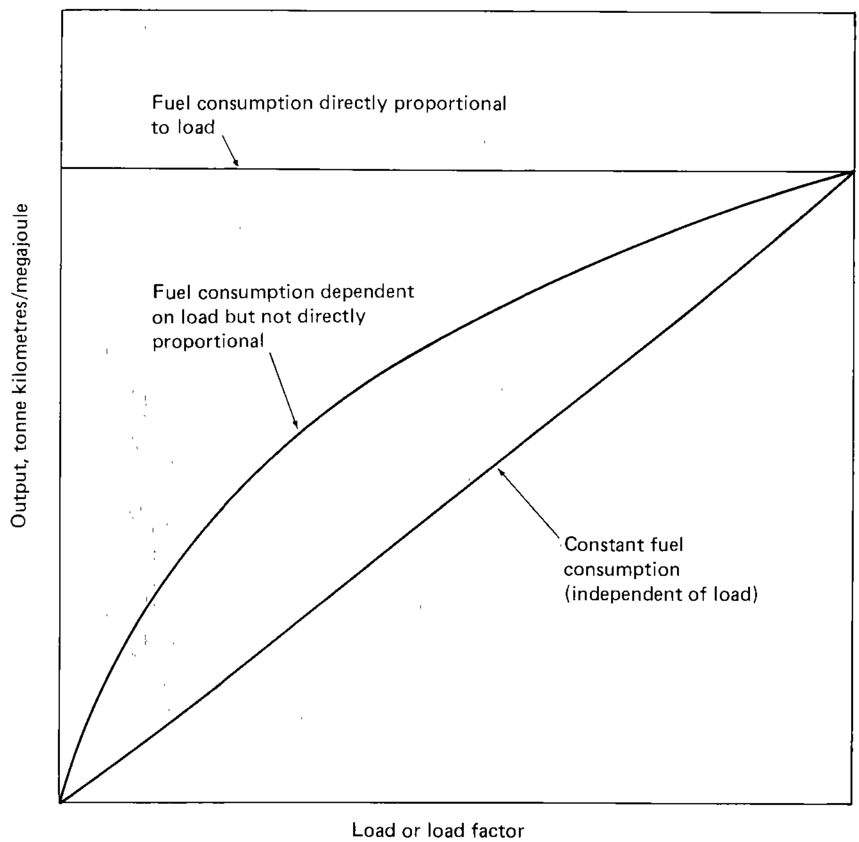


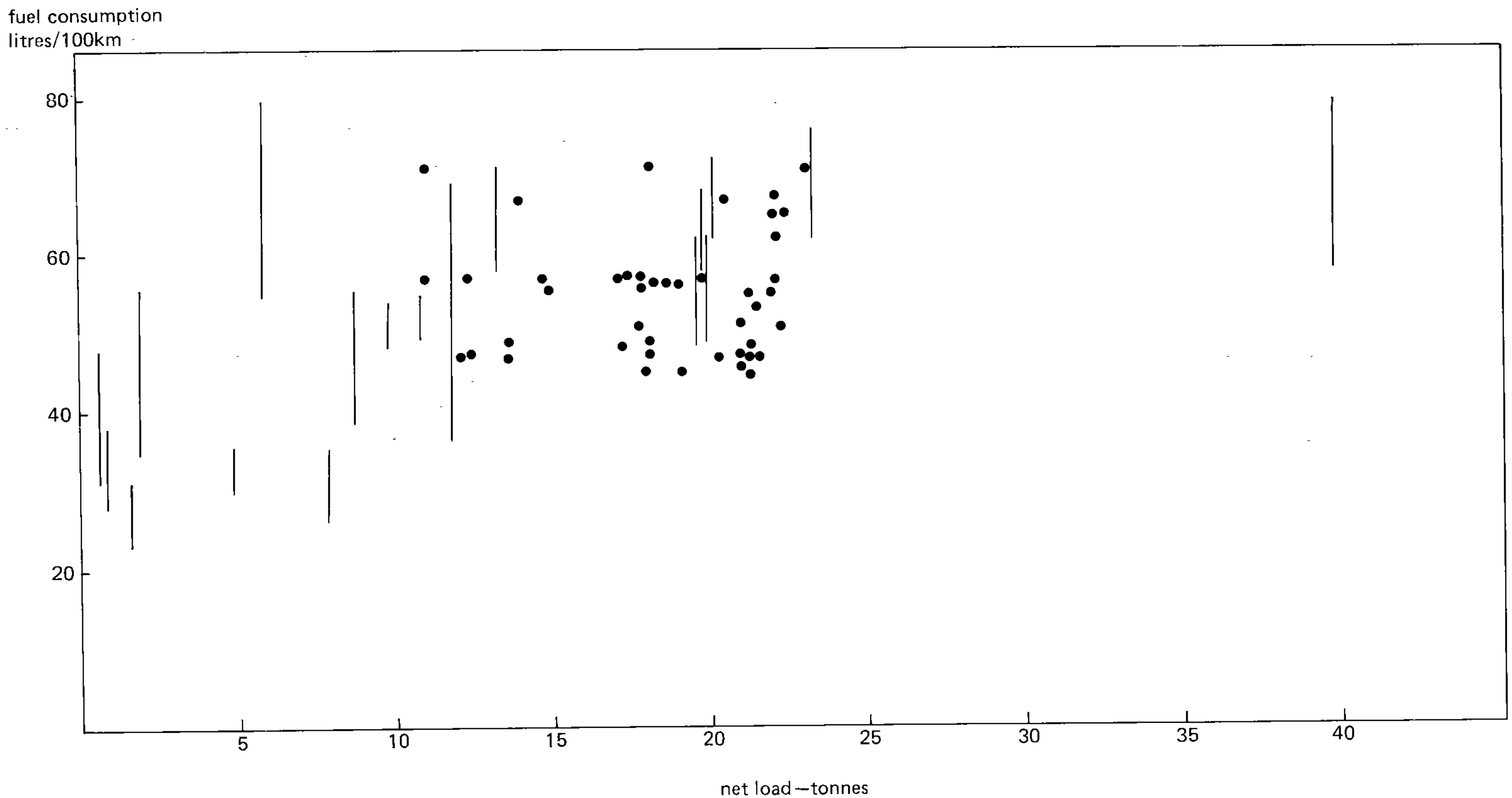
FIGURE I.1
ENERGY EFFICIENCY CURVES FOR THREE ALTERNATIVE FUEL CONSUMPTION CHARACTERISTICS

Road Data

The data obtained from the road sector suggest that the actual fuel consumption of trucks does not vary appreciably with load, and the efficiency would therefore be of the second type described at the beginning of this appendix. This is a rather surprising result, since it would be intuitively expected that less fuel would be required to drive a lightly loaded truck than one which is fully loaded, and the observation requires closer examination. Not all returns provided separate fuel consumption data for forward and return journeys with different loadings. Of those that did, however, fourteen quoted identical fuel consumption in both directions. The loads carried in opposing directions by those fourteen were in an average ratio of 0.68 to 1.0.

Actual fuel consumption data are plotted against load in Figure I.2 and it can be seen from this figure that there is at the most only a very weak relationship between load and fuel consumption.

A possible explanation for the fuel consumption not declining significantly with load is that drivers still continue to use the full performance of the truck, and travel faster in the lightly loaded condition. This theory may be examined by some simple calculations. It is known that the aerodynamic resistance of a truck is proportional to the square of the speed, whereas the rolling resistance is directly proportional to the mass. If it is assumed that under normal full load highway operations the power requirement is split equally between rolling resistance and aerodynamic drag then the fractions of full load power at different loads and speeds are as shown in Table I.1. It will be seen from this that when operating at half load, a 5 per cent increase in speed results in the fuel consumption falling to only 91 per cent of full load fuel consumption, and a 10 per cent increase in speed brings this up to 96 per cent. The figures support the theory that in practice fuel savings achieveable due to lighter loadings are offset by quite modest increases in speed.



● Average value specified

| Range of values specified

FIGURE I.2
TRUCK FUEL CONSUMPTION

TABLE I.1 - VARIATION OF TRUCK FUEL CONSUMPTION WITH LOAD AND SPEED (per cent of full load fuel consumption)

SPEED	LOAD		
	Full	Half	Quarter
Normal	100	86	68
Normal + 5%	-	91	73
Normal + 10%	-	96	78

Rail Data

Victoria

Victorian Railways have undertaken a series of tests on the Melbourne to Albury standard gauge line during which measurements were taken of the fuel used on each freight train trip during a period of six weeks in 1980. Since only two types of locomotive are used for this traffic, and it was found that there was considerable variation in the gross trailing load of trains during the tests, the results provide an indication of the way in which railway fuel consumption characteristics vary with load, and a regression analysis was undertaken. The data are separated into four sets, for X Class and C Class locomotives, each for up and down directions(1). These data are shown in Figures I.3-I.6 and the corresponding regression curves obtained are:

C Class	up	$y = 5.875\ x^{0.499}$
	down	$y = 4.944\ x^{0.374}$
X Class	up	$y = 5.307\ x^{0.559}$
	down	$y = 5.232\ x^{0.575}$

where x is expressed in thousands of tonnes of gross trailing load.

(1) Here, and elsewhere, the convention is followed that the up direction is towards the State capital city.

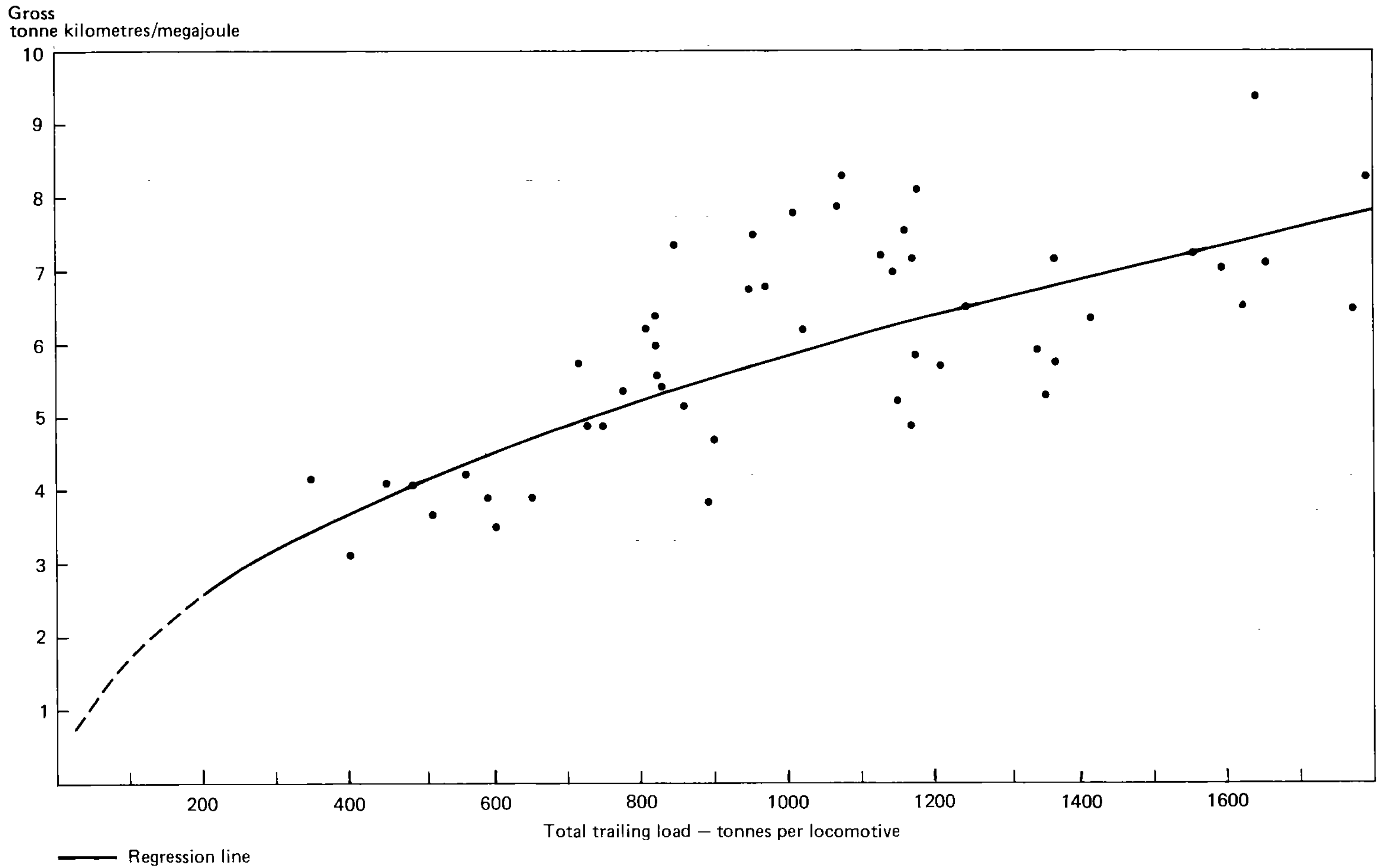


FIGURE I.3
RAIL FREIGHT ENERGY EFFICIENCY ON THE MELBOURNE-ALBURY LINE
C Class locomotive, up direction

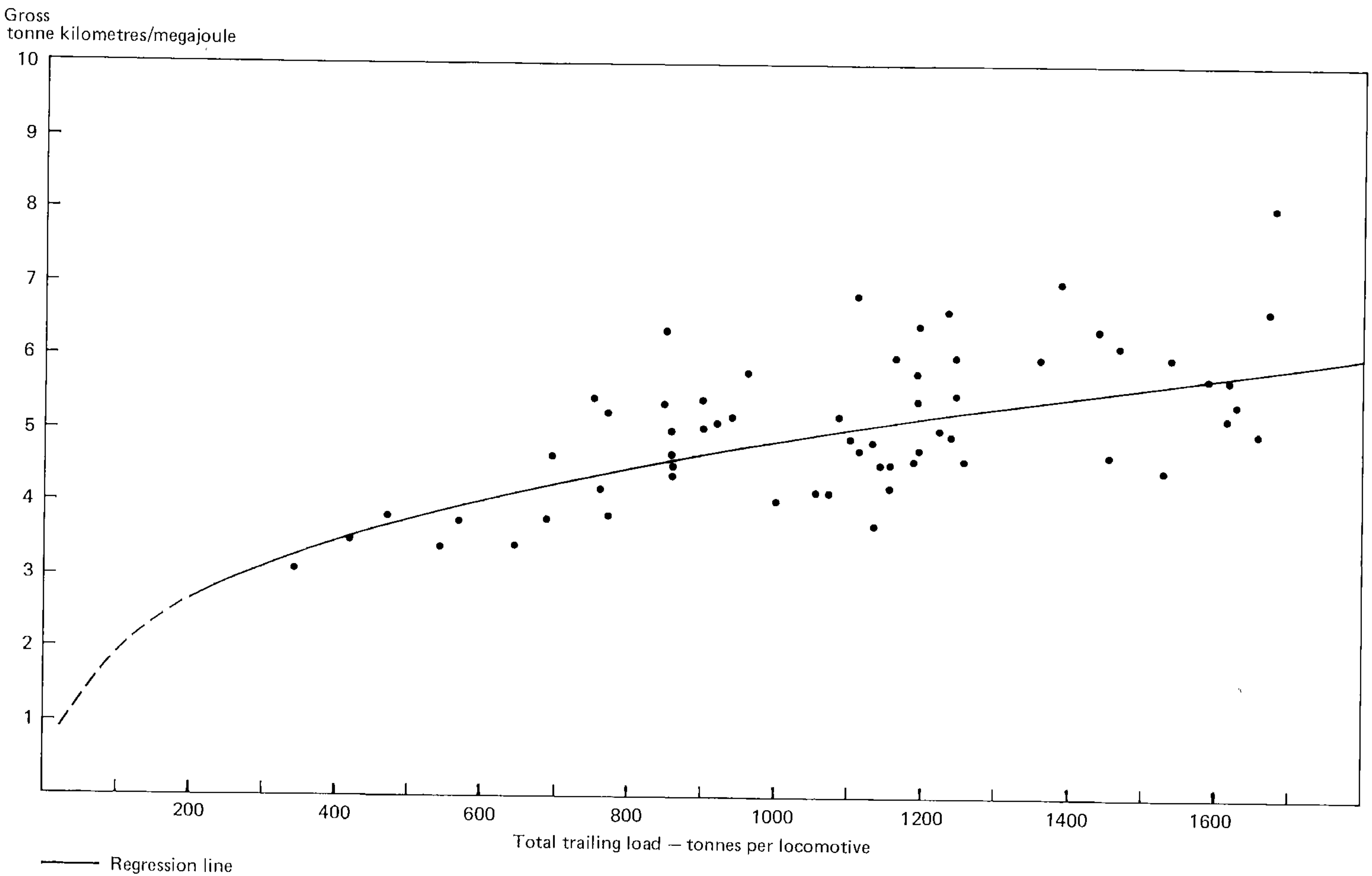


FIGURE I.4
RAIL-FREIGHT ENERGY EFFICIENCY ON THE MELBOURNE-ALBURY LINE
C Class locomotive, down direction

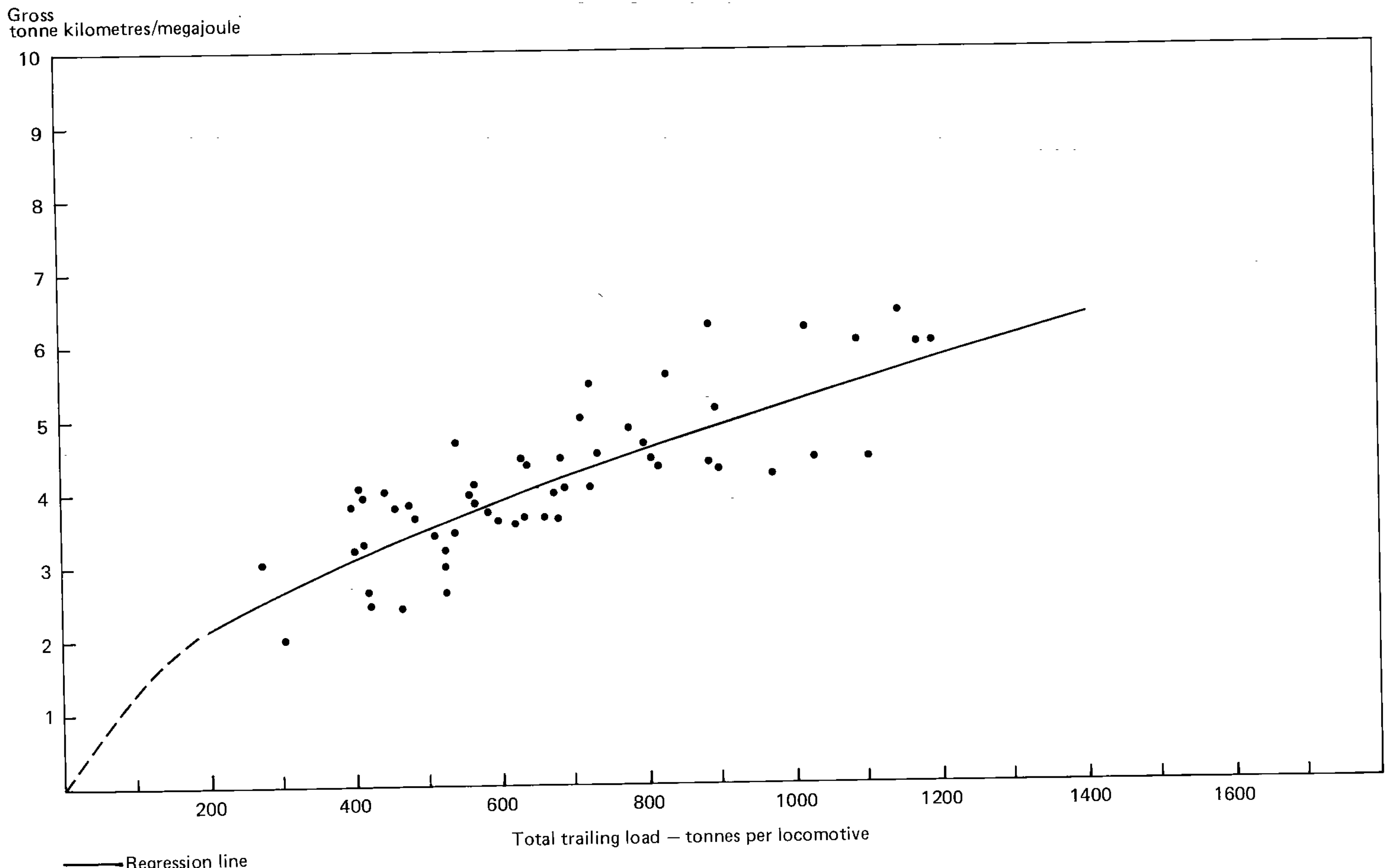


FIGURE I.5
RAIL FREIGHT ENERGY EFFICIENCY ON THE MELBOURNE-ALBURY LINE
X Class locomotive, up direction

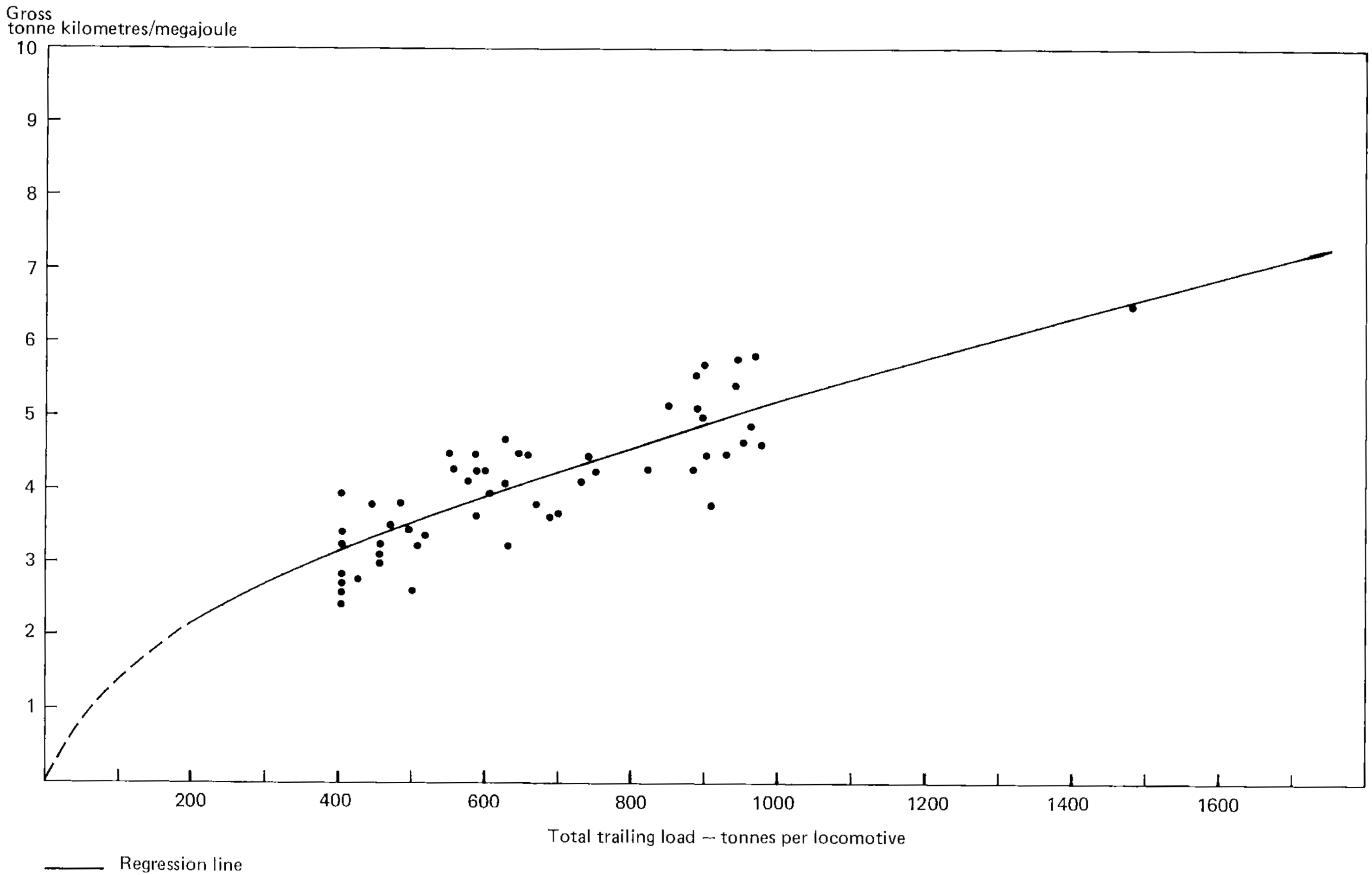


FIGURE I.6
RAIL FREIGHT ENERGY EFFICIENCY ON THE MELBOURNE-ALBURY LINE
X Class locomotive, down direction

These results indicate a systematic difference in the up and down directions which is in keeping with the net change of elevation. There is a net rise of 155 metres over the 317 kilometre distance, so that gravity contributes (or absorbs) 4.83×10^{-3} MJ/gross t-km. This cannot be rigorously compared with the observed variations, since these are also load dependent, but it may be noted that at a load of 1000 tonnes the gradient effect calculated above would account for 30 per cent of the regression curves' variation between up and down directions for the C Class locomotives, and 370 per cent of the corresponding variations for the X Class locomotive.

It will also be seen that the regression curves for the C Class locomotive are more curved than those for the X Class locomotive (ie the exponent of x is smaller) which suggests that the C Class locomotive maintains its efficiency better at part load as well as being more efficient overall. The power unit of the C Class locomotive is essentially a turbocharged version of that installed in the X Class locomotive, and this characteristic could be accounted for if the turbo-turbocharger design was optimised for part load performance. Since this is normally the practice in automotive application where the engine is required to operate over a wide range of power outputs this result is also in keeping with expectations.

The foregoing comments, relating minor differences between the four sets of observations to physical characteristics of the system, involve detail of too fine a nature to incorporate in a general purpose rail characteristics. A simplified equation is therefore used to indicate the likely range of performance obtained, which is of the form:

$$y = A\, x^{0.5}$$

and A is determined for upper and lower limits by matching with the extreme data points. When this is done the results obtained are:

C Class locomotive	upper limit	$y = 7.96\ x^{0.5}$
	lower limit	$y = 3.67\ x^{0.5}$
X Class locomotive	upper limit	$y = 6.25\ x^{0.5}$
	lower limit	$y = 3.65\ x^{0.5}$

These upper and lower limit curves are shown in Figure I.7 which also shows all the data points. (The lower limit for X and C Class locomotives are indistinguishable and a single curve only is drawn.)

New South Wales

The New South Wales State Rail Authority has provided fuel consumption data estimated by means of computer simulation for the various segments of three main lines - the Main South, North Coast and Western. Thus for each line, which is simulated for operation at the constant ruling gradient load throughout, the segment by segment simulation provides an indication of variability due to terrain. The results obtained are shown in Figure I.8 which is a part tabular, part graphical representation. It will be seen from Figure I.8 that the Main South line in the 'up' direction (towards Sydney) shows the highest values of tonne-kilometres per megajoule and the largest spread, both of which are accentuated by the very high value of 7.55 t-km/MJ for the Moss Vale to Sydney run which is markedly downhill. The high values are also in part attributable to the higher ruling grade load of 1025 tonnes which applies throughout this run. Other lines, simulated for operation mainly at 615 or 600 tonnes, yield noticeably lower values grouped more closely together.

The data for the Western line does not include Sydney-Lithgow which is electrified and therefore cannot be directly compared, and the Parkes-Broken Hill data are treated separately on account of the much higher trailing load which is run on this line. It should be noted that in calculating the mean and standard deviation values for the performance along the various sectors of the line no weighting was attached to individual values to compensate for varying distance run in each sector, since the purpose was to obtain an indication of variability according to terrain type. Thus the mean values are not a rigorous determination of the overall performance from end to end of the line, although in fact they are very close to the overall average. In Figure I.9 the values from Figure I.8 are plotted against total trailing load with the envelope curves for Victorian Railways data shown for comparison. It will be seen that the average values for each of the three train loads simulated lie very close to the lower limit curve for Victorian Railways data.

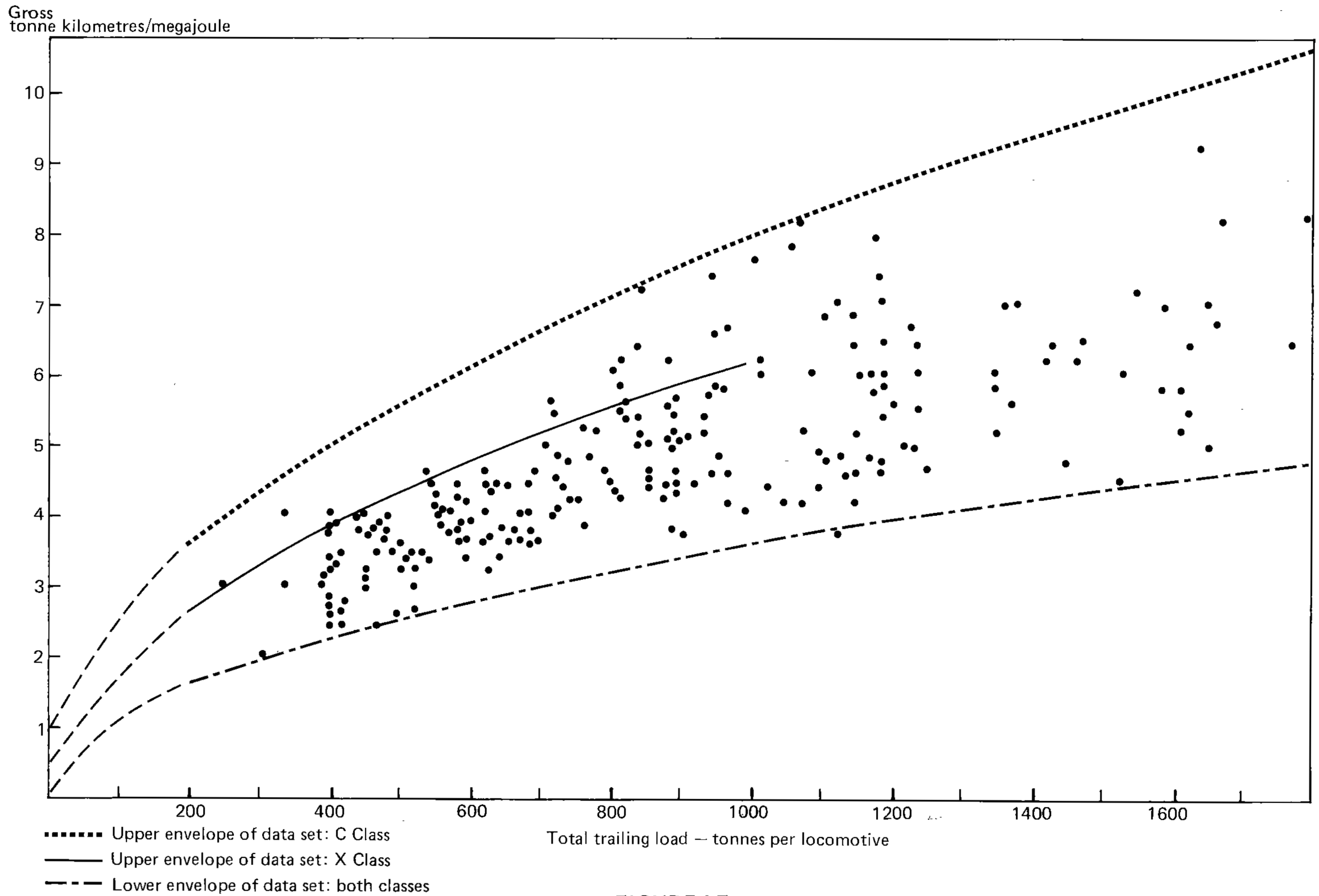
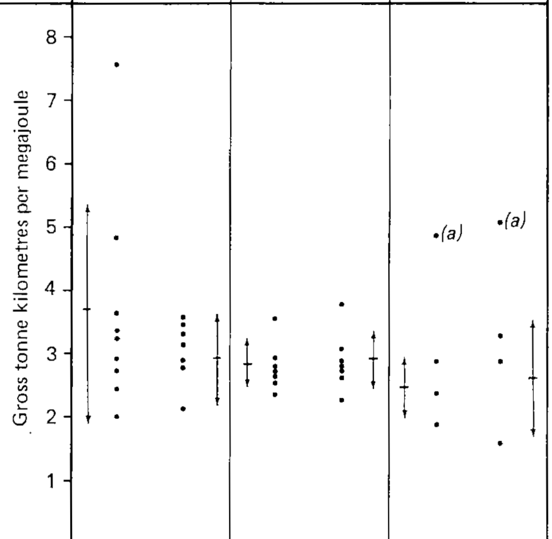


FIGURE I.7
RAIL FREIGHT ENERGY EFFICIENCY ON THE MELBOURNE-ALBURY LINE
Both classes locomotive, both directions

LINE	MAIN SOUTH		NORTH COAST		WESTERN	
DIRECTION	UP	DOWN	UP	DOWN	UP	DOWN
GROSS TONNES	1025	615	615	615	600	600



MEAN	3.61	2.83	2.78	2.84	2.37	2.54
STANDARD DEVIATION	1.68	0.75	0.37	0.47	0.51	0.89

• Simulated performance on one sector of line

↕ Mean & standard deviation

NOTE: (a) Parkes to Broken Hill, trailing 1600 tonnes not included in average for Western Line.

FIGURE I.8
RAIL FREIGHT ENERGY EFFICIENCY—COMPUTER SIMULATED RESULTS ON NSW MAIN LINES

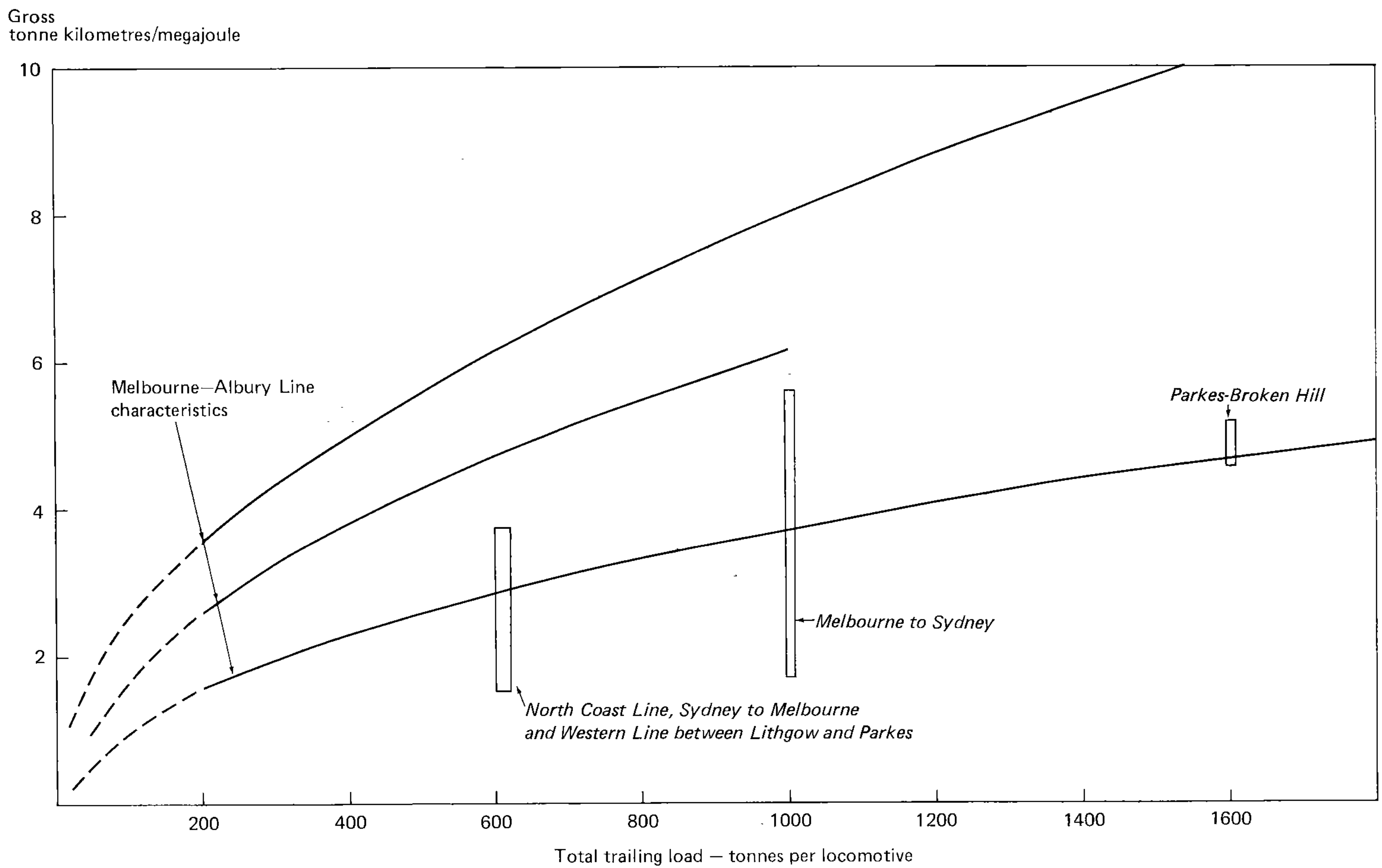


FIGURE I.9
RAIL FREIGHT ENERGY EFFICIENCY ON N.S.W. MAIN LINES COMPARED WITH MELBOURNE-ALBURY LINE CHARACTERISTICS

Queensland

Data provided by Queensland Railways related to two lines -Brisbane to Toowoomba and Brisbane to Rockhampton - and had been obtained for internal purposes in two short surveys in 1979 and 1980. These surveys were less detailed than the Victorian Railways survey of the Albury-Melbourne line, and consequently the reliability of the data is less certain (for example, no details on fuel recording procedure are known). Nevertheless, with data recorded for 18 trains in each direction on each line, a sufficient body of data was obtained to give a good indication of the characteristics. The data are shown in Figure I.10, and the following features are noted:

- points representing trains running from Brisbane to Toowoomba are strongly clustered around 600 tonnes trailing load and 2.4 t-km/MJ;

- points representing the return journey are very much more widely scattered, ranging from 1.6 to 8.6 t-km/MJ: the reasons for this much greater variability are not known, but it is suspected the more extreme points, particularly the lowest, may be spurious;

- data points for the Brisbane-Rockhampton line are generally grouped in the range 3.5 to 5 t-km/MJ at about 750 tonnes with some outlying points and show much less variation between opposing directions than the Brisbane-Toowoomba line: this is to be expected because of the different gradient characteristics of the two lines.

In Figure I.10, the envelope curves obtained for the Victorian Railways data are shown superimposed onto the Queensland data points, and it will be seen that whilst the top boundary appears reasonably consistent with the Queensland data, the cluster of data points representing trains running from Brisbane to Toowoomba fall below the lower boundary. This is consistent with expectations based on the much more rugged terrain and net change of altitude experienced on the Brisbane-Toowoomba run, and is also comparable with the NSW simulated results for basically similar terrain.

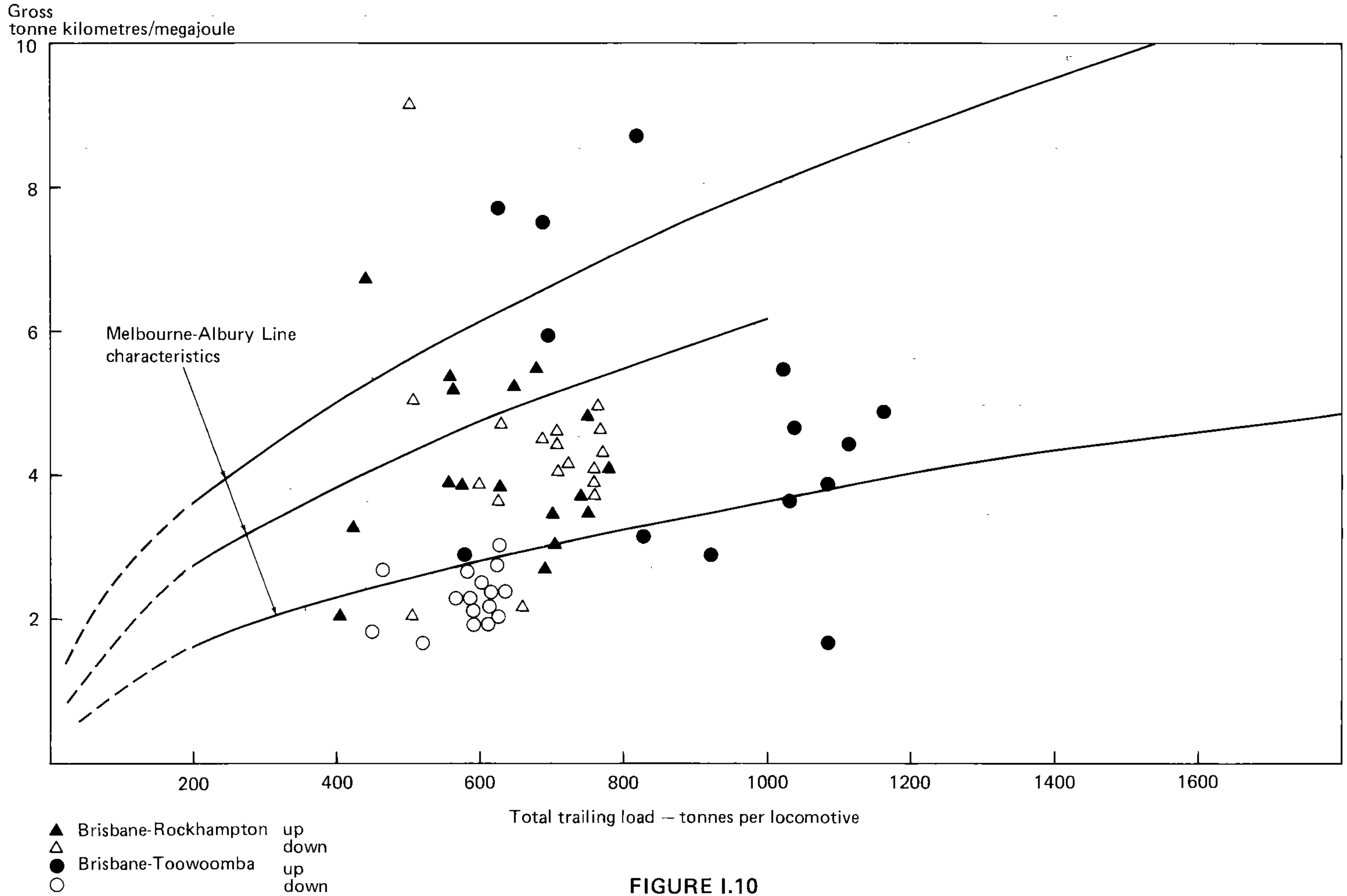


FIGURE I.10
RAIL FREIGHT ENERGY EFFICIENCY ON QUEENSLAND MAIN LINES COMPARED WITH MELBOURNE-ALBURY LINE CHARACTERISTICS

Western Australia

Westrail provided information extracted from an earlier study which analysed in some detail the fuel usage on the Kalgoorlie-Perth section of Westrail's network. In this instance the gross tonnage figures are not provided since the results are based on actual freight movements, and actual fuel consumptions and payload capacity of trains. Since there is a substantial imbalance between eastbound and westbound traffic, the train movements were calculated by dividing the westbound tonnage by the payload capacity of an average train, and then assuming that for each Kalgoorlie-Perth trip there is one return trip. The number of trips is required to estimate the amount of shunting fuel consumption to be allocated per tonne-kilometre. The relevant information is tabulated in Table I.2 from which it will be seen that the average performance on this line is 6.0 t-km/MJ for single header trains and 5.0 t-km/MJ for double header trains.

TABLE I.2 - SHUNTING AND LINEHAUL FUEL USE IN WESTERN AUSTRALIA

Shunting		
Intersystem freight: received (westbound), tonnes	868 000	
: forwarded (eastbound), tonnes	257 000	
Distance one way, km	661.5	
Total output, t-km	744×10^6	
Shunting fuel: total, litres	510 941	
: per net tonne of freight, litres	0.454	
: per net tonne of freight, MJ	17.4	
Linehaul	Single header	Double header
Payload of westbound trains, tonnes	1 129	1 670
Round trip fuel consumption, litres	4 176	7 430
Output per round trip, t-km	968×10^3	$1\ 432 \times 10^3$
Net linehual energy efficiency: t-km/L	232	193
: t-km/MJ	6.0	5.0

The data in Table I.2 is based on the round trip performance. In order to compare the results on this line with the other rail data it is necessary to estimate the performance in the eastbound and westbound directions separately. For this purpose it is assumed that the relationship between fuel consumption and load is of a form consistent with the curves of Figure 3.3. Using this assumption and the data of Table I.2, estimates for the separate trips can be calculated based on balanced wagon flows. These are shown in Table I.3.

TABLE I.3 - ESTIMATED WESTBOUND AND EASTBOUND FUEL CONSUMPTION BETWEEN PERTH AND KALGOORLIE

Route	Single header	Double header
Westbound		
Net tonnes	1 129	1 670
Assumed gross/net	1.4	1.4
Tare	452	668
Fuel used (litres)	2 450	4 360
Net t-km/MJ	7.94	6.60
Eastbound		
Net tonnes	334	494
Gross tonnes	786	1 162
Gross/net	2.35	2.35
Fuel used (litres)	1 726	3 070
Net t-km/MJ	3.33	2.77

Australian National Railways

Australian National Railways supplied data relating to the movement of freight trains from Adelaide via the Port Pirie bogie exchange and Port Augusta to the Parkeston depot at Kalgoorlie and the results are shown in Table I.3. It should be noted that fuel consumption data are obtained from two different sources (specific train tests and cumulative average for locomotive type). Gross and net loads used to calculate the final performance figures are obtained from observations during fuel consumption tests only (for gross tonnes), and average gross to net ratios for the line. There is therefore a degree of uncertainty as to how accurately the fuel consumption and net tonnage figures correspond.

TABLE I.4 - FUEL CONSUMPTION OF FREIGHT TRAINS ADELAIDE-KALGOORLIE

Source of data	Route	Litres per net tonne	net t-km/MJ
Sample train tests	Westbound Eastbound	14.67 32.75	3.54 1.59
Average for loco class	Westbound Eastbound	17.40 29.10	2.98 1.78

APPENDIX II

ROAD TRANSPORT QUESTIONNAIRE

BUREAU OF TRANSPORT ECONOMICS

FREIGHT TRANSPORT ENERGY USE

SURVEY OF ROAD SECTOR

(CONFIDENTIAL TO THE BTE)

Please complete this questionnaire and return as soon as possible to

Bureau of Transport Economics
Freight Transport Energy Study
Planning and Technology Branch
PO Box 367
CANBERRA CITY 2601

For enquiries please contact

Roger Quarterman 062/46 9873

Notes

1 This questionnaire is divided into two parts : Part A is intended to provide a general description of the type of operation; Part B is for the provision of fuel use and freight movement data for the specific routes being studied.

2 Information has been requested in a form which it is believed most operators will be readily able to provide. If, however, you have data relating to your fuel consumption and freight movement which does not fit the form of Part B you are invited to forward that data. We will examine it and contact you only if we need further information to be able to use the data.

3 Any supplementary or explanatory comments which you may wish to make will be much appreciated.

4 The study is concerned with all types of general freight including bulk liquids and solids, but specifically excludes express parcels services, livestock transport and abnormal loads.

C O N F I D E N T I A L

PART A

1 Please complete your company name, and the name, address and telephone number of a person in your company who can be contacted if further information is required

Company --

Contact --

Phone : STD Code ----------------- Local Exchange No -----------------

2 How many linehaul vehicles do you have in your fleet in each of the following categories

a) Prime movers for semitrailer operation --------

b) Cargo units

	Rigid trucks	Semi trailers
Insulated or refrigerated van	--------	--------
Pantechnicon	--------	--------
Other van	--------	--------
Liquid tanker	--------	--------
Dry bulk hopper	--------	--------
Tippers/bottom dumpers	--------	--------
Flat top	--------	--------
Other open truck	--------	--------
Other (please specify)	--------	--------
------------------------------	--------	--------
------------------------------	--------	--------

3 Which of the following descriptions most nearly fits your type of operation. (Usually = more than half of your net tonne kilometres)

	Usually	Sometimes
i) Depot to depot linehaul carrying a consolidated load which is distributed/collected at each end by other vehicles	--------	--------
ii) Collection from and/or distribution to several clients using the linehaul vehicle for collection/delivery	--------	--------
iii) Unit load collected from a single consignor and delivered to a single consignee	--------	--------
iv) Other (please specify)	--------	--------

4 Which of the following most nearly describes your usual fuelling procedure

i) Refuel vehicles from commercial bowsers on an as required basis --------

ii) Refuel vehicles from small number of contract suppliers --------

iii) Refuel vehicles from your own bowser(s) --------

5 Which of the following items of information do you normally record <u>for each vehicle type</u>

i) Fleet average fuel consumption --------

ii) Fuel consumption for each individual vehicle --------

iii) Average fuel consumption on each of your main routes --------

iv) Fuel consumption for each particular journey --------

Do you maintain any other statistical records of fuel consumption relating specifically to particular vehicle type or particular route? If so please describe the records you keep.

6 For each journey, do you record information which accurately determines the mass of the cargo (this could be either a weighbridge certificate or a precise description such as '100 bags of cement')

i) Always --------

ii) Only when load is expected to be near maximum permitted --------

iii) Not normally --------

7 If the answer to Question 6 is (ii) or (iii) is this because

i) the driver is responsible for loading, and is only required to be satisfied that the vehicle is not overloaded --------

OR

ii) the type of freight carried is known to be limited by cube, not by mass, and the mass carried is therefore of no concern --------

If other reason, please give details

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PART B

This part contains several identical data sheets.

Each sheet is intended to be used for one vehicle type, but allows for the recording of information for several different routes.

The routes on which data are sought are listed below. Please indicate by ticking the appropriate space which routes you operate, and whether the scale of your operations is small, medium or large. For this purpose take small to mean less than 100 tonnes per week, medium 100-250 tonnes per week and large over 250 tonnes per week. Count tonnages as the total moved in both directions between the city pairs.

	Small	Medium	Large
Sydney-Melbourne	-------	--------	--------
Sydney-Brisbane	-------	--------	--------
Sydney-Newcastle	-------	--------	--------
Sydney-Canberra	-------	--------	--------
Sydney-Orange	-------	--------	--------

Please use these sheets to provide information on the main vehicle types which you use, for all of the listed routes over which you operate regularly.

Please take the terms forward loading and return loading in the sense implied on the data sheet irrespective of the location of your depot of office.

You are invited to provide data for any convenient period which suits your record keeping (eg monthly average for 1979, a particular sample month/week etc). However please state exactly what basis you are using in the space marked 'Sample period' on the data sheet.

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DATA SHEET

Vehicle Type : Make/model:
Engine make/capacity:
Fuel: Petrol/diesel (2)
Is the engine turbo charged? Yes/No (2)
Rigid/Prime mover and semitrailer (2)
Body Type:
Total number of axles on rig:
Tyres: radial/crossply (2)
Tare mass:
Gross vehicle/combination mass:
Is the vehicle fitted with any special fuel economy accessories? Please specify

Sample period :

Route: Round trip between Sydney and:		MELB	BRIS	NEWC	CANB	ORANGE
Round trip distance (km)						
Number of trips on which data is based						
Freight carried (1)						
Forward loading :	Total tonne - km along corridor					
	% capacity (3)					
Return loading :	Total tonne - km along corridor					
	% capacity					
Fuel used (1)						
Forward loading :	Total litres					
	L/100km - worst					
	- average					
	- best					
Return loading :	Total litres					
	L/100km - worst					
	- average					
	- best					

NOTES

(1) If separate data for forward loading and return loading are not available, please provide round trip data.
(2) Delete whichever is inapplicable.
(3) Physical capacity. Thus if you are carrying a light weight cargo which fully utilises the available space in your vehicle, record 100% even though the maximum permitted mass has not been reached. Estimate percentages as best you can.

REFERENCES

Australian Bureau of Statistics 1978. *Survey of Motor Vehicle Usage Twelve Months Ended 30 September 1976.*

Australian Institute of Petroleum 1979. *Oil and Australia the Figures behind the facts.*

Barnes, R.S. 1976. *The Energy Involved in Producing Engineering Materials.* I.Mech.E. Proc., 190.

Bureau of Transport Economics 1977. *Australian Sea Freight Movements 1975-76.* AGPS.

Bureau of Transport Economics 1978. *Estimates of Interregional Freight Movements 1975-76.* AGPS.

Bureau of Transport Economics 1979. *Australian Rail Freight Movements 1975-76.* AGPS.

Department of National Development and Energy 1979. *End Use Analysis of Primary Fuels Demand Australia 1973-74 to 1986-87.* AGPS.

Foley, G. 1973. *Long Range Planning and the Energy Crisis.* Railway Gazette International, Dec.

Hirst, E. *Energy Intensiveness of Passenger and Freight Transport Modes, 1950-1970.*

Lawlor, L.C. and Brown, M.A. 1980. *Consumption of Transport Energy in Australia 1975-76.* AGPS.

Lukasiewicz, J. 1975. *Energy and Transportation in Canada and the United States.* High Speed Ground Transportation Journal, 9, 3.

McDonell, G. 1980. *Report of the Commission of Enquiry into the NSW Road Freight Industry.*

Quinlan, H.G. 1978. *The Current Domestic Freight Situation.* Paper from the Workshop on the Future of Domestic Freight in Australia, AGPS.

Railways of Australia 1980. *Saving Liquid Fuels During a National Emergency by Diversion of Freight from Road to Rail Transport Part 1.*