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THE ROLE OF RAIL IN ENERGY CONSERVATION: FINDINGS OF RECENT ARRDO STUDIES

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ABSTRACT: *This paper summarises the most pertinent findings of the ARRDO study on "Energy and the Railways".*

A major objective of the study was to carry out empirical measurements of fuel consumption for diesel hauled freight and passenger trains and to develop techniques for predicting fuel consumption on the basis of these measurements. Findings arising from investigations on two techniques, namely computer-based train simulation and multiple regression, are presented in the paper.

The total energy used by Australian government railway systems is analysed by category of service i.e. non-urban freight, urban passenger and non-urban passenger, and the scope for energy savings in rail operations is discussed.

Finally the energy intensiveness of rail is compared to that of other modes on both an average basis for the different categories of service and for traffic tasks on specific routes.

INTRODUCTION

Large real liquid fuel price increases in recent years have stimulated a growing national interest in energy conservation and increasing government concern about possible interruptions to liquid fuel supplies. In recognition of the national relevance of these energy issues and their importance to railway planning, a project on energy and railways was included in ARRDO's 1980/81 Work program.

The study had the following objectives:

- to carry out measurements of rail fuel consumption and use these to develop models which can be used to estimate fuel consumption for specific tasks.
- to investigate energy consumption by Australian railways and assess the scope for reducing fuel consumption.
- to report on the comparative fuel efficiencies of rail and competing transport modes.
- to investigate the significance of future energy price and demand scenarios and possible fuel supply emergencies for the role of railways.
- to review the current state-of-the-art with respect to various alternative energy sources for rail motive power.

This paper describes the approach and major findings of the study with respect to the first three of these objectives. A detailed discussion of findings, including some pertinent to areas not covered in this paper, are contained in various ARRDO working papers (ARRDO 1981 a-c).

APPROACH

Since the study was of only one year duration, it was decided at the outset to carry out primary data collection for the rail mode only and to evaluate the findings of published and other on-going and yet unpublished research on fuel consumption for the other modes.

The results of two other studies on comparative fuel consumption by mode, became available during the period of the project (Lawlor and Brown, 1980 and Quarterman, 1981). These results supplemented with data obtained directly from some transport companies and the findings of some earlier Australian and overseas studies, provided a sound basis for inter-modal comparisons.

FUEL MEASUREMENTS

To develop a technique that can be used by railways to estimate diesel fuel use for specific transport tasks, it was necessary to conduct a series of controlled fuel consumption measurements.

Of major importance in the selection of a method for measuring fuel consumption was the need to be able to relate fuel consumption to various causal factors such as grade and speed. This was achieved by inserting flow meters into the engine's fuel intake and outflow lines which enabled the fuel consumed by the locomotive in carrying out various tasks to be continuously monitored. A micro-electronic interface and a digital recorder were used to produce a continuous record of fuel consumed against time and locomotive performance features including speed, throttle setting and dynamic braking.

The equipment was developed and tested by Queensland Railways and measurements were carried out using a recently commissioned General Motors 12 cylinder, 1230 kilowatt (class 2470) locomotive operating on the Brisbane - Toowoomba and Brisbane - Rockhampton lines. The tests were conducted for the locomotive hauling various train types, namely express freight, local freight and passenger.

Whereas this approach has involved a considerable amount of equipment development and the outputs required substantial data processing, it has enabled development of predictive tools that relate fuel consumption to the main causal factors.

MODELLING RAILWAY DIESEL FUEL CONSUMPTION

The data from the fuel consumption measurements were used in two ways. First they were used to assess the accuracy of computer train simulation techniques for predicting fuel consumption. Secondly since computer simulation can be time consuming and a simpler predictive technique is often needed, the data were also used to develop multiple-regression equations based on readily measurable variables.

MTRAIN Simulations

MTRAIN is a train operations simulation program which has been developed to its current format by the State Rail Authority of New South Wales. Train tasks and operating parameters similar to those observed during the field tests of diesel fuel consumption, were simulated to assess whether or not the program could be used for accurately estimating fuel consumption. The simulation thus took account of the way the train was driven on the particular trips studied.

The accuracy of the estimates of fuel consumption produced by the program was found to depend largely on the rolling resistance equation used. Recent research (FRA, 1978) has shown that, while the general form of the rolling resistance equation originally developed by Davis in 1926 is still valid, more recently developed methods for calculating the coefficients may provide better estimates of the resistance.[(1)]

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1. The Davis equation which is an empirical modification of classical formulations has the general form:
Rolling Resistance = $A + BV + CV^2$, where V = train speed and A, B and C are coefficients obtained from empirically derived formulae.

   A is primarily associated with journal resistance, wheel and track deflection and surface deformation, B with flange friction, wave action in the rails, spring hysteresis and damping on vehicles, and C with head or end wind pressure, skin friction along the train and drag behind the trailing vehicle.

For freight trains MTRAIN was run using four different sets of rolling resistance coefficients as follows:

- the original Davis equation (Davis 1926).
- the Davis equation with coefficients recommended in the MTRAIN program manual (ie. the program default coefficients).
- the Davis equation using Tuthill's modified coefficients (FRA 1978).
- the Davis equation using 'Canadian National' modified coefficients (FRA 1978).

The first three equations substantially overestimated the fuel required but the fourth (the Canadian National) equation predicted overall fuel consumption to within 2.5%, which is within the experimental margin of error.

MTRAIN was also used to simulate passenger running in both directions between Brisbane and Gympie. Two rolling resistance equations were tested namely:

- The Davis equation with the default coefficients used in the MTRAIN program.
- The Davis equation with Totten's modified coefficients for non-streamlined passenger trains (FRA, 1978).

The Totten equation came within 2% of predicting the actual overall fuel consumed in each direction, whereas the unmodified Davis equation underestimated by between 9% and 12%. The Totten equation came within 10% of the actual fuel consumption on all but three of the 17 line sections simulated and never deviated by more than 12%.

Using MTRAIN for fuel prediction

The research demonstrated that provided appropriate modified rolling resistance coefficients are substituted into the Davis equation and provided various adjustments are made as discussed below, MTRAIN can accurately simulate fuel consumption. The following rolling resistance equations gave the best results:

For freight trains: 'Canadian National' equation

$$R = 0.27 + 9.07 \frac{n}{w} + 0.003\, v + 0.012 \frac{v^{2}}{w} \qquad (1)$$

For passenger trains: 'Totten' equation

$$R = 0.58 + 13.15 \frac{n}{w} + 0.0125\, v + (0.0005 + 0.019\,(L/30)^{0.7})\, v^{2} \qquad (2)$$

where
- R is rolling resistance in kg/tonne.
- n is number of axles per wagon or carriage.
- w is average axle load in tonnes.
- L is average length of carriage in metres.
- v is train speed in km/hour.

These equations are discussed in more detail elsewhere (ARRDO, 1981a). The present version of MTRAIN could be enhanced for purposes of predicting fuel consumption by incorporating the following changes to the program:

- Modification of default rolling resistance coefficients in conformity with the above findings.
- Calculation of fuel consumed during dynamic braking; this would be a simple modification, and is necessary for accurate fuel estimation.
- Provision for specifying fuel consumed during idle and low idle, which at present is assumed in the program to be identical to fuel consumed by auxiliaries during line running. In practice the absence of this provision results in a small over-estimation of fuel consumption, especially for local goods trains, unless manually adjusted.
- Provision to allow various specific fuel consumption rates to be input for different throttle settings, as distinct from a single rate for all settings as at present. This could produce slightly more accurate results.

Until such time as the program is modified, users are urged to adjust for these effects manually. In particular it is recommended that users substitute the modified rolling resistence coefficients in place of the default coefficients, as indicated.

Regression Equations

In addition to the MTRAIN simulation, regression equations were derived from the data for freight and for passenger trains hauled by the 2470 class locomotive, as follows:

Freight equation:

$$\text{Fuel}/1000\text{GTK} = -16.05 + 0.73\ r - 0.27\ f + 156.8/s + 61/L^{0.2} \tag{3}$$

$(R^2 = 0.89,\ n=119)$

Passenger equation:

$$\text{Fuel}/1000\text{GTK} = 0.83 + 0.94\ \text{Rise} - 0.24\ \text{Fall} + \frac{112.7}{\text{Speed}} \tag{4}$$

$(R^2 = 0.82,\ n=81)$

Where fuel is measured in litres

GTK	is	gross tonne km (including weight of loco)
r	is	summation of all vertical rises expressed in metres/kilometre for the route.
f	is	Summation of all vertical falls for the route (m/km).
s	is	average speed for the trip excluding stop time. (km/hr).
L	is	gross train load, including locomotive weight (tonnes).
n	is	number of observations.
R^2	is	co-efficient of determination.

These equations, being based on a set of data points which included a range of speeds and gradients, can be expected to give fairly reliable estimates for fuel consumption of locomotives similar to the 2470 class, on most rail lines under normal operating conditions. However it would be desirable to conduct further tests to confirm this. Where lines include lengthy sections (say 10kms or more) with the majority of grades steeper than 1 in 80, the findings suggest that

better results are obtained if independent estimates are made for these sections based on fuel consumption at maximum throttle for the expected travel time in the section[1].

Validation of Regression Equations and Application to Other Similar Locomotives.

The reliability of the freight train regression equation was tested by using it to predict total fuel consumption for two additional trips by the same 2470 class locomotive. The equations were accurate to within 2.5% for each of these trips.

A further validation of both freight and passenger equations was carried out by reference to a VicRail study of fuel consumption (VicRail 1980). The VicRail study included fuel consumption measurements for X Class locomotives operating on the Melbourne-Albury standard gauge line.

The X Class locomotive has a different power rating to the 2470 Class[2] (1650 kilowatts traction power for the X compared to 1230 kilowatts for the 2470) but has similar specific fuel consumption characteristics (expressed in litres/kilowatt-hour). An 'equivalent speed' concept enables an assessment of how well the equations for the 2470 can estimate the fuel used by the X Class locomotives.

To a sufficient level of accuracy for our purposes it can be assumed that fuel consumption is directly proportional to the tractive effort required. Locomotives with different power ratings typically have different tractive effort versus speed characteristics and therefore in carrying out the same task, (i.e. averaging the same tractive effort), would operate at different speeds. The average operating speed for the X Class locomotives in the course of the VicRail fuel consumption tests was known and to carry out the validation the equivalent speed at which the 2470 Class would do the equivalent amount of work was determined and inserted into the regression equation. Allowance was made for the fact that rolling resistance varies with train speed.[3]

Using this procedure the regression equations were able to replicate the average fueld consumption of X Class locomotives to within 5% for freight trains and to within 7% for non-urban passenger trains.

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1. The relationship between fuel consumption and vertical rise is not exactly linear and on lengthy sections of steep rising grades the regression equations tend to underestimate fuel consumption.
2. The VicRail X class has the same General Motors 645E diesel engine as does the 2470 class but has 16 cylinders whereas the 2470 has 12.
3. Because rolling resistance decreases as speed reduces and thus more power is available for accelerating the train, a 2470 locomotive would actually be able to operate at a slightly higher speed than that indicated by the available tractive effort.

ENERGY USED BY RAILWAYS

Total Energy Used by Rail Systems

Australian railways (government and private) use 5% of the total primary energy consumed for domestic transport to carry out 29% of the domestic freight task (in net tonne kilometres) and 4% of the domestic passenger task (in passenger kilometres). (Lawlor and Brown, 1980)

In 1979/80 trains on government railways consumed 640 megalitres of distillate and approximately 475 x 10^6 kilowatt-hours of traction electricity, representing a total energy consumption equivalent to 795 megalitres of distillate.[1] Of the five main government railways, the highest consumers were the State Rail Authority (SRA) of NSW which used 40% of primary energy and Queensland Railways (QR) which used 22%. VicRail, Australian National (AN), and Westrail (WR) respectively used 17%, 12.5% and 7.7% (See Table 1).

Total rail energy consumption has increased only slowly in recent years (approx 3% per annum between 1975/76 and 1980).

Energy Use by Category of Service

Rail freight transport uses slightly more than 75% of total rail line running energy. The energy used for freight is comprised of approximately 570 megalitres of diesel fuel and electricity equivalent to 31.5 megalitres of diesel.

Urban passenger services use approximately 18% of total line running energy, comprising 20 megalitres of diesel fuel and electricity equivalent to 122 megalitres. Non-urban passenger services are predominantly diesel powered and account for a total of 50 megalitres (equivalent) or 6% of total energy.

The average energy intensiveness of urban passenger services is 0.031 equivalent litres per passenger-kilometre compared with 0.022 litres for non-urban passenger services. SRA urban services are the most energy efficient (0.022 litres per passenger-km) largely due to relatively high occupancies. (table 2). Westrail and QR achieve lower than average energy intensities for non-urban passenger services. Energy intensiveness for freight is 0.016 litres per net tonne-km overall and ranges from 0.012 in Westrail to 0.020 in SRA, which has a relatively high proportion of its traffic task passing over relatively steep grades.

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1. It has been decided to use equivalent litres of distillate as the common unit for energy consumption as it is considered that most readers comprehend such a unit more readily than alternatives. On average the secondary energy content of 1 litre of distillate is 38.4 megajoules or 10.7 kilowatt hours. The primary energy content of a litre of distillate (i.e. including any energy losses incurred in refining) is assumed to be 11% greater than the secondary energy, i.e. 42.6 megajoules per litre (Fryer, 1972). To express electrical energy in equivalent litres it is assumed that only 26% of the primary energy contained in the coal remains after allowing for generation and transmission losses. Thus on the basis of the primary direct energy content of each, 1 kilowatt hour (i.e. 3.6 megajoules) of traction electricity is equivalent to 3.6/(0.26 x 42.6) (i.e. 0.325) litres of distillate.

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TABLE I ENERGY CONSUMED IN LINE RUNNING BY CATEGORY OF SERVICE (1979/80) (EQUIVALENT MEGALITRES) [(a)]

Rail System	Freight		Urban Passenger		Non-Urban Passenger		Total			
	Diesel	Elec[(b)]	Diesel	Elec[(b)]	Diesel	Elec[(b)]	Diesel	Elec[(b)]	All	%
SRA of NSW	196	28	-	69 [(c)]	24	-	220.0	97	317	40.0
VicRail	67	3.5	-	49.5	13	1	80.0	54	134	16.9
Queensland Railways	157	-	9.5	3.5	4.5	-	171.0	3.5	174.5	21.9
Australian National	93	-	-	-	6	-	99.0	-	99	12.5
Westrail	58	-	1.8	-	1.5	-	61.3	-	61.3	7.7
STA [(d)]	-	-	9.2	-	-	-	9.2	-	9.2	1.1
Total	571	31.5	20.5	122	49	1	640.5	154.5	795.0	100.0

Sources: Rail Systems, ARRDO estimates.

Notes:

a. details of how these estimates were obtained, are contained in (ARRDO 1981b). Total distillate used for non-urban freight and passenger operations is divided in proportion to train gross tonne kilometres.

b. For electricity, energy consumption is expressed in terms of equivalent diesel megalitres. It is assumed that 1 kw hour of traction electricity consumed equals .325 litres of distillate. This equivalent makes allowance for generation and transmission efficiency of 26% and for the energy consumed in refining the distillate, which is about 11% of the energy available in the refined product. (see footnote on page 6).

c. Includes interurban to Lithgow and Gosford.

d. STA = the State Transport Authority of South Australia.

TABLE 2 - AVERAGE ENERGY INTENSIVENESS OF VARIOUS TYPES OF RAIL SERVICES BY RAIL SYSTEM [(a)]

Rail System	Passenger Services Equivalent litres of distillate per passenger-km(b)		Non-urban Freight litres of distillate per net tonne-km
	Urban	Non-Urban	
SRA of NSW	.022[(c)]	.023	.020
VicRail	.036	.023	.018
QR	.032	.018	.014
AN	-	.023	.017
Westrail	.025	.016	.012
STA	.053	-	-
Overall	.028	.022	.016

Source: Rail Systems, ARRDO estimates.

Notes:

a. Details of how these estimates were obtained, are contained in (ARRDO 1981b). Total distillate used for non-urban freight and passenger operations is divided in proportion to train gross tonne kilometres.

b. For electricity, energy consumption is expressed in terms of equivalent diesel megalitres. It is assumed that 1 litre of distillate equals 42.6 megajoules of primary energy. (i.e. that 1 kw hour of traction electricity consumed equals 0.325 litres of distillate). This equivalence is based on the assumption of 26% for generation and transmission efficiency of electricity. It is assumed that the energy consumed in refining the distillate, is about 11% of the energy available in the refined product.

c. Includes interurban to Lithgow and Gosford.

SCOPE FOR ENERGY SAVINGS IN RAILWAYS

Many measures have been proposed from time to time for reducing energy consumption in railways and most of these have been appraised and discussed in the project reports (ARRDO, 1981b).

The most relevant of such potential energy saving measures were found, on the basis of theoretical analyses and discussions with rail system managements, to be as follows (roughly in order of assessed importance):

- increased consolidation of loads by increased wagon loadings and train loadings.
- improvements to driver performance on both electric suburban trains and diesel electric locomotives.
- improved techniques for forming and scheduling trains (eg. using computers) to reduce the number of fuel wasting stops at crossing loops and to minimise the number of shunting and marshalling operations.
- improved materials and designs that yield lower gross to net weight ratios.
- selective lowering of speed limits, and
- reduced fuel use during idling and standing.

A number of other measures such as reduction of fuel spillage or greater streamlining of trains were assessed to be of relatively minor importance.

Taken together the above measures could give rise to substantial savings. However adoption of some of the measures could have significant and possibly undesirable implications for various aspects of railway operation. Increased consolidation of loads for example may require a reduction in the frequency of some freight and passenger services which may be unacceptable. Better consolidation (particularly backloading) would also result in longer terminal dwell times of some wagons and may interfere with the placement of rolling stock for alternative traffics or require additional investment in wagons. Selective lowering of speed limits will increase crew costs and possibly increase line congestion. In practice an appropriate trade-off needs to be found between energy saving and these other factors. Industrial issues would probably need to be resolved also.

The scope for savings from modified driver behaviour seems prima facie to be considerable but it would be necessary to conduct practical experiments to verify that such savings are attainable.

The use of light weight materials such as aluminum and fibreglass can substantially reduce fuel requirements and can at the same time reduce maintenance costs. The effect of light weight designs, such as skeletal flat wagons, on overall maintenance costs is not clear. In the case of aluminium the considerable fuel saving needs to be offset against the high electrical energy consumption of producing the metal.

This study has found that there appears to be scope for substantial energy savings within Australian railways. These savings could amount to as much as 10% of consumption or the equivalent of 80 megalitres of distillate per year, but until further studies, which focus on implementation of energy saving measures, are carried out, it will not be clear how readily such savings can be achieved.

RAIL COMPARED TO OTHER MODES

For many transport operations, but not all, our findings indicate that rail is very energy efficient compared to alternative modes.

A rigorous comparison of the energy efficiency of alternative transport modes, needs to examine not only direct energy consumption but also the indirect energy consumed in the construction of infra-structure and rolling stock. There have been no Australian studies of indirect transport energy consumption and therefore only rough estimates can be made based on overseas studies (Fels, 1975). However, such estimates suggest that the relative energy intensiveness of modes is not significantly different from comparisons based on direct energy use.

Urban Passenger

For peak period urban travel, at existing occupancy levels and with existing operating practice , rail is the most fuel efficient mode (see Table 3). Peak urban rail transport is on average eight times less energy intensive than private car. In the major urban areas rail has the additional feature that it utilises electrical energy and thereby enables conservation of scarce oil resources. Almost all suburban services in Sydney and Melbourne are operated with electric trains and the Brisbane network is currently being electrified.

Even for off-peak urban travel, rail, despite its relatively low occupancy level, is more energy efficient overall than any other mode presently operating in Australia.

Urban private motor vehicle trips currently account for 40% of domestic transport energy consumption, being equivalent to 6440 megalitres of distillate per annum[1]. A transfer of 5% of these trips to rail, if it were possible, could save 350 megalitres of motor spirit per annum, which is equivalent to about 40% of the total energy consumed by all government railways, or 2.5% of the energy used for all domestic transport.

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1. Equivalent to approximately 7200 megalitres of motor spirit.

TABLE 3 - DIRECT PRIMARY ENERGY INTENSIVENESS OF URBAN PASSENGER MODES AT EXISTING OCCUPANCIES

Mode	Average Energy Intensiveness[a] (Equivalent Litres of Distillate per Passenger-km)			Vehicle Occupancies		
	Peak	Off-Peak	Overall	Peak %	Off-Peak %	Overall %
Rail (500 seat train)[b]	.013	.045	.028	62 [c]	16	29
Private car (5 seat)	.099	.072	.090	26	30	28
Bus (38 seat)	.027	.108	.054	63	13	26
Tram (50 seat)	.023	.084	.032	60	20	40

Source: ARRDO (1981c), Lawlor and Brown (1980), Lonie (1980), Clark (1975) and Melbourne and Metropolitan Tramways Board estimates.

Notes: a. While the best estimates of average vehicle occupancy available at the time of conducting the study were used, the energy intensiveness estimates are clearly sensitive to the occupancies assumed.

b. Electrified rail services operate in Sydney, Melbourne and Brisbane. The occupancy rate of 62% for peak period trains is based on a global average of 310 passengers per train. Actual train seating capacities vary, the Sydney double deckers having a capacity of 1000 seats in peak periods. (In off-peak periods, reduction of these train consists to 4 car units subsequently halves their total seating capacity).

c. The figures for rail are based on 1979 data from VicRail. The peak is defined at 7am to 9am and 4pm to 6pm and trains in both peak and counter-peak directions were included. Trains running outside these hours are allocated to 'off-peak' even though in some cases there may be repositioning movements before or after the peak period.

Non Urban Passenger

Overall, for non-urban passenger travel at existing occupancy levels, rail transport was found to be more energy efficient than private car, much more energy efficient than air transport , but less energy efficient than buses (See Table 4). However, on services with high occupancy levels, the energy intensiveness of railways can be as good as or better than that of buses. This was found to be so for example in the case of well patronised rail motor services such as the Prospector from Perth to Kalgoorlie, interstate sit-up trains, and peak (eg. Friday night) country train services.

The only situation in which the energy intensiveness of private cars approaches that of rail transport is in relation to overnight rail sleeper services, but since these trains provide a very different type of service to the car, the two modes are often not in direct competition.

Although air transport consumes much more fuel per passenger than rail, its advantages in terms of time saved will often outweigh energy considerations. Likewise the flexibility offered by the private car will often preclude rail as a viable alternative. Nevertheless there is substantial potential for fuel saving via even a small modal shift from air and car to rail (or bus).

On the basis of the 5% modal shift the saving would be the equivalent of 70 megalitres of distillate, which is almost 9% of the total energy consumed by railways or about 0.5% of fuel used for all domestic transport. Some comparisons of fuel consumption for a number of specific routes have been estimated and are summarised in Table 5.

Freight

In most circumstances rail and coastal shipping are far more energy efficient than road for the movement of non-urban freight (Table 6).[1] Overall rail transport is four times as energy efficient as road transport (0.016 litres / net tonne km for rail compared to 0.068 litres / net tonne km for road). The average energy intensiveness for coastal shipping (0.0065 litres /net tonne km) is less than half that for railways. However, this is partly due to the fact that over 90 per cent of the coastal shipping task is made up of very fuel efficient bulk freight movements. Rail and shipping often have similar energy intensiveness rates for the movement of these traffics.

Some comparisons of road and rail fuel consumption for specific traffics, which have been estimated in the course of this project, highlight the extent to which relative fuel efficiencies depend on the traffic and route. (See Table 7).

It is estimated that if 5 per cent of existing non-urban general freight moved by road in transferred to rail, 50 megalitres of diesel fuel could be saved annually.

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1. Urban freight movement has not been examined as it is of limited importance to future rail operations, for reasons unrelated to energy.

TABLE 4 - DIRECT SECONDARY ENERGY INTENSIVENESS OF NON-URBAN PASSENGER MODES

Mode	Energy Intensiveness (Equivalent litres of Distillate Per Passenger Kilometre)	Existing Average Occupancy %
Rail - Overall	0.022	na(a)
- Specific Services		
Interstate Sleeper (Southern Aurora)	0.036	78
Interstate Sit-up (Intercapital Daylight)	0.016	57
Locomotive hauled country service (Melb-Bendigo)	0.017	56
Rail Motor (Perth-Kalgoorlie)	0.016	70
Private Car (5 seat)	.03	58 (b)
Bus (36 seat)		
Interstate	.018	55
Country	.015	55
Air		
Intercapital	.064	75
Other	.15	na

Source: ARRDO, 1981c

Note:
a. Overall number of seats provided is not available for railways although it can be obtained for specific trains.
b. Occupancy figure used by Lawlor and Brown (1980). The Australian Bureau of Statistics "Survey of Motor Vehicle Usage" (1976) determined an average occupancy of 44% but Lawlor and Brown conclude that this is not consistent with the findings of other Australian studies.

TABLE 5 - COMPARATIVE FUEL CONSUMPTION OF ALTERNATIVE MODES FOR SOME SPECIFIC INTER-URBAN ROUTES [(a)]

Line	Total Direct Primary Energy Used (litres of diesel equivalent per passenger)			
	Rail [(b)]	Bus	Car	Air
Brisbane-Rockhampton	23.9	12.2	19.9	40.7
Melbourne-Sydney	15.0 or 35. [(c)]	15.9	26.5	46.0
Perth-Kalgoorlie	8-10.5 [(d)]	10.7	17.8	54.0
Melbourne-Bendigo	2.7	2.3	4.7	-

Source: ARRDO (1981c)

Notes:

a. Numerous estimates had to be made about average occupancies, vehicle types, train consists, etc. occupancies for car and bus were taken as 58% and 55% respectively. Air occupancies varied. (ARRDO, 1981c).

b. The fuel consumption rates for rail were calculated using the regression equations discussed in this paper.

c. The lower figure relates to the 'Spirit of Progress' and the 'Intercapital Daylight', the higher figure to the 'Southern Aurora'.

d. The lower figure applies at mid-week when the train consists of trailer/motorcar only. The higher figure is for the average train consist of two motor cars and one trailer car.

TABLE 6 - AVERAGE DIRECT ENERGY INTENSIVENESS ON NON-URBAN FREIGHT MODES

Mode	Energy Intensiveness (Litres of Distillate Per Net Tonne Kilometre)
Rail-Overall	.016
Specific Traffics	
Grain (Ararat-Portland)	.007
Steel (Newcastle-Brisbane)	.012
Cement (Geelong-Melbourne)	.006
General Freight (Melbourne-Geelong)	.012
General Freight (Shepparton-Tocumwal)	.022
Road-Overall	.068
Interstate	.034
Intrastate	.086
Coastal Shipping Overall	.0065
Interstate Bulk	.0070
Intrastate Bulk	.0035
Container Vessels	.0180

Sources: Rail Systems, ARRDO regression equation for freight train fuel consumption, Lawlor and Brown (1980), Quarterman (1981), A.N.L. and others. (ARRDO, 1981 b, c).

TABLE 7 - COMPARATIVE FUEL CONSUMPTION OF FREIGHT MODES FOR VARIOUS SELECTED TRAFFICS[a]

	Total Fuel Used (litres of diesel equivalent per tonne)	
	Rail[b]	Road
Container Traffic (Brisbane-Newcastle)	13.8	27.0
General Freight (Melbourne-Geelong)	2.6	4.5
Grain Traffic (Ararat-Portland)	1.3	7.4
Fruit Traffic (Shepparton to Seymour)	1.3	2.6

Source: ARRDO (1981c)

Notes:

a. Numerous estimates had to be made about average occupancies, vehicle types, train consists, etc. These are discussed in ARRDO (1981c).

b. The fuel consumption rates for rail were calculated using the freight train regression equation described earlier.

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