SOUTH AFRICAN TRANSPORT

AN ENERGY MODEL TILL THE YEAR 2000

by

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SUMMARY

The South African transport industry is analysed sector by sector in terms of the transport service provided and fuel energy requirements. Taking cognisance of energy availability, technical, social and economic criteria, estimates are formed to predict the likely transport pattern and associated energy demand over the next quarter century. It is found that the transport industry remains primarily dependant upon petroleum fuels over this period, and that the demand could be satisfied by oil produced locally using oil-from-coal production. The limitations on present forecasting methods used for the transport sector are discussed and the need for a review of current estimates is considered. The potential for energy conservation using modified transport patterns is explored together with alternate energy sources and the implications of transport deficiencies on the national economy.

Salient figures from the analysis appear below in approximate form.

		1975	2000
Total Annual Transport Work Performed			
Passenger kilometres $\times 10^9$		76	176
Freight tonne kilometres $\times 10^9$		153	340
Total Annual Fuel Requirement			
Coal	Tonnes $\times 10^6$	7	66
Imported Crude Oil	Barrels $\times 10^6$	106	157

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

During the past thirty years South Africa has experienced a massive growth in population, economic wealth and industrial output, with a corresponding increase in the standard of living amongst all its racial groups. Directly and indirectly these factors have combined to place a heavier demand on the nation's transport industry both within the country and for import/export trade. Without exception, all the major transport modes have undergone a marked upsurge in the level of passenger and freight transport operations, and similarly, the energy consumption for domestic transportation has increased. In the light of the so-called "oil crisis", and with petroleum products providing the major source of transport power, this thesis attempts to analyse the energy requirements of the transport network, using historical data to forecast raw fuel consumption up until the year 2000 modified where necessary to take account of technological improvements, operational changes and national transport policy. By way of a formal introduction, the various transport modes are discussed separately in the following sub-sections.

1.1 Air Transport

Of all transport modes in South Africa, air transport has established itself and expanded at the greatest rate. Present annual expansion rates are of the order of 6% per annum and this is expected to continue at least

until

until 1990, after which time the depletion of world natural oil reserves is likely to begin to have adverse effects on fuel supply and costs. This high expansion rate has already manifested itself in terms of greatly increased service size and this is expected to show a further four-fold increase over present levels by the year 2000.

Although primarily a means of passenger transport, the rapid freight service possible with air travel has meant that the use made of this service has also increased, and recent trends show that air freight has enjoyed an even higher rate of expansion than the passenger service. The most obvious application is that of the air mail postal service, but short delivery times and the ability to safely move delicate cargo (certain foodstuffs, scientific equipment, etc.) has ensured widespread utilization of this facility. This is however, the most expensive form of goods transport so its ultimate application is restricted to special products or circumstances where the above advantages outweigh cost considerations. It is also the most energy intensive form of passenger and freight transport so is particularly susceptible to fuel cost and availability.

Passenger transit by air is expensive, restricting its use to the more affluent or sponsored (business) section of the community, and is thus at the mercy of economic down-trends. This was apparent in South Africa over the period 1973 - 1975 when the "oil crisis" and the beginning of a period of economic depression actually reduced the total service performed. The low profit margin of airline operation reduces the potential to

absorb/...

absorb any direct increases in fuel or operating costs and rises in either of these must invariably be passed on to the users of the service.

South African Airways is the national flag carrier and performs most of the domestic commercial air transport. The introduction, over the past 15 years, of new aircraft by SAA has resulted in the current permanent aircraft fleet comprising almost exclusively of pure jet powered aeroplanes. Three aircraft alone are turboprop powered although some piston engined types are operated on minor routes by hire agreements between SAA and other carriers. Delivery has recently been taken of Boeing 747 SP and Airbus A 300B2 aircraft, these representing the latest aircraft available in the western world today and ensuring that SAA remains the equal of any contemporary airline elsewhere in the world.

1.2 Rail Transport

Rail transport within this country falls under the auspices of a single governing body, the South African Railways, with the exception of a few localised lines which are privately operated. In any country without extensive inland waterways, the major portion of all industrial transport is undertaken by the rail system. South Africa is no exception and has an extensive railway network throughout the country, consisting of more than twenty thousand kilometres of permanent rail track. This is concentrated around the major industrial centres, in particular the Witwatersrand area and the link to Durban for foreign trade movements from this, South Africa's largest harbour.

The SAR established its services with steam traction, abundant and cheap coal making this source of motive power especially suitable. It is only since 1965 that the steam locomotive fleet has been superceded to any extent by diesel electric and pure electric traction, although steam is still extensively used. Despite the steam locomotives appalling thermal efficiency, its simplicity and non-demanding maintenance result in it still being the cheapest form of motive power in this country. Its disadvantages become apparent when comparing the start-up time with other locomotive types and the general cleanliness of operation.

Diesel electric and pure electric traction is expensive in comparison with steam motive power for the following reasons. The locomotives themselves entail a higher capital outlay, and trackside electrification in the one case, and diesel fuel in the other, increase the total operating costs. Both types require quite sophisticated workshop facilities and in-service maintenance, with the attendant costs of additional machinery, test equipment and trained personnel. Cleanliness, crew comfort and practically instant start-up times are of particular importance on high density rail routes and together with almost continuous availability, this has characterized the advantages of these tractive units. Electric locomotives have the further advantage of low noise levels, important for urban use, and the localization of air pollution to power stations where it can be most economically controlled.

The large scale/....

The large scale introduction of air travel and the extensive use made of private motor vehicles has reduced the demand for long distance passenger travel by rail among upper income group persons. The lower income group however, make extensive use of the service as often it is the cheapest and most convenient transport. Suburban train services for commuters in the larger centres continue to expand as more and more people realize the benefits of not taking a car into congested centres where vehicle operating and parking expenses are becoming prohibitive. Passenger transport is however a relatively minor portion of the total railway service, freight transport providing the backbone of all rail movements throughout the country.

1.3 Road Transport

Freight transport by road is primarily of the form of a distributional network, serving areas without railheads and distributing produce within urban and semi-urban areas. Of all the freight transport systems, road transport provides the most versatile service, enabling door to door delivery and also the initial collection and final distribution of industrial or agricultural produce moved by rail or air. Road transport is in the hands of several private operators on a commercial scale and is independant of a single governing body as is the case of air and rail transport. Although government control does exist regarding long distance road freight routes and charges, open competition between various companies has resulted in an efficient service being offered to industry as a whole.

For passenger/......

For passenger transit over long distances, commercial road transport has largely been ousted from the prime routes by air and rail services, but finds other application on secondary routes. The private motor vehicle provides unequalled convenience for short distance travel and consequently is becoming increasingly popular, especially as the standard of living among all population groups increases. Generally speaking, all forms of road transport enjoy exceptional flexibility and user convenience for the conveyance of passengers and small quantity freight distribution. Cost wise road transport cannot compete with the railways for bulk movements (providing of course, a suitable rail link exists) but rather supplements this service with a distributional function at the destination.

The larger freight vehicles are invariably diesel engined units using conventional reciprocating motors of two, and more usually, four stroke design. Smaller vehicles tend to be petrol powered although for freight vehicles a significant number are also diesel powered. The private vehicle range is almost exclusively petrol powered with only one or two manufacturers producing diesel engined saloon cars. Diesel engines are also used to power commerical onmibuses, even the smaller models.

South Africa has a very well developed road system with high standard national roads connecting the major cities and towns. Traffic densities at present have not warranted long distance freeways although the development of feeder freeways to the large centres is well developed. Plans are under way at present which will ultimately link Cape Town, Port Elizabeth and Durban with

Johannesburg and Pretoria by freeway,although with the high cost involved, this is a long term project. District roads serve all rural areas with the large majority of medium and small sized towns having tarred road access to other centres.

1.4 Shipping and Harbours

South Africa's harbours are the focal point of most of the import and export trade with foreign countries. Except for a very small fraction of the total freight movement carried by air, and limited road and rail services to South Africa's northerly neighbours, shipping provides the sole means of transport for overseas trade. At present levels,coastwise traffic represents approximately 3% of the tonnage handled in local harbours indicating that most shipping movements represent true import/export trade movement.

In line with world trends, local ports are adapting facilities for containerized cargo which, when fully implemented, will improve the handling capacity of current equipment as well as reduce labour and energy requirements per unit of cargo handled. Similarly, bulk discharge and loading facilities for commodities like oil, iron ore, coal, sugar, etc. and the development of harbours at Saldanha and Richards Bay will further enhance the handling capacity of South Africa's sea links.

Passenger travel by sea has become increasingly uneconomic recently with high staff and fuel costs and many mailship services have already been disbanded, with the remaining few to be withdrawn during 1977.

Shipping/....

Shipping therefore constitutes a negligible fraction of the overseas passenger journeys, this all being undertaken by the airways.

1.5 Pipeline Transport

There exists at present a pipeline network, operated by South African Railways and Harbours, connecting Durban with the Witwatersrand for the conveyance of bulk petroleum products (crude oil and refined produce) This system interconnects the oil refineries at Durban and Sasolburg and provides a distribution system between major centres on the Gold Reef and to points en route.

In view of the large quantities involved, the pipeline system is viable over this route and its implementation has enabled a considerable reduction in the rail traffic over adjacent lines, releasing tank wagons and locomotives for service elsewhere. The transport efficiency of the pipeline system is high, national grid electricity being the sole power source. Ecologically, the system has a minimal effect on the environment being clean, quiet and leaving little evidence of itself along its route. However, the system is not very flexible and installation and maintenance costs (including cathodic protection) are neither cheap nor simple. The system does come into its own though when sufficient transport demand exists over prime routes. A wide range of products other than oil may also be transported by pipeline, namely : coal and certain mineral ores by crushing the solids and pumping them in the form of a fine water slurry. Perhaps the development of the Northern Cape mineral deposits will lead to this system having an application in South Africa.

CHAPTER 2

AIR TRANSPORT

2.1 General

As the South African Airways carry out most of South Africa's internal and overseas air transport, a study of this organization will cover most of the commercial aviation undertaken in this country. SAA have built up an impressive record of performance, both in terms of passenger and freight movement and in the standard and speed of these services. The last fifteen years have shown what amounts to a ten-fold increase in the total amount of traffic handled and a changeover from early piston engined and turbo prop aircraft to the latest types of jet aircraft available today.

It is noteworthy that this increase in service has been performed with substantially the same number of aircraft in the total fleet, this alone giving an indication of the increase in size and travelling speeds of the commercial aeroplanes being used today compared with those of only 15 years ago. In the decade preceding 1973, output, in terms of passenger kilometers has increased by 325%, aircraft kilometers flown by 130% and hours flown by 53%, highlighting the advances made in only 10 years (Appendix 1).

Air travel, being the most energy intensive form of mass transit, must be particularly alert to any form of energy conservation in a world which is steadily becoming more energy conscious.

Careful planning/....

Careful planning is needed to ensure that air travel remains attractive to a wide range of potential users, and socially acceptable in terms of pollution levels and rate of energy consumption. It is not possible in this report to consider social aspects, but just as technical efficiency can affect the use of aircraft fuel, so is overally efficiency dependent on the use made of the service by industry and the travelling public.

The introduction of jet aircraft to commercial aviation has been responsible for the boost in air transport and the industries tremendous growth rate by providing fast and convenient means of medium and long distance travel, whilst setting new standards of transport safety and reliability. Technologically no new concept developments are on the horizon and sub-sonic jet aircraft will represent the prime vehicle of commercial air transport well into the future. Supersonic transport will only slowly become established, and then its benefits will only be realized on transoceanic long distance flights (because of the shock wave associated with supersonic flight), so its ultimate applications will be limited. As a result, the meteoric growth of air transport can be expected to slacken slightly compared with the past two decades, but still retain a healthy development rate. Faced with what now appears to be a stablization in aircraft type, technology can now concentrate its efforts to provide more efficient variants based along the lines of the subsonic, jet-powered aircraft.

2.2 Current Aircraft and Power Plants

Almost without exception commercial aircraft existing in the world today, including those presently being designed for service in the next decade, fall into the following general category :

All metal construction, particular use being made of alumunium alloys.
Fixed geometry lifting surfaces using wing sweep back angles of 15^o to 40^o.
Maximum operating weights 40 to 400 tonnes.
Cruising speed Mach 0,7 to Mach 0,85
Number of passengers 80 to 350.
Freight capacity (with passengers) 8 to 55 tonnes.
Range (with reserves) 800 to 5000 naut. miles (1400 to 9000 km).
Engines - 2,3 or 4 axial flow jet turbines.
Cruise Altitude - 8000 to 12000 metres.

Probably the two most significant developments made in the past few years have been the wide-bodied breed of airliner and the high bypass ratio turbofan engine. New technology and advances in the wing design have enabled heavier loads to be carried on the same sized wings with less aerodynamic drag while the basic jet core engine has benefited from having a turbine driven fan added to the compressor stage which blows atmospheric air through a shroud surrounding the engine (passing several times the volume of air than the core engine itself) and which supplies up to 80% of the total thrust.

Further/......

Further developments could yield gains of up to 50% increase in fuel efficiency over present levels by the turn of the century. (Ref.1) In terms of fuel usage, this would mean an increase in services by half, for no extra fuel consumption above present values. Further benefits from these expected advances will be quieter and more pollution free aircraft, each type of which will be matched to specific operating conditions. Far from stagnating, the sub-sonic airliner can be expected to improve considerably and continue to do so, particularly with regard to operating fuel efficiency. It has been estimated (Ref.1) that from the present time until 2015 AD advancing technology will save 2000 million tonnes of fuel (or two-thirds of the total estimated North Sea oil production) on a world wide basis. This saving also represents a mere 6% of the cost of developing oil production to perform the aircraft technology improvements which, by anyone's standards, is financially attractive.

Initially, it is necessary to obtain accurate data of the aircraft in-flight conditions and this is most conveniently done in level flight steady state conditions which are at, or near, the normal operating state. Figures for three types of aircraft - Boeing 727, Boeing 737 and Boeing 707 appear in Appendix 4. These figures were obtained by SAA personnel performing the manufacturer's approved tests on the aircraft under typical local operating conditions. These tests are performed on each aircraft periodically to ascertain whether its performance is within limits for safe operation, particularly with regard to the fuel reserves it should carry, bearing in mind the aircraft's deterioration with age.

2.3 Fuel Consumption

To form a quantitative base for calculations and estimates of expected future trends, it is necessary to obtain initially a prediction of the expansion of the Airways in terms of transported goods. Basic units of passenger and tonne kilometers give an excellent means of comparing the relative sizes of transport industries, and it is these units which have been chosen as the reference points throughout this report. Figure 2.1 depicts both historical and predicted data of passenger kilometers moved annually for the forty year period 1960 - 2000. Data prior to and including March 1976 represents actual performance based on SAA records (Appendix 1). Predictions to the year 2000 are based on a mean Annual Growth Rate of 6% which is representative of predictions on a world wide scale (Ref. 1) With the probable onset of the depletion of world oil reserves, a lower expansion rate is expected from approximately 1990 onwards. Rising fuel costs are expected to slow air transport growth down in this period.

In order to obtain a realistic picture of the fleet in future years, it is necessary to obtain information on the expected size of the aircraft, projecting historical facts along the lines of aircraft manufacturers estimates (Ref. 1) of the size of future airliners. This is graphically represented in Figure 2.2.

Using the expression shown in Appendix 2 it is possible to estimate the total number of flying hours per annum. Further to this, by making an assumption of the flying utilization of the fleet (% of total time airborne) the actual fleet size may be determined. This is graphically

represented in/......

represented in Figure 2.3. Data and the selection of the flight utilization factor appear in Appendix 3.

Considering that the service will increase in size by 6% per annum in terms of passenger kilometers moved (Figure 2.1) and that aircraft size will increase at 3% per annum in terms of seat capacity (Figure 2.2), the distance flown by the fleet aircraft must increase by the difference of these two growth rates, i.e. 3% per annum. As flying speeds and stage lengths will remain substantially constant (subsonic cruise over existing routes), the flying time will also increase at 3% per annum as a direct result of the increased total distance flown. With stagnant technology, the overall fuel requirements of the fleet would increase at the same (3%) rate, but it has been predicted (Figure 2.4) that the mean fuel efficiency improvement rate will be of the order of 1% per annum, resulting in an overall fuel consumption increase in the region of 2% per annum. This is depicted in Figure 2.5.

2.4 Efficient Aircraft Operation

It is possible, by a revision of basic operating techniques, to improve the fuel efficiency of existing jet aircraft in service. Reference 5 details several ways of modifying flight management to conserve fuel in operating conditions. The following is an outline of the principles involved and their relative effect on the overall fuel efficiency of an aircraft.

For a known aircraft mass and flying speed there exists an optimum flying altitude at which fuel consumption is a minimum. While the aircraft is airborne its total mass is continually decreasing as fuel is consumed by the engines. To maintain the minimum fuel consumption the aircraft must gradually climb throughout the cruise sector of its flight. While it is quite possible to achieve this from a practical viewpoint, air traffic control regulations insist on the aircraft maintaining a fixed altitude, to facilitate separation between incoming and outgoing aircraft. In certain cases, usually on lengthy flights, it is possible for the aircraft to climb in steps to higher approved altitudes as the flight progresses. Benefits attained however are small with the present flight control system and a review of air navigation regulations could definitely improve this means of economising. Figures quoted in Ref.2 indicate that approximately a 1% consumption penalty occurs for every 1000 feet above or below the optimum altitude.

In certain instances, it is possible to reduce fuel consumption slightly by operating aircraft at reduced cruising speeds. Speed reduction of 3 to 4% will reduce overall fuel consumption per flight by 1,5 to 2% but also increase flight time by an average of 5% on medium distance flights (Reference 2). Fuel economy thus has to be played off against longer flight times and the airline concerned will have to choose the balance.

Other factors like reduced descent speed, reduced landing weights and carrying less reserve fuel will all make slight savings in overall fuel consumption, as will a reduction in the aircraft empty operating weight. Even more subtle changes include route planning to encounter coolest possible atmospheric temperature, one stop long range flights, ground operations revision, all with slight effect on the overall fleet consumption.

Unfortunately/.....

Unfortunately, several of these requirements conflict with those of safety, of other requirements and the social acceptability of the service offered. However, a revision of operating procedures and flight management along the lines mentioned above will result in a worthwhile saving in fuel used. SAA has implemented as many of these options as possible, but unfortunately no figures exist for aircraft performance prior to this which would allow a direct comparison of the fuel consumed and the savings achieved.

2.5 Data Analysis

The information represented graphically in Figure 2.1 of the projected increase in passenger kilometers transported until the year 2000 was the basis for the extraction of other data into the future. This information was obtained by extending historical SAA performance along realistic trends anticipated by world-wide aviation. With South Africa's healthy economic position and an industrial growth rate comparable to the foremost Western nations, there is no reason to believe that the expansion of air travel here will deviate markedly from world trends.

A similar argument may be used in support of the expected growth in individual aircraft size over this period (Figure 2.2) It is unlikely that South African aviation will generate special demands for aircraft size in opposition to world trends and it is equally unlikely that she will develop and manufacture her own specialized aircraft in the short term future.

Appendix 2 shows how the information represented in Figures 2.1 and 2.2 was manipulated to give estimates of the aircraft hours flown (Appendix 3) the results being displayed in Figure 2.3.

Appendix 9/...

Appendix 9 shows the trend of the actual percentage time an aircraft spends airborne. The markely higher value of 29,6% for 1975 is the result of having all the aircraft in the fleet well established as far as maintenance schedules are concerned, none of the aircraft being brand new or undergoing acceptance testing. With the introduction of two new types (B747 SP and A 300) at present under way, it is expected that the 1976-1977 figure will be much lower. This will come about due to two reasons, viz.: the new aircraft undergo a considerable non-productive testing period and also the sudden increase in fleet capacity means that all the fleet aircraft need fly less to maintain the existing service. Both of these factors will tend to depress the average percentage time all aircraft of the fleet are airborne. The large size of these two new types will result in them having to fly less time than the older aircraft they supersede, to still provide the same service.

While the potential for an increase in the total flying time of these new types is greater due to reduced maintenance time and quicker ground handling and stop-over turn-around time (resulting from improved technology), it is expected that the nett result of a suppression of services (to raise load factors and profitability) and the above considerations will result in the average flying time remaining of the order of 25% well into the future.

Based on this 25% value, the total estimated annual flying time may readily be transformed into the number of aircraft in the fleet at any time in the future. This is represented in Figure 2.3.

Figure 2.4 shows/...

Figure 2.4 shows the world trend of best individual aircraft types in terms of propulsive fuel efficiency. Propulsive efficiency is defined here as being the fraction of propulsive energy produced over the total fuel energy content. Appendix 4 details the specific data used to compile the propulsive efficiency of three SAA aircraft types. Using specific data in References 1, 2 and 3 and orientating quoted world aircraft efficiencies with those of the above mentioned figures, estimates are possible for all the aircraft types operated by SAA. This information is presented in Appendix 5. From the number of each of the types of aircraft in service and details of the total fleet flying time (Appendix 1),it was possible to calculate a weighted mean fleet efficiency based on historical data. This information is shown in Figure 2.4 and extrapolated along the same world trends to show the predicted movements in SAA's overall fleet efficiency.

Appendix 7 shows the figures used to calculate the fleet mean hourly fuel consumption. This information was transposed to Figure 2.6 along with estimated figures from Appendix 6 for the 1980 SAA jet fleet. From the number of aircraft in the future fleet, the total expected flying time and the estimates of improvement in fuel efficiency, a prediction of future fleet hourly fuel consumption was also obtained and plotted, working from historical data as a base reference point.

Figure 2.5 is the culmination of the expected fleet mean fuel consumption per hour and the prediction of annual hours flown expressed in terms of the SAA fleet total annual fuel consumption. Appendices 8, 10 and 11 are included to indicate the origin of the performance

figures quoted/....

figures quoted and represent the remainder of the information required to perform the analysis.

Appendix 13 details the argument and figures used to estimate relative airport size and the required increase in passenger handling facilities by the turn of the century. A brief look at the seating to freight payload ratio of existing and presently proposed aircraft indicates a fairly consistent ratio of 6 to 7 seats available per tonne of freight and this is not expected to change markedly in the future. (This figure includes baggage allowance of 20 kg per passenger, separate from the aircraft freight capacity). With the aircraft capability remaining constant, it can be expected that the ratio of passenger kilometers to tonne kilometers moved per annum will also remain constant. Using historical data as a basis,the freight tonne kilometers moved are also placed on Figure 2.1 and extrapolated in the same manner as the passenger movements.

2.6 Discussion - Air Transport

The sub-sonic, jet-powered airliner is firmly established as the prime mover in modern air travel and this concept is expected to remain at least until the turn of the century. It is unlikely that South Africa will develop and manufacture her own civil aircraft, although construction under licence is a possibility. By third world standards SAA operates a very respectably sized fleet, one which has kept abreast of world trends and which should continue to do so. Choice of future aircraft will depend primarily on traffic density and range, enabling selection to be made from the range of aircraft available at the time. Certainly, if past performance

is an indication/..

is an indication, SAA will be able to continually update the serving fleet with the latest, most economical and practical aircraft.

The air transport industry has established and maintained an enviable growth rate since its inception in the 1930's. It is anticipated that this expansion will continue from now until the turn of the century, the annual expansion rate slackening though, with the inevitable rise in fuel costs. This last factor is likely to eventually halt the growth of the conventional jet engined fleet, by which time it is quite likely that an alternative form of aircraft will be available to the industry.

Jet fuel alone has been considered since it is obvious that petrol engined aircraft constitute a small and decreasing proportion of air travel in terms of energy consumed. Estimates in Reference 1 indicate that only 2,5% of all air transport will be performed by small air craft in the year 2000, and even then it is likely that a number of these will be jet or turbo-prop powered. With South AFrica's traffic density and routes, these figures should still be representative.

With the demand for air travel well established in this country, particulary for travel between main centres and long distance international flights, it becomes possible to increase the size of aircraft, while still maintaining substantially the same service frequency, and still be able to guarantee economical loads. By slightly suppressing the level of services offered it becomes possible to attain load factors of the order of 65%, even in the face of uncancelled bookings, a perennial problem for air transport concerns.

Despite/........

Despite the predicted increase in the size of SAA operations, this may be achieved with only a 60% increase in the number of flights, i.e. traffic density will increase by a factor of 1,6 above present levels by the year 2000. Airport handling facilities will, however, have to be enlarged by a factor of four, directly in line with the increase in the number of passengers per annum.

In relation to the amount of energy consumed by an airliner on an operational flight, the energy required for the ground handling of the passengers and freight at the flight's origin and destination will be very small. Considering the case of a 50 seater bus conveying passengers at most 1 kilometer from the aircraft to the terminal and consuming less than 5 litres of fuel, will show that the energy requirements at an airport are insignificant when compared with the jet fuel requirements for the flight itself. For this reason airport facilities have not been considered as consuming any significant energy in the airways system.

2.7 Conclusions - Air Transport

While it has been predicted that South African Airways will quadruple its services by the turn of the century, fuel energy requirements will only double and traffic density increase by just over one and a half times present day levels. Technological improvements to the aeroplane itself will be the biggest single reason for this remarkable trend. Far from being on a technical plateau, the aircraft industry will be supplying larger and more efficient aircraft well into the future. The proposed geared mid-fan (GMF) engine, improved airframe construction techniques and materials and the development of really high efficiency aerofoils will form the nucleus of these new super-planes.

Based in a stable, wealthy and fast developing country the Airways can look forward to a bright future at least until the mid-1990's. From this point onwards, world wide air transport will be adversely affected by a global shortage of oil. Fuel prices are bound to rise rapidly in the face of a decrease in the availability of all forms of petroleum fuel. Alternative power sources and aircraft types, while likely to be available at this stage, will probably still be under development and hence expensive and not readily obtainable. It is almost certain, however, no matter what the outcome, that SAA will be in a position to exploit any revolutionary developments and to provide a continuing service to the nation.

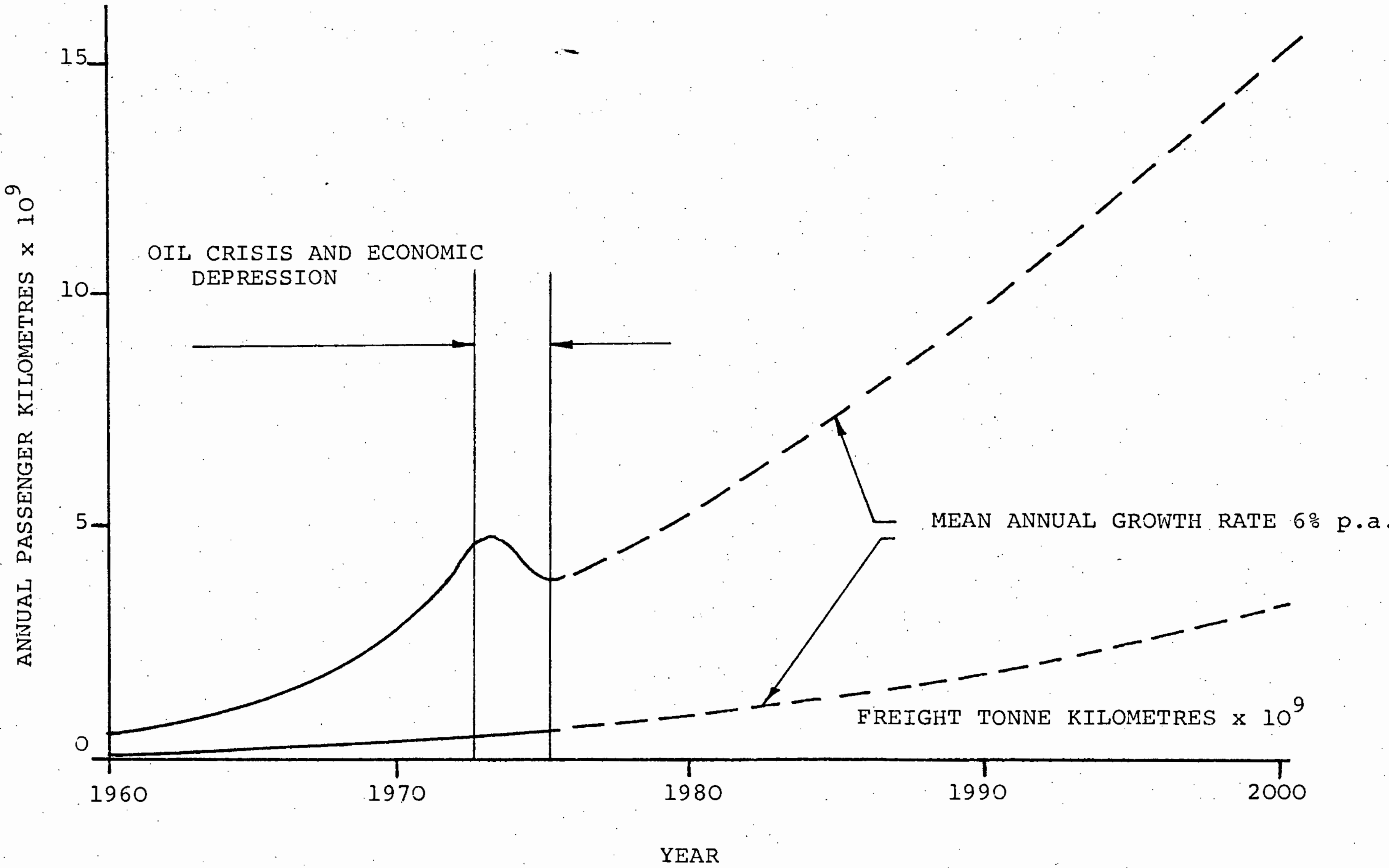


FIGURE 2.1 : GROWTH OF SAA SERVICES (Passengers and Freight)

FIGURE 2.2 : PREDICTED GROWTH IN SAA AIRCRAFT BY SEATING CAPACITY.

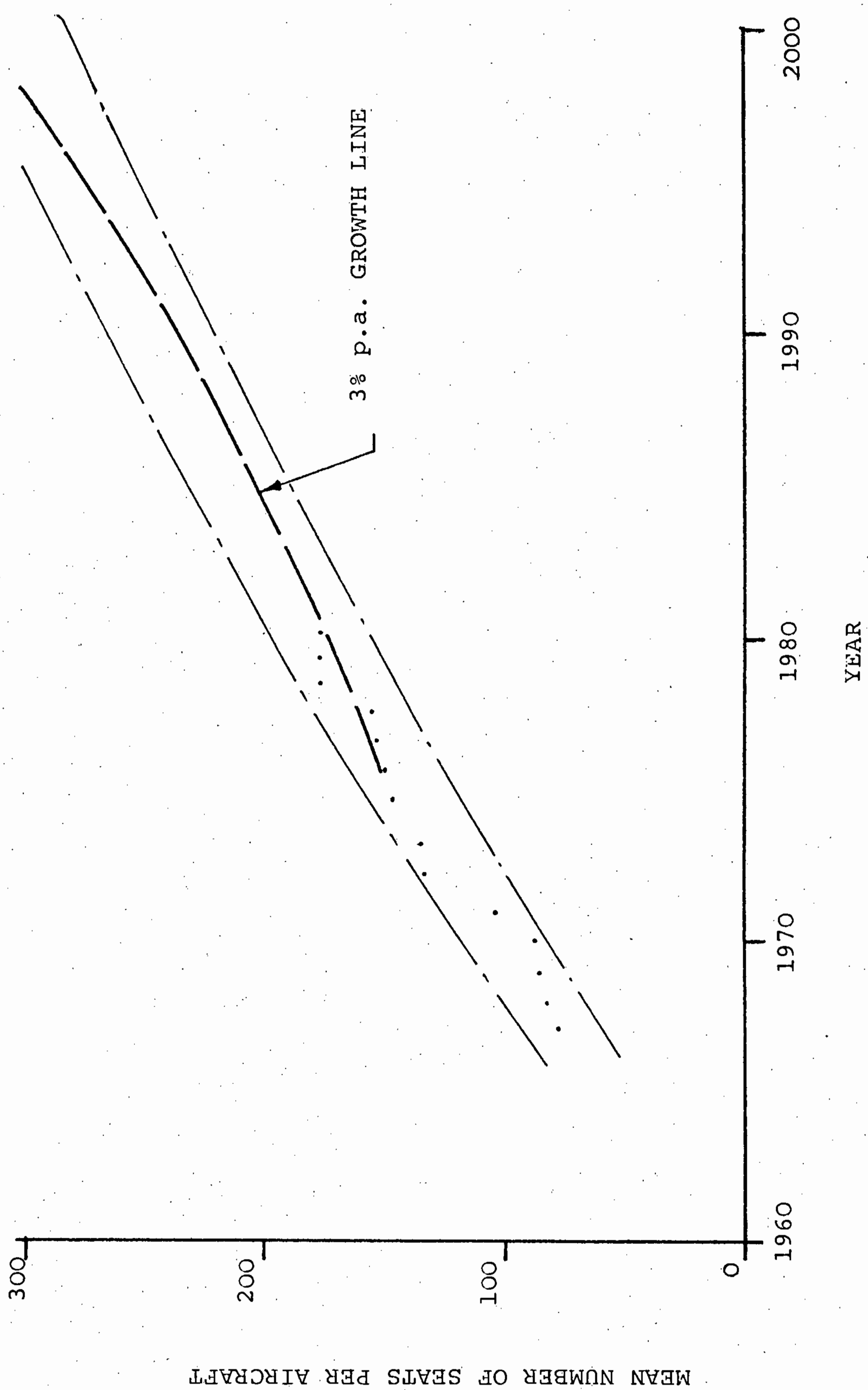
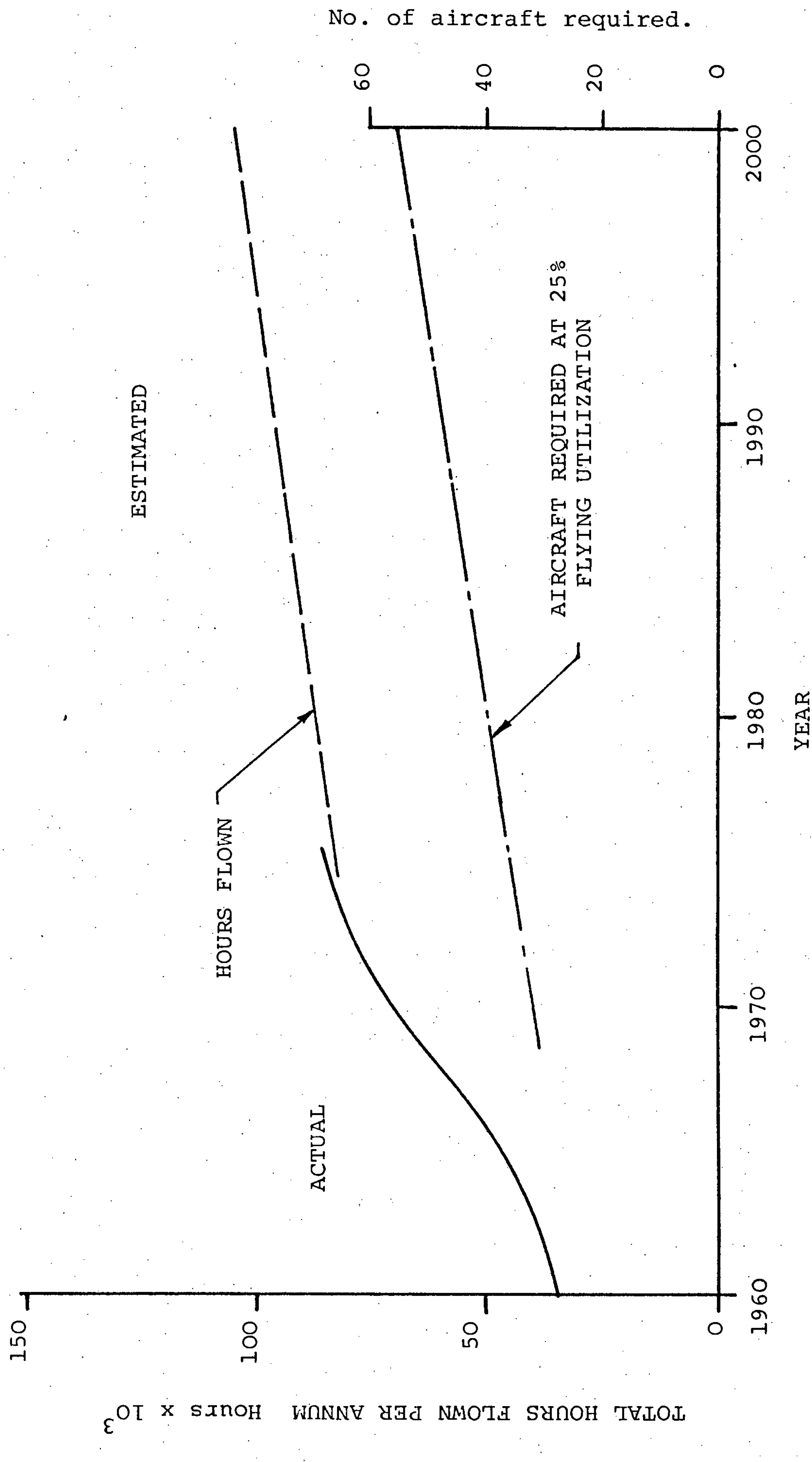
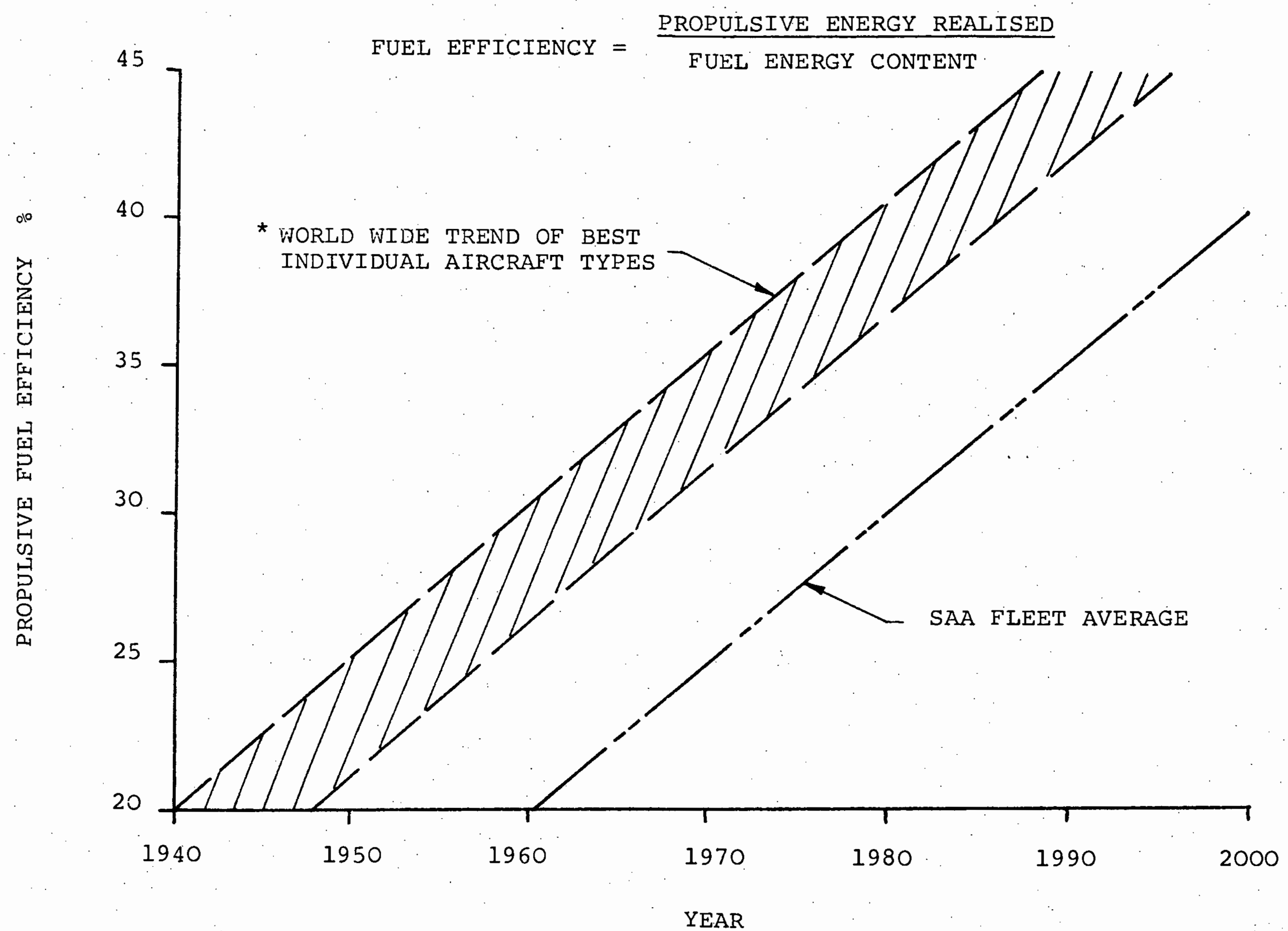


FIGURE 2.3 : SAA AIRCRAFT HOURS FLOWN AND PROJECTED FLEET SIZE





*Source : Reference 1

FIGURE 2.4 : PROJECTED SAA FLEET FUEL EFFICIENCY

FIGURE 2,5 : ESTIMATED ANNUAL FUEL CONSUMPTION - SAA JET FLEET

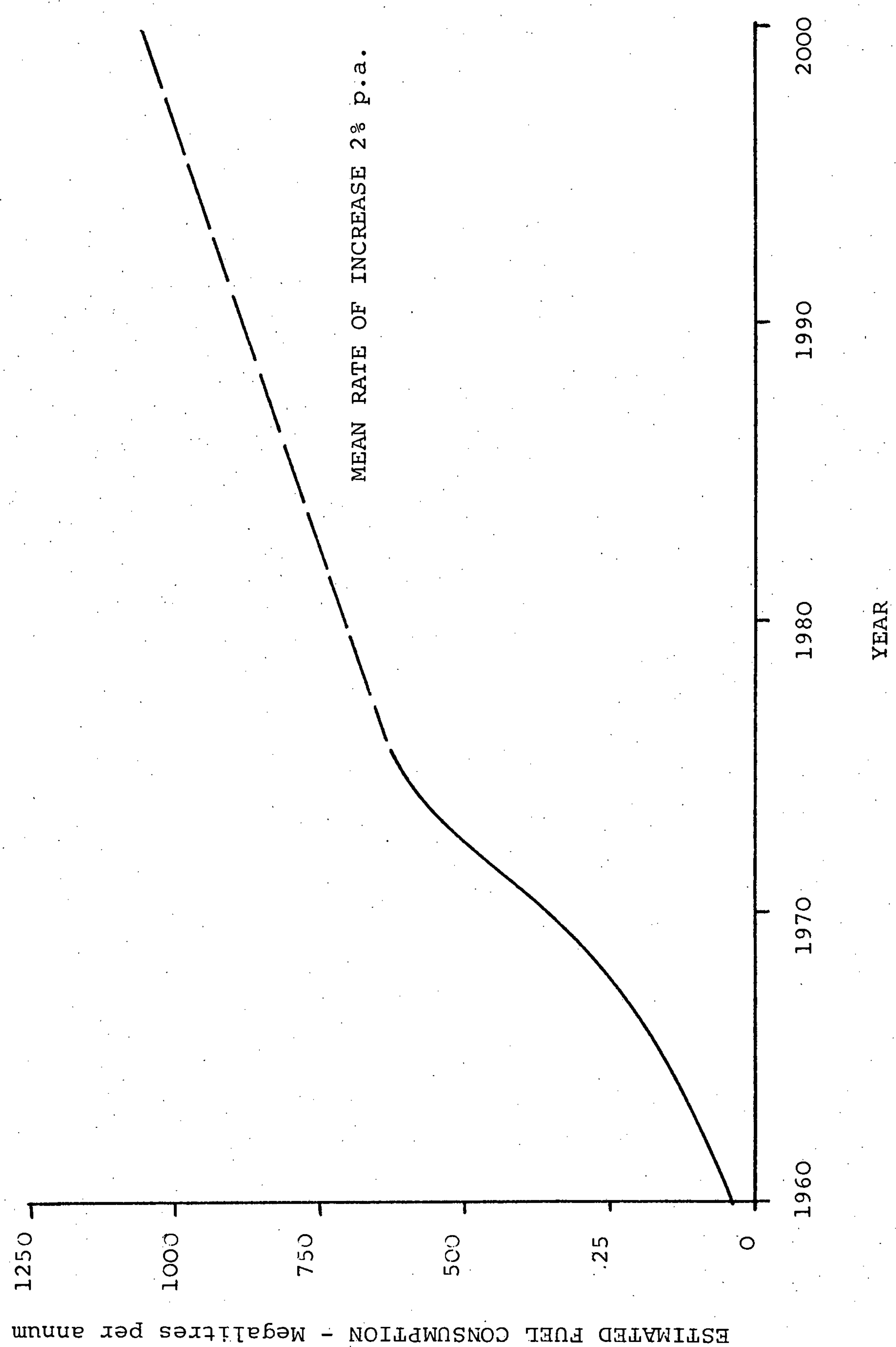
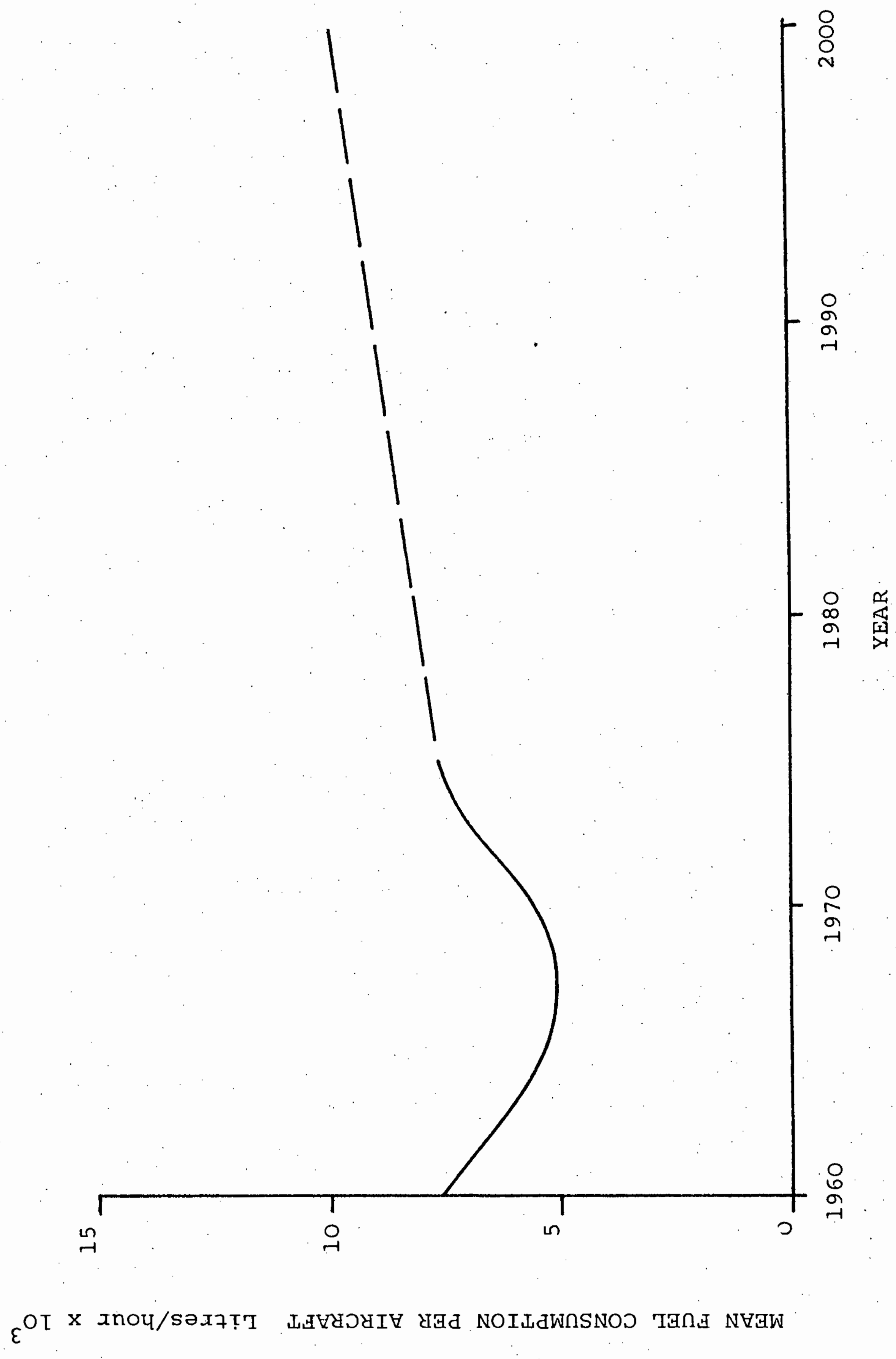


FIGURE 2.6 : SAA JET FLEET MEAN HOURLY FUEL CONSUMPTION



CHAPTER 3

RAIL TRANSPORT

3.1 Brief History of South African Railways

In any industrial country the local rail service is of great importance, providing the primary form of bulk transport of both raw materials and the finished product to and from industrial areas. In a country such as South Africa with large overland distance separating her major cities and with the industrial epicentre well inland, the railways provide the bulk of all domestic transport. Road and air transport perform essential services in the distribution of transported goods but the emphasis here is on convenience and speed. By far the greatest proportion of domestic long distance freight transport is performed by the Railways.

The past few years have seen a dramatic swing away from steam traction, this classic being replaced by cleaner and more efficient diesel electric and pure electric motive power units. Since its inception the SAR has provided a service which has grown in step with industrial transport requirements. This trend can be expected to continue into the future since the advent of new transport systems (pipelines) with their invariably high capital costs and restricted usefulness will only very slowly encroach on the domain of rail transport. The phasing out of steam locomotives has already had the effect of reducing the railways transport energy requirements, resulting in a marked upswing in the overall efficiency of the system. The SAR have achieved raw energy input savings of the order of 35% over 1960 levels and the ultimate saving could be as much as 65% fifteen years from now.

3.2/.....

3.2 Locomotive Efficiency

3.2.1 Diesel Locomotive

Considering the diesel power unit alone :
Typical peak thermal efficiencies of turbo charged diesel engines of the size used in railway locomotives are of the order of 55% ($\pm$ 5%) realized in the engine speed range of 60-80% full speed (Ref.6). Assuming 55% as a representative mean figure for SAR locomotives, and 95% conversion efficiency in the main generator (alternator) :

Peak generating set efficiency = 52%

On average, auxilliary power requirements (traction motor cooling fans, engine radiator fan and control systems) run at 10% of the developed generator power (Ref.7). So electric power for traction purposes is delivered at (52 x 0,9)% i.e. 47% efficiency.

Mean conversion efficiency of electrical into tractive power (traction motors and drive gear) is approximately 85% (Ref.7).

Peak thermal efficiency of a typical locomotive :
= (47 x 0,85)% = 40%

Locomotive utilization factor :
Whilst a shunting locomotive might typically spend 50% of its on-line life in the idle condition (no useful work output) a main line locomotive might spend as little as 15% or even 10% in this condition. Accurate determination of this utilization factor would require a massive project whereby a sufficiently large percentage of the fleet of

locomotives/....

locomotives would be carefully monitored to determine a mean duty cycle of idle time, full load time, cruising time, etc. For the purpose of this report it has been intuitively estimated that the mean load cycle of service locomotives involves 25% idle time and 75% at cruise settings.

This will result in a mean in service thermal efficiency of 30% for diesel electric locomotives. The possible range of this figure would be ± 5%, bearing in mind the estimations made in the formulation i.e. an accurately determined efficiency would lie in the range 25-35%. In this report the 30% value has been employed as the mean thermal efficiency of diesel locomotives.

3.2.2 Electric Locomotives

Direct current electrification is used nation wide, power being supplied and then converted from the national power grid. It is assumed that the conversion, transmission and pickup of this power by the locomotive is performed at 85% efficiency. D.C. rectification and transmission will account for two thirds (approximately) of the losses, the remainder being lost in transformers and in the wiper pickup contact on the locomotive. Traction motor cooling fans and controls are estimated to consume 5% of this delivered power (Ref.7) and traction motor and drive losses are based on the 85% efficiency used for diesel electric bogies (traction motor and drive systems being similar). Due to the different nature of the pure electric locomotive, it is assumed that 90% of its "live" time is spend under load conditions, only 10% at the equivalent of idle conditions (train stationary but all auxilliaries operating) This assumption is based on the fact than an electric loco may be shut down immediately it is not required and re-started with no warm-up delay (not possible with diesel powered locomotives) and the fact that pure electric locomotives are not used for shunting operations (high idle time) as diesel and steam engines are.

This results in an overall operating efficiency for electric locomotives of 60% when operated on national network electricity.

3.2.3 Steam Locomotives

The operating efficiency of a steam locomotive is almost impossible to estimate accurately. Varying boiler pressure, a long warm up time, even fireman performance can greatly affect any estimated figures. An alternative method has been used below whereby the energy inputs and work performed by steam locomotives are compared with diesel and electric unit performance.

From Appendices 14, 15 and 16.

Locomotive	Mean Energy Consumption kWh/km	Tractive Effort kN
Steam	403,5	168,5
Diesel	40,9	191,0
Electric	20,8	172,0

Adjusting these values directly to equate the Mean Energy Consumption to a locomotive tractive effort of 175,0 kN :

Steam	419,0 kWh/km
Diesel	37,2 kWh/km
Electric	21,2 kWh/km

Diesel locomotive efficiency (from 3.2.1) = 30%. For locomotives of identical tractive effort, their efficiencies may be compared by considering their relative energy inputs (outputs being substantially equal within the performance limits considered).

$$\text{Steam loco efficiency} = 30\% \times \frac{37,2}{419,0} = 2,7\%$$

Using the same method and comparing steam with electric traction :

$$\text{Steam loco efficiency} = 60\% \times \frac{21,2}{419,0} = 3,1\%$$

It can be concluded that the overall thermal efficiency of steam traction is of the order of 3%.

3.3 Energy Requirements

As a basis for determining the expansion and energy requirements of the SAR, the annual transport work performed is considered, expressed in terms of goods tonne kilometres moved. This is graphically represented in Figure 3.1 Historical data of the growth of the transport industry in terms of its contribution to the Gross Domestic Product (Ref.4) indicates a mean annual growth rate of 3% between 1945 and 1973. With no major

changes in/.....

changes in the siting of new industrial areas, and a smoothly continued national industrial growth rate, it is reasonable to expect this trend to continue into the future. However, with the advent of pipeline bulk transport and the 6% growth rate of air transport, the more classic forms of transport (road and rail) may be expected to have a lower annual expansion rate than the industry average. In view of the relative sizes of air, pipeline and rail transport, and to provide a smooth continuance of the previous railway growth rate, a figure of 2½% mean annual growth rate was chosen as the basis for predictions until the year 2000.

This figure gave the basis for a prediction of the locomotive kilometres travelled per annum. The trend in modern rail transport is to an improved payload to train mass ratio. This has been possible with better truck design, reducing the mass of the wagon itself while maintaining the same load carrying ability. Ultimate axle loads and the long term life of rolling stock (approximately 25 years) prevent a sudden change in this factor however. Locomotive size is similarly limited by permissible track axle loads. Manoeuverability considerations limit the number of bogies and axles per bogie on a locomotive and six driven axles on two bogies is the practical maximum (Ref.2). Axle load directly affects traction friction between the rail and driving wheels, and so the ultimate tractive effort of the locomotive. With speed restrictions according to gauge width, the above factor effectively limits the maximum power of any single locomotive. Sturdier track with higher permissible axle loads will raise this locomotive tractive power but track replacement and consequently the average locomotive size will increase relatively slowly (App.20). Bearing the foregoing in mind and studying previous data, a locomotive annual distance run graph (Figure 3.2) was compiled with an annual growth rate of the order of 2%.

Steam traction is being phased out and it is not expected to continue beyond 1990. Boiler life is the most crucial factor in maintaining a steam fleet and to retain these locomotives in service boilers would have to be locally manufactured in quantity. While steam power was almost exclusively used even until 1960, the poor efficiency and dirty operation of these locomotives has resulted in them being rapidly replaced by electric and diesel electric units. While electric traction is the cleanest and most economical from an operating stand-point, the actual electrification of permanent way is expensive. The diesel locomotive provides the ideal stop-gap between steam and full electrification. It is however, at the mercy of world oil supplies and should availability of fuel decrease, with the consequence of increased prices, the situation could rapidly be attained whereby it becomes uneconomical to operate these units.

The combined effect of diesel-electric, steam and pure electric traction is estimated in Figure 3.2. Until 1990 it is expected that diesel locomotives will roughly compensate the declining steam fleet, whilst the electric locomotive will absorb the necessary increase in motive power requirements. It is likely that fuel shortages will have an adverse effect on the use of diesel locomotives as early as 1985, this being represented by a sudden decline in the use of diesel traction by 1990. As this coincides with the last phases of steam operation a rapid increase in electric traction is predicted. It is at this stage that the electrification programme will have to be sharply increased. Present level of track electrification is approximately 25% of all permanent way (Ref.4) while electric traction performs some 50% of all rail movements, indicating that electrification of all major routes is already at a high level. This will have to be extended to cover all but the lowest density traffic lines by the turn of the century.

Having established a basis of locomotive utilization and bearing in mind the foregoing remarks regarding locomotive size, it was possible to obtain values for locomotive annual power requirements by considering the energy consumption per kilometre travelled by three types of motive power. This is represented in Figure 3.3 Again by considering the relative thermal efficiencies of these locomotives (Chapter 3.2) the useful energy produced during operation could be determined and added to Figure 3.3. The increase in the thermal efficiencies of locomotive power is dramatically indicated with the falling off to one quarter of 1960 levels the motive power raw energy requirements, by the year 2000.

Appendix 18 shows the SAR energy consumption for the financial year 1974/1975 giving a breakdown of individual energy sources and uses. It can be seen that excluding power for traction, the system energy requirements amounted to 2,2 x 10^6 MWh, or a mere 6,5% of the total. It has been presumed that this figure will increase at the same rate as the goods handling rate i.e. 2,5% and this has then been added to Figure 3.3 to give the total system energy requirements (Figure 3.5). By the year 2000, with the reduced motive power energy requirement, this will have risen to approximately 4,1 x 10^6MWh and represent 25% of the total power requirement (i.e. 75% of the total energy requirement will be for motive power).

3.4 Data Analysis

As described in the previous chapter, the initial phase in determining the SAR energy requirements was a prediction of the freight tonne kilometres moved per annum until the year 2000. A mean annual expansion rate of 2½% was derived as a basis for the relative growth rate of the Railways also in this previous chapter (3.3). In terms of locomotive kilometres travelled per annum, the mean expansion rate can be expected to be lower than the overall growth of 2,5% p.a. for the following reasons :

Within the limits of track axle load limits, the trend is towards larger and more powerful locomotives. Truck design and improved construction materials are tending to increase the train payload to total mass ratio. Both of these factors will reduce the locomotive kilometres travelled for a requisite number of tonne kilometres moved. In view of these relatively slow trends however, a mean annual increase in the distance travelled by the locomotive fleet of 2% p.a. has been considered as being realistic.

This growth factor was used to predict the total annual locomotive distance run (Figure 3.2) and the mean locomotive tractive effort (Appendix 20) based on a linear increase in locomotive power with the mean freight load per train up until the turn of the century. Considerations given in Chapter 3.3 allowed a breakdown of the total locomotive distance travelled into steam, diesel and electric traction categories.

Using historical data on the power consumption of the various types of locomotive (Appendices 14, 15 and 16) it was possible to estimate type power requirements

in terms/......

in terms of the annual distance run. This was compiled (Appendix 19) and is represented in Figure 3.3. It was noticed that the steam power requirement and tractive power effort per locomotive was increasing gradually. This could be explained by the selective phasing out of the older locomotives, leaving the more modern (and more powerful) types in service. A similar phenomenon was noted for diesel traction, with the fleet becoming more powerful and as a result the mean fuel consumption increasing. As the largest locomotives are already operating at maximum axle loads, this trend is going to stabilize at, or very near the present levels. Engine technology improvements will tend to cancel any tendency to increased fuel consumption due to more powerful locomotives, and the overall change in present levels is expected to be insignificant. A similar argument was applied to the pure electric locomotive where efficiency levels (already high) are not expected to rise drastically in the future.

Appendix 18 shows the SAR breakdown of fuel and power consumed during the 1974/75 fiscal year. Using the calorific value of the various fuels, a total system energy requirement was determined. It is reasonable to assume that the energy consumption excluding railway motive power will increase fairly linearly with the quantity of goods handled. These figures are presented in Appendix 22 based on the system mean expansion rate of 2,5% p.a. This was then compounded with the annual locomotive power requirements and presented in Figure 3.5 to produce an estimate of the total system power requirements until the turn of the century.

By a very/.......

By a very general assumption that the useful work performed by this non-tractive energy represents 30% of the energy input (varying between 10-15% for motor vehicles and as high as 95% for some electrical appliances) it is possible to determine a mean system efficiency for the entire system. In view of the small fraction of the total, this assumption for non-tractive energy will have very little effect on the mean system efficiency. This has been done in Appendix 21 and graphically represented in Figure 3.4 in terms of total energy input and useful work performed.

To indicate the marked change in energy requirements per tonne kilometre moved, Appendix 23 was compiled in conjunction with the system energy requirements and the annual quantity of goods moved represented in tonne kilometres. The results, expressed in kilowatt hours per tonne kilometre are presented in Figure 3.6 for the period 1960-2000. Passenger travel, expressed in tonne kilometres, represents a very small fraction of the freight tonne kilometres and has therefore been neglected throughout this analysis. This was estimated at 100 kg per travelling passenger i.e. 10 passenger kilometres to the tonne kilometre and for 1970 represents approximately 2,5 x 10^9 tonne kilometres against a freight figure of 53 x 10^9 tonne kilometres (when calculated optimistically.)

3.5 Conclusions - Rail Transport

It is evident from the projected figures of SAR raw power requirements that the phasing out of steam locomotives will have an enormous effect on the overall figure, as a result of the far superior thermal

efficiencies/...

efficiencies of diesel and electric locomotives. The total energy requirement will fall to roughly one half of the present consumption over the next 25 years. However, it is too easy to lose sight of the fact that, for electric traction, coal has to be burned in thermal power stations to generate the required electrical energy. Nevertheless, this "external" coal consumption is performed in a far more efficient manner than is possible in a locomotive. It also limits air pollution to localized areas and reduces the total quantity of emission produced as a result of performing a unit of rail transport work.

The diesel locomotive, whilst having a superior thermal efficiency and very short warm-up time (almost instantaneous by steam standards) is readily threatened by the onset of the depletion of world oil reserves. This may appear to have little bearing on present day locomotives since this shortage is unlikely to become crucial much before 1990, but the working life of a typical locomotive will be upwards of 15 years. This could well place locomotives on order in a position where their economic life is terminated prematurely on the grounds of rapidly rising fuel costs.

In a country with excellent coal (and therefore electricity) reserves, the pure electric locomotive appears to be the ideal solution. Its use is however restricted by the requirement for costly trackside equipment. Capital outlay is high for electrification of an existing standard line and until now has only been justified on high density traffic routes where the utilization factor of the line is high. With the limitations mentioned on steam and diesel locomotives,

it becomes /.....

it becomes apparent that long term planning for route electrification is imperative. The reintroduction of steam traction could ward off a catastrophic reduction in motive power available should the diesel fleet become inoperative through lack of fuel, but because of the high level of air pollution and waste of coal, this would be by necessity, a short term stop gap.

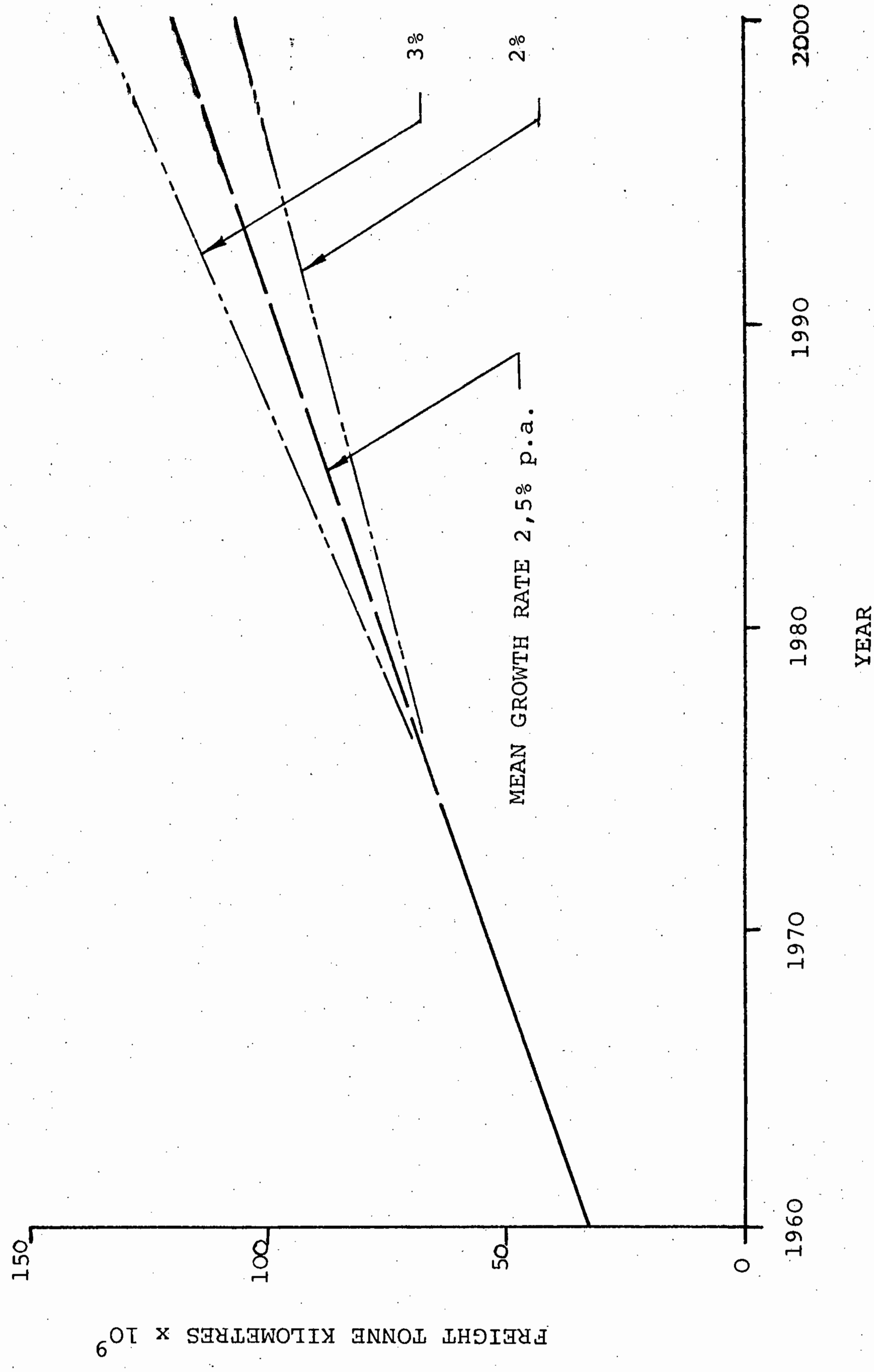
SAR must look to full electrification of the system, with at least 80% of all rail transport being performed by electric traction by the year 2000. Obviously the higher density lines offer the best utilization of an expensive electrification system, so this may represent only 50% of all the permanent way being electrified. It is impossible at this stage to determine the criteria which will govern the choice of locomotive power at the end of the century, but included in the label of cost effectiveness will be new terms such as "energy effectiveness" and "minimized pollution" which could override certain pure financial considerations.

It is evident in any industrial country in the world that its rail system must keep abreast of industrial production. To a large extent, forecasting the SAR's energy requirements and level of operation may be achieved by considering S.A.'s industrial growth potential. If industrial production is up 100% in the next 25 years, the rail service will have to be up a similar amount. It appears that full electrification will be the ultimate answer to SAR's energy requirements and the system as a whole can look forward to an expansion programme every bit as dynamic as that of the nations industries.

With the rapid/....

With the rapid increase in the use of air travel and an increasing standard of living enabling more families to own motor vehicles, long distance rail travel will not increase in proportion to the freight service of the Railways. Suburban commuter lines in the major cities of South Africa will, however, continue to enjoy a steady demand especially amongst the lower income group, since such a service is invariably cheaper than the omnibus service. In view of the relatively light load intensity of humans compared with freight goods, and the short distances travelled, this will continue to have only a very small effect on the total railway service in terms of tonne kilometres transported.

FIGURE 3.1 : S.A. RAILWAYS FREIGHT GOODS MOVED PER ANNUM



<u>FIGURE 3.2</u> : S.A.R. LOCOMOTIVE DISTANCES TRAVELLED PER ANNUM

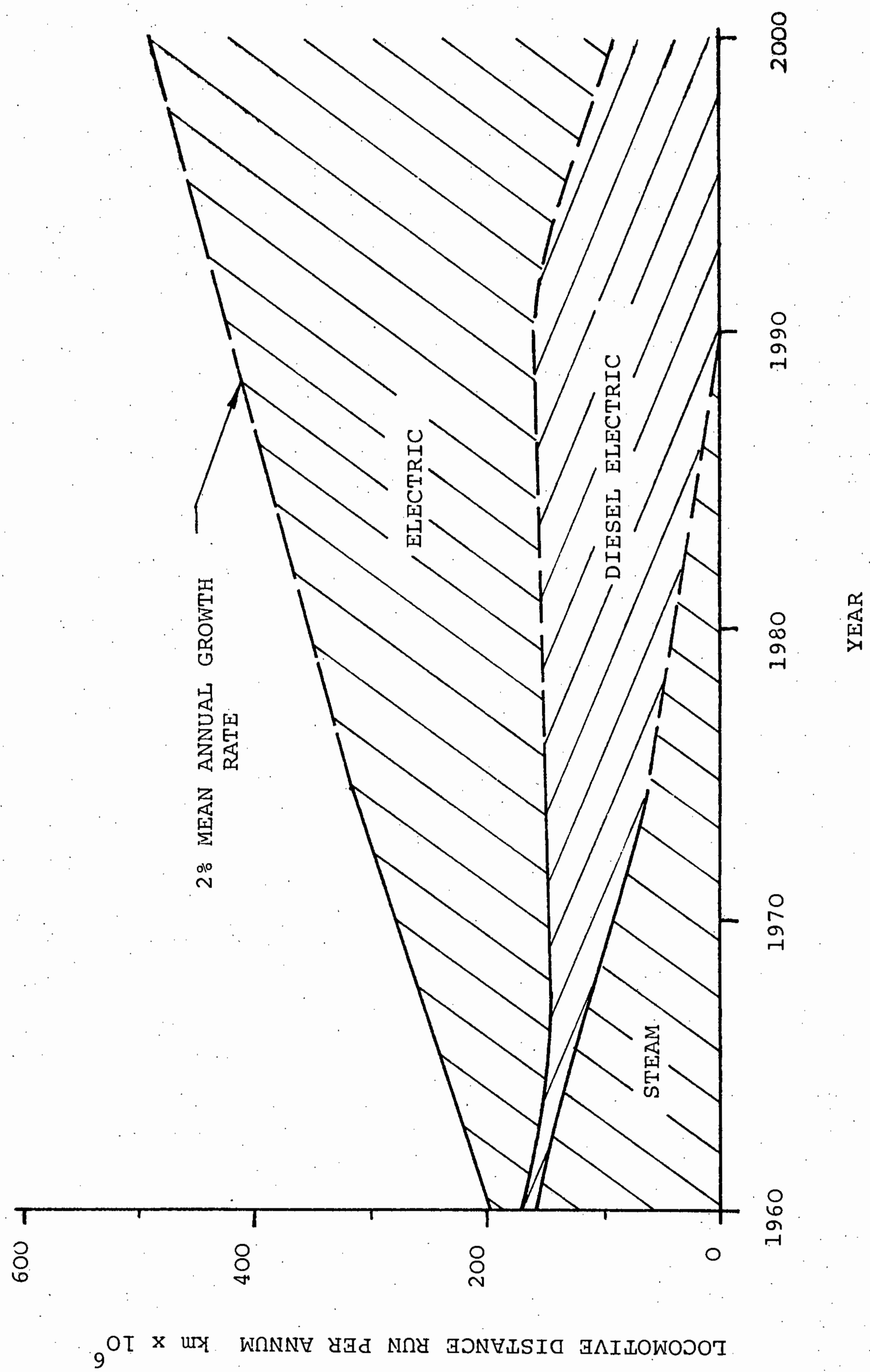


FIGURE 3.3 : S.A.R. LOCOMOTIVE ENERGY REQUIREMENT

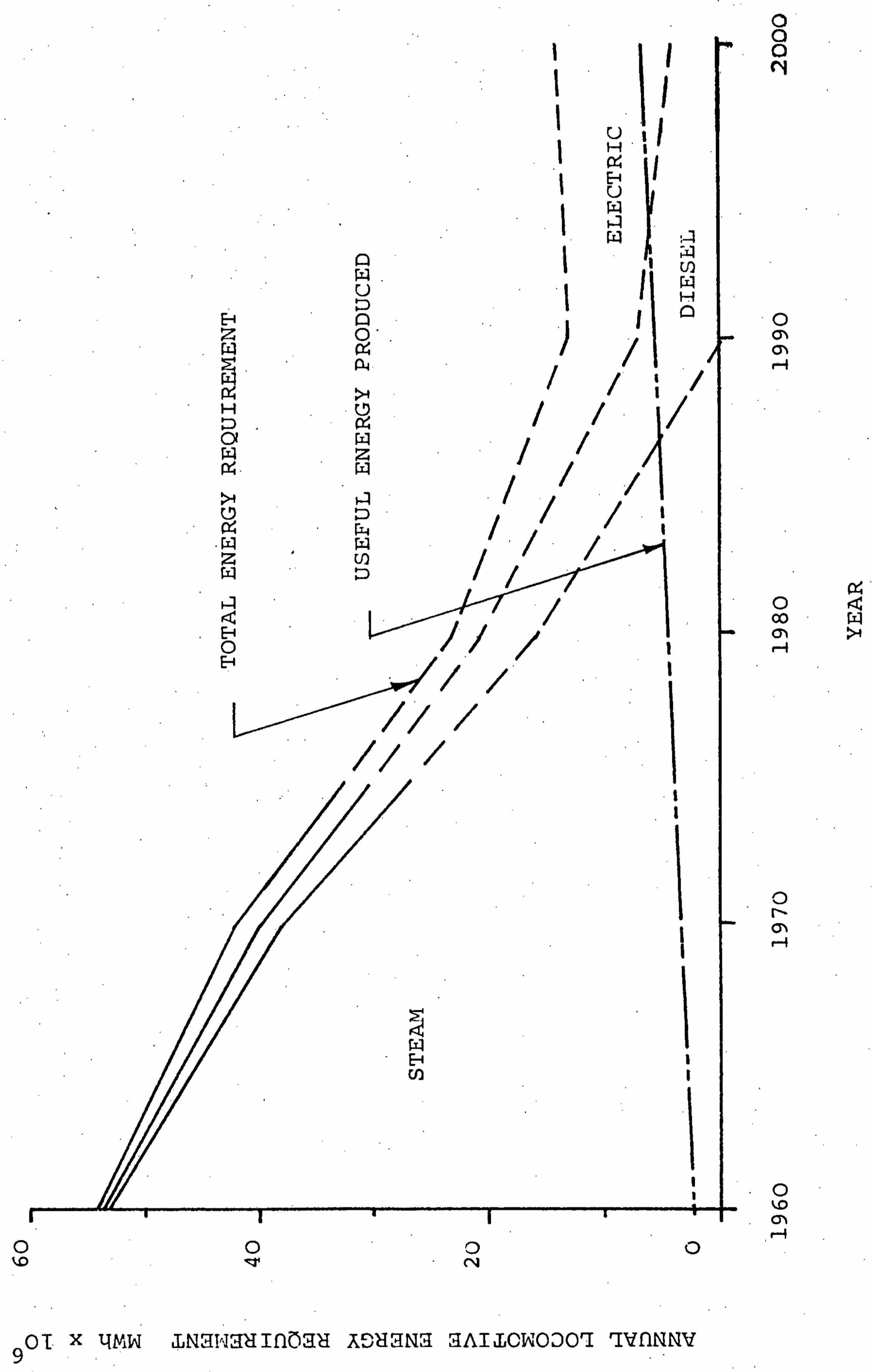


FIGURE 3.4 : S.A.R. OVERALL SYSTEM THERMAL EFFICIENCY

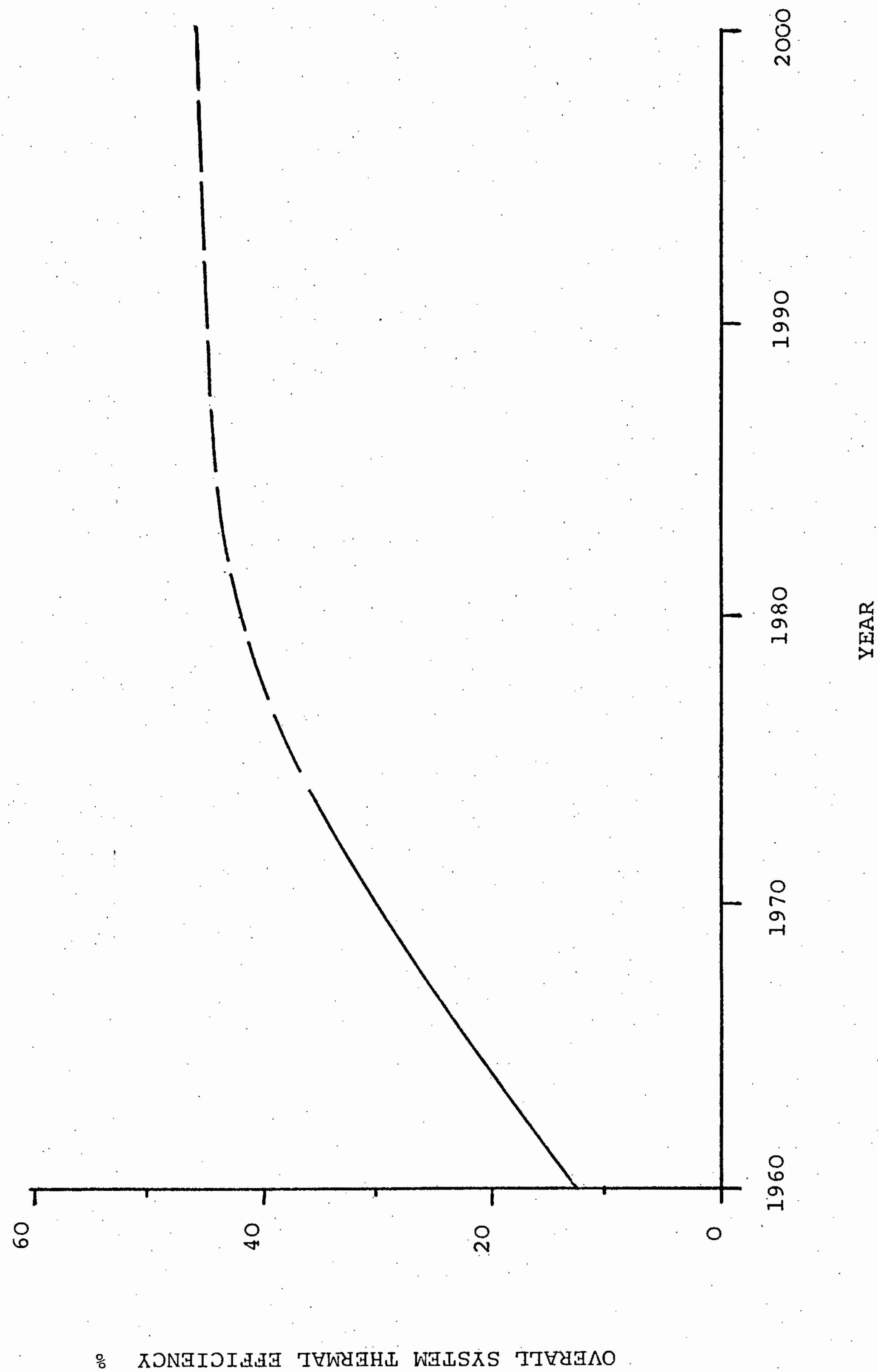


FIGURE 3.5 : TOTAL S.A.R. ENERGY REQUIREMENT

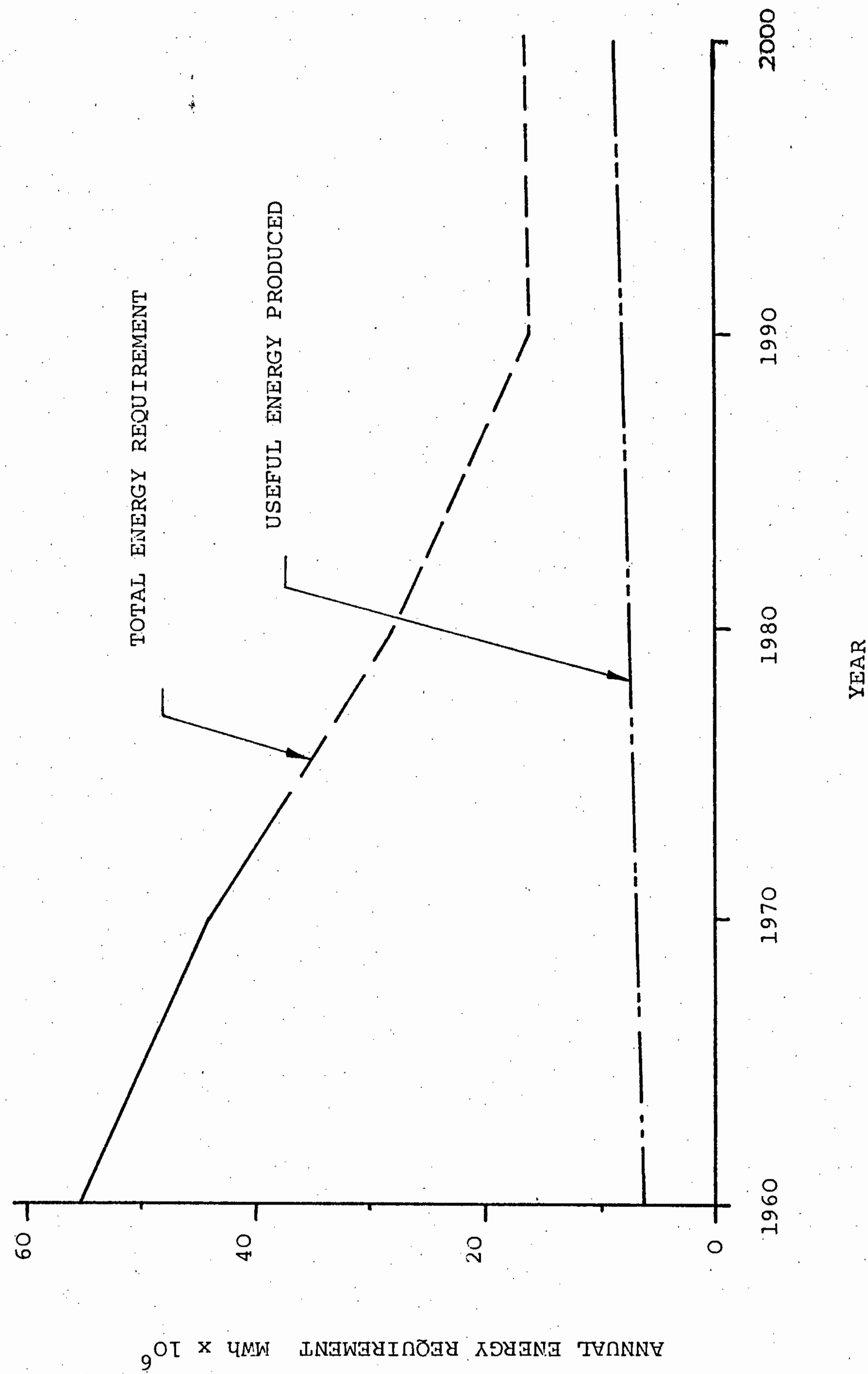
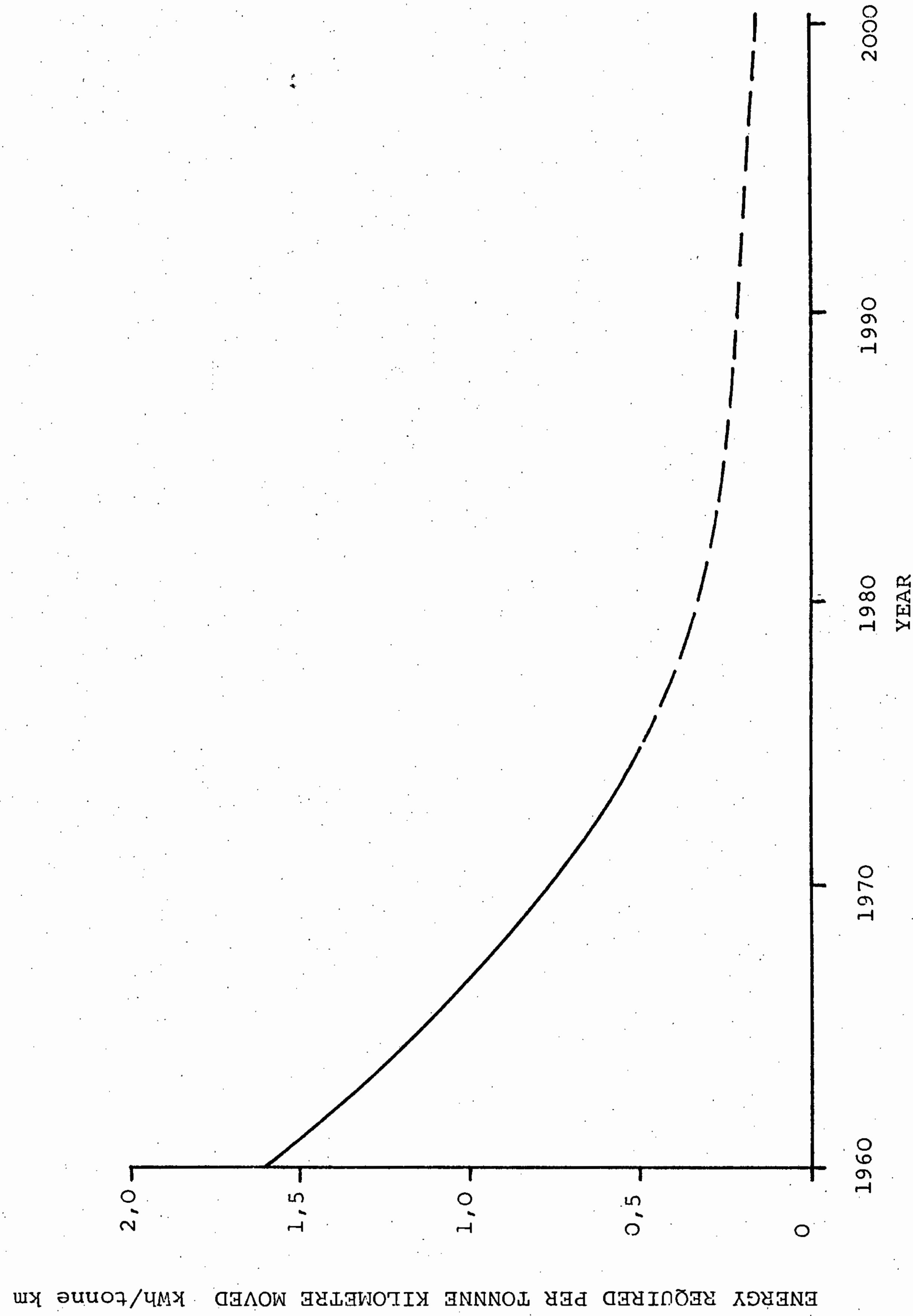


FIGURE 3.6 : SAR ENERGY REQUIREMENT PER UNIT OF TRANSPORT WORK



CHAPTER 4

ROAD TRANSPORT

4.1 Omnibus and Trolleybus Operations

4.1.1 Introduction

South African omnibus services, both urban and rural, are operated by a mixture of private companies, town municipalities and to some extent by the South African Railways road motor services. Particularly in the larger towns and cities with the majority of the labour force living some distance from town and industrial centres, the domestic bus services provide a vital role moving these workers to and from employment centres. Long distance bus travel provides an alternative to train transport between places with no railheads or limited rail services. Coach tours for sight-seeing and holiday travel also play a part in the overall picture, albeit a small one, usually restricted to foreign tourists and for special events.

For the purpose of this analysis, an omnibus is defined as a passenger carrying vehicle with a seat capacity in excess of 40 seats, operating for reward over specified routes. Although commonplace in Cape Town, Durban, Johannesburg and Pretoria a few years ago, trolleybus services are on the decline in this country and at present, only Johannesburg still operates them, and in terms of the South African total accounts for less than 2% of all bus transport (Ref.12). This service is operated by the Johannesburg Municipality.

Private firms are headed by Putco operating in the Transvaal and Natal, City Tramways in the Cape and United Transport in the Transvaal.

Together with smaller private companies, town municipalities make up the remainder of the bus services in South Africa. The flexibility of omnibus transport, using existing roads with minimal alterations (bus stops and shelters) has ensured its implementation in any area where the need for mass passenger transit exists. The system is essentially free from expensive permanent way equipment incumbent on any rail transport system and therefore is economically viable at much lower traffic density levels than train operations.

Bus and rail commuter services can essentially be split into two categories, viz. Suburban commuter trains operating along central routes with bus services providing transport to and from railheads, and pure bus services providing transport as required to complete the overall commuter network.

4.1.2 Omnibus Power Plants

Without exception all omnibuses in commercial operation in South Africa are diesel engined. Appendix 28 gives typical engine sizes by various manufacturers and these makes, forming the vast majority of bus types, can be taken as representative. Older types in existence will have engines of similar capacities, all engine types being of the high speed diesel type. This pattern is unlikely to change in the near future with the proven reliablity and efficiency of these engines. The operating fuel consumption remains substantially

constant for/......

constant for these engines and a figure of 2,7 km/litre appears to be representative (quoted by City Tramways, Cape Town) for all bus types.

4.1.3 Fuel Efficiency

Appendix 25 gives a detailed account of the operating statistics achieved by South African Municipal bus services combined with figures for the three largest private omnibus companies, in order that realistic mean values are obtained. By using the British figure for Transport Energy requirement (Ref.13) it was possible to estimate the total number of passenger kilometres transported, from which the remainder of the values were calculated. The use of this overseas figure is justified with load factors and bus types being very similar (Ref.12) to local conditions. The figures calculated in this section have been extrapolated (Appendix 26) to yield figures for the whole of South Africa. This was performed on the basis of the number of buses in service commercially in the country. A more detailed analysis of the smaller omnibus companies was not possible. For example, in the Durban area alone there are 200 small companies operating one and two buses individually. With approximately 80% of all operations accounted for in Appendix 25, it was considered that this precluded any possiblility of the small operators having any marked effect on the figures already established.

Considering just the diesel engine itself, typical peak thermal efficiencies for engines in this size and class is of the order of 40% to 50% depending on the age of the design and the installation (Ref.14). With an assumed drive train (transmission) efficiency of 80%

relatively/....

(relatively low as a result of semi-automatic gearboxes and clutches and the hydraulic pumps required) this yields, with an engine efficiency of 45% a peak operating thermal efficiency of the order of 35%. Evidently the engine does not operate continuously at this optimum level but fluctuates almost continuously under service conditions between idel and full power requirements. Bearing in mind the stop-start nature of bus operation in the majority of cases, coupled with regular periods of dense traffic conditions, it is reasonable to expect the power units to spend quite a large portion of their "Live" time under idle conditions. It is estimated, largely intuitively, that the operating conditions approximate 70% operation, at or very close to optimum efficiency levels and the remainder at idle, no useful work being produced. Using these assumptions, the overall operating (thermal) efficiency is of the order of 25%. Although a detailed study of omnibus efficiency under local conditions is not available, it is doubtful whether this would change the above figure much. This value is also not likely to change markedly in the future since the engine type is well established and no significant economy improvements are envisaged in the next few years.

4.1.4 Trolleybus Operations

As stated previously, the only trolleybus operations at present undertaken in South Africa are performed by the Johannesburg municipality. Figures for operation in 1973/74 appear in Appendix 27. The higher load factor (percentage occupancy) of this service over regular omnibus services is a result of the service operating in a prime transport area where continual use is made of the service outside of traditional peak hours. The capital outlay required for overhead wires and their maintenance has ensured that the service operates over high density traffic routes where there is a sustained demand for bus services.

Despite the advantages of silent, pollution free (in the city) operation, the trolleybus has become obsolete because of the cost, route inflexibility, and unsightliness of the overhead cables required and the chaos caused to such a system by any interrruption in the electricity supply. The reduced transport energy requirement appears attractive compared with diesel bus services, but the generation of electricity in the first place, with the associated losses, in effect cancels out this apparent advantage. By comparison with the diesel omnibus, trolleybuses have an operating efficiency (using supplied electricity as a baseline) of the order of 60% (Ref.15). Considering coal as the primary energy source, this figure becomes compatible with diesel powered units and there would appear to be no nett advantage, other than localization of pollution, in favour of either type, diesel buses however enjoying freedom from any roadside equipment.

4.1.5 Efficient Omnibus Operation

As mentioned earlier, the absence of any revolutionary improvements in engine efficiency for the very well established diesel engine requires that for any marked fuel efficiency improvements, the only avenue open for improvement is in the operating mode. The most obvious alternative is to improve the load factor (mean bus occupancy) under operating conditions. Peak hour conditions with buses running at capacity dictate

the size/.....

the size of the bus fleet in the vast majority of cases some attempt should be made to maintain higher service levels during quieter, off peak periods. This entails presenting a service that is attractive enough to dissuade the public from making unnecessary use of private motor vehicles, but rather to utilize public transport facilities. Attractiveness, in this sense, largely hinges on providing quick, reliable and "on time" bus services at realistic fare rates. To achieve this it is necessary to ensure that buses have essentially traffic free service routes and comfortable, convenient shelters at all bus stops. Bus lanes and even special traffic privileges are ways this may be achieved as these would helpensure rapid services and discourage private motorists who have to contend with congested roads and restricted parking in city and industrial areas. If omnibus services can offer the same degree of personal mobility as the private motor car along with shorter transit times, it is inevitable that public transport will gain in popularity and realize even larger savings in fuel energy as well as reduce congestion and pollution in concentrated urban areas.

4.1.6 Omnibus and Trolleybus Services

The cost of overhead electrification for trolleybus operation and other associated service disadvantages (Section 4.1.4) have resulted in a decline in the service operated to the extent that trolleybus transport consitutes a negligible fraction of the overall omnibus service. Total passenger kilometres transported are graphically presented in Figure 4.1 using information extracted from Appendices 24, 26 and 27. For the period 1960-1975, the mean annual expansion rate is approximately 4½%, apparently high in terms of the average value for the transport industry (3% p.a.) (Ref.4). However, the past few years have seen the decentralization of urban areas, with a large portion of the labour force being moved to outlying areas some distance from employment centres. As this sector of the population accounts for the largest fraction of bus commuters, it becomes obvious that the apparent increase in services offered is a result, not only of an increase in the number of passengers carried, but also of the distance each passenger travels.

The resettlement scheme is largely complete at the present moment so the artificially high annual bus transport growth rate is expected to diminish slightly. A further consideration is that as the average standard of living increases among the nation's labour force, along with the average individual's earning capacity, more and more people in this category are able to operate private motor vehicles. This increased vehicle ownership reduces the use made of public transport and over the 7 year period 1966 to 1972, the mean annual increase in the number of motor cars registered in this period was 5% p.a. (Ref.4) Considering all of the aforementioned factors, an annual expansion rate for the bus industry of 2½% p.a. was chosen as the basis for predictions for services offered until the turn of the century. Using this figure and the estimated thermal efficiency (25%), the graph illustrated in Figure 4.2 was prepared to indicate the fuel energy requirement and useful energy produced by this sector of the nation's transport network.

FIGURE 4.1 : S.A. BUS SERVICES - PASSENGER KILOMETRES TRANSPORTED

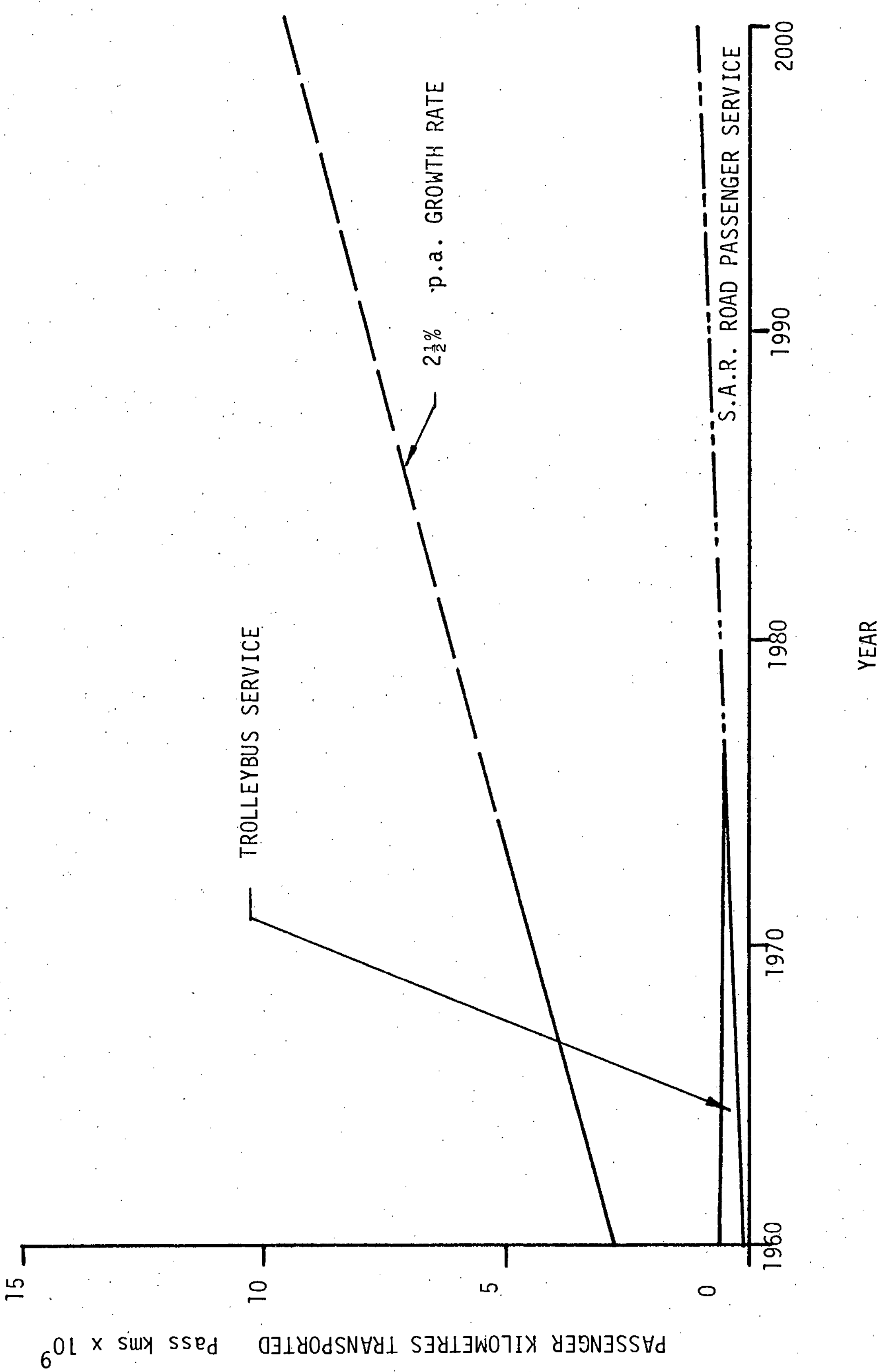
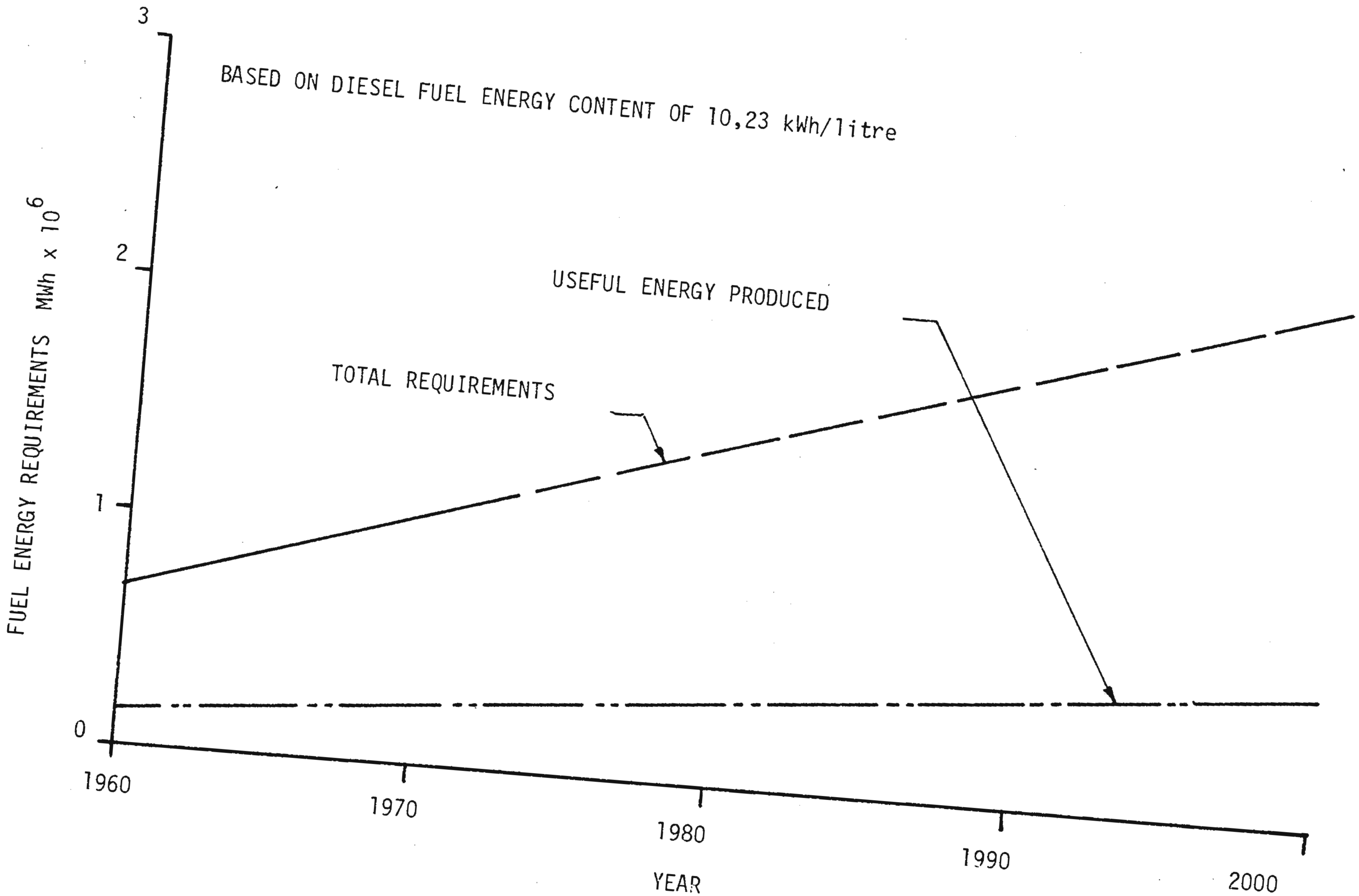


FIGURE 4.2 : OMNIBUS FUEL ENERGY REQUIREMENT



4.2 Commercial Road Transport

4.2.1 Introduction

Whilst road transport moves the bulk of South Africa's long distance domestic goods traffic, road transport provides a specialist service in the form of a distribution and collection network as well as transport to areas without railheads. The road transport system is, for obvious reasons, far more flexible than the railways and can also provide relief for seasonal peak requirements when any section of the rail system is overloaded. Typically road transport stage lengths will be shorter than rail journeys and as a rule cannot compete with rail for bulk transport over anything but the shortest routes. In certain instances road transport can provide a more rapid service than the railways over the long distance routes, and for certain domestic products this saving is necessary, ensuring that long distance trucking is utilized. Cost wise this type of service provides for an alternative between low speed bulk rail transport and the very rapid, but limited quantity air transit. Road transport however, really comes into its own for distribution and collection services over relatively short distances. For convenience and flexibility it may be said that road transport has no competition in this sphere of operation. The range of products that may be transported by road is unlimited, from very large abnormal loads through liquid and refrigerated produce down to the smallest and most delicate items, all are well within the scope of this very versatile system.

4.2.2 Truck Power Plants and Thermal Efficiencies

As with omnibuses, the standard truck power plant is the reciprocating diesel engine. Depending on the size and sophistication of the vehicle, the engine may be a small, simple and completely conventional unit, a high speed turbo-charged two stroke variant for large power demands, or anything in between. The peak thermal efficiencies of these engines lie in the range 30% to 50% depending upon engine size and refinement (Ref.14). Assuming a drive train efficiency of 90% and a typical engine peak thermal efficiency of 40% as a mean value results in a maximum efficiency of approximately 35%. For a medium sized truck operating over a fairly typical short to medium stage length, with a portion of this under urban traffic conditions, a 10% idle time (no useful work) appears realistic. With the varied engine duty cycle resulting in a mean thermal efficiency of 90% of the peak value, the overall operating efficiency will be in the region of 30% (ratio of useful work performed to total fuel energy). It is almost impossible to determine the exact figure but it is felt that this value of 30% will be very close to the real figure and this is born out by British studies of vehicles in the same class (Ref.13)

4.2.3 Trucking Fleet

To obtain the predicted increase in road freight traffic until the year 2000, data on the number of registered commercial vehicles since 1940 was compiled and presented in Figure 4.3. The annual increase in the size of the commercial fleet has remained substantially constant at approximately 6% per annum over the past few years.

With the fuel/....

With the fuel conservation legislation applicable in South Africa, and steadily rising fuel costs which will encourage industries to make more effective use of their vehicles, this expansion rate is expected to subside slightly and a value of 4% p.a. has been used as the basis for predictions into the future (Fig.4.3) As the source (Ref.4) of the numbers of vehicles registered includes all commercial type vehicles (light vans etc.) it has been assumed that only 35% of this number falls into the true road transport category, diesel powered with a payload in excess of two tonnes. This is in line with current British estimates (Ref.13), the ratio between freight vehicles and other types being similar in South Africa (Ref.16). This is also shown in Figure 4.3 and is the basis for further calculations on energy requirements.

4.2.4 Road Transport Energy Requirements

Considering only freight* transport vehicles with payloads in excess of 2 tonnes this will exclude all private vehicles (light vanettes) and most petrol driven vehicles which are not used exclusively for road transport and haulage work. As mentioned in Section 4.2.2, the vast majority of the vehicles now considered are diesel powered. With the small percentage of petrol driven vehicles and the similar calorific value of petrol fuel (gasoline), these vehicles have been ignored and incorporated in the totals as diesel powered vehicles. As a result of the foregoing, the total energy requirement will be unaffected by this omission.

* included liquid carriers, bulk carriers, refrigerated trucks, etc.

A recent British survey has revealed that the mean payload for haulage vehicles in this **class is** 4,45 tonnes and each vehicle travels an average of 22 000 km per annum (Ref.13). Due to the similarity of vehicles used, the mean payload is expected to be much the same under South African conditions, whilst the annual distance travelled will be substantially greater by virtue of the large route distances prevalent in the Republic. The annual distance travelled by individual vehicles varies enormously from less than 30 000 km to more than 80 000 km although most vehicles fall within the range. For comparative figures the mean annual distance travelled by an omnibus in South Africa is 53 000 km (Appendix 25), i.e. approximately 150 km per day. Bearing this in mind, and considering the operational modes of bus and freight transport, it is estimated that the average freight vehicle in the category considered will travel 45 000 km per annum. Over a 10 year working life this results in each vehicle travelling a total distance of 450 000 km in line with reasonable estimates of life expectancy (Ref.13).

By virtue of the specialised services operated by the SAR road motor fleet (Appendix 24) the average distances travelled are lower than the commercial road haulage average, although similar vehicles are used.

As average vehicle payloads are in the same range as the industry average, the fuel energy requirement of 1,64 kWh/tonne km (Appendix 24) is used for the total haulage service. (Provided by the S.A.R.)

The estimated figure/..

The estimated figure for total freight tonne kilometres transported in 1975 (Appendix 30) indicates that by comparison with rail freight transport, road transport accounts for just less than 50% of all rail movement. Alternatively this means that road transport performs roughly one third of all land transport in South Africa. The largest portion of this road transport is involved with goods distribution over non-rail routes (estimated at 60%) the remainder operating on competition with direct rail services where criteria discussed in Section 4.2.1 become operative.

As a result of the foregoing, with each haulage vehicle transporting 4,5 tonnes of payload, a mean distance of 45 000 km this analysis represents a transport productivity per vehicle year of 200×10^3 tonne kilometres with an annual power requirement of 330 MWh, 30% of which is converted to useful energy. In general terms, these figures are not expected to change significantly in the future, the services having already reached near optimum performance. Although the large sized vehicles show an improvement in operating efficiency over smaller vehicles, increasing size tends to reduce services flexibility and is ultimately confined to maximum limits imposed by road construction and governmental road traffic legislation. Considering the large variety of present road users it is deemed unlikely that a demand from such a small sector of the users will result in any changes in present road networks to accommodate larger vehicles. Moreover, these extra large vehicles encroach more and more on the traditional territory of rail transport which is more efficient for the transport of bulk commodities and large freight consignments. As a result of these considerations, the total road transport industry has been projected in terms of number of vehicles operating annually, efficiency levels and power requirements

remaining/....

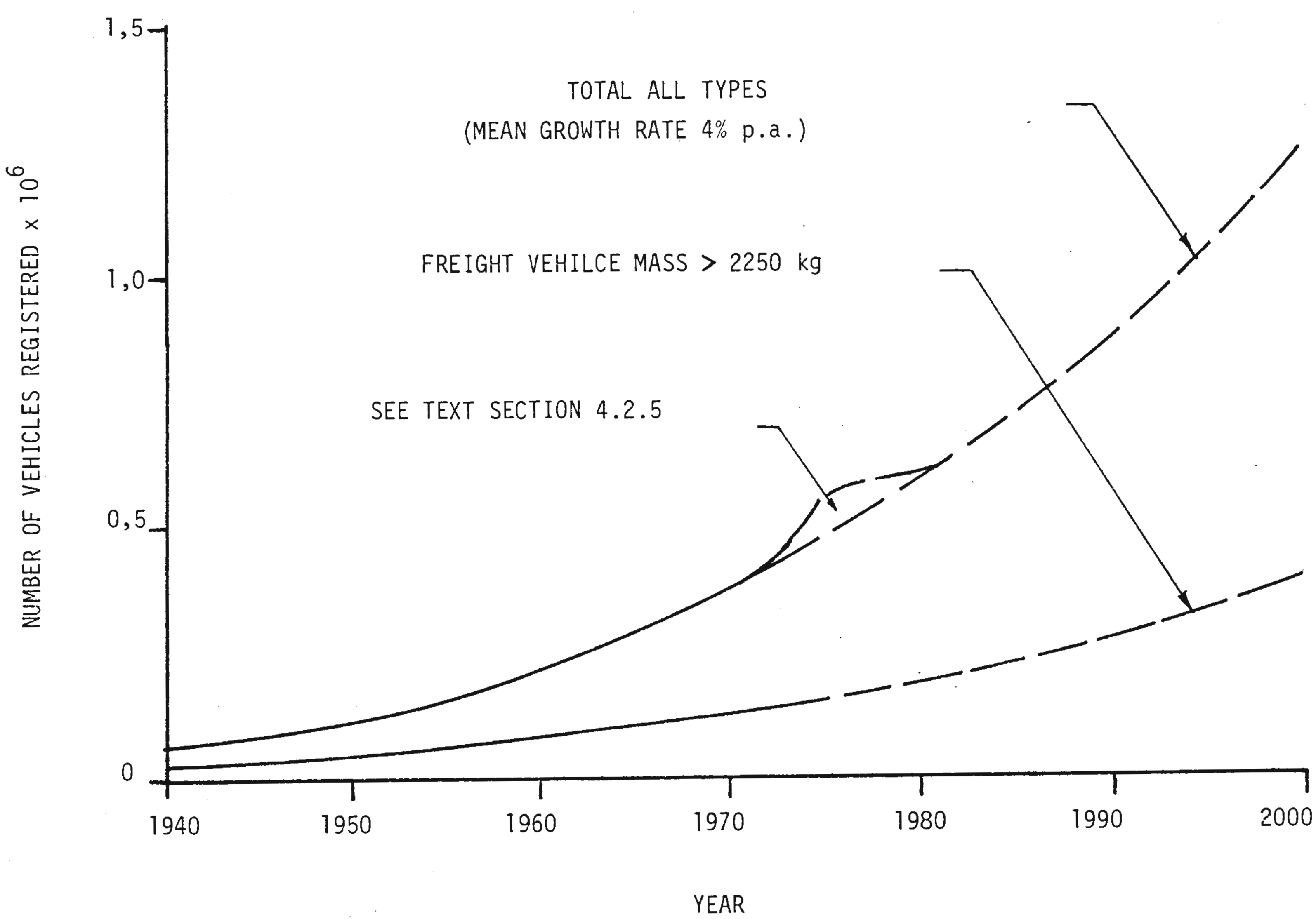


FIGURE 4.3 : COMMERICAL ROAD FREIGHT VEHICLES REGISTERED

FIGURE 4.4 : ROAD FREIGHT TONNE KILOMETRES MOVED PER ANNUM

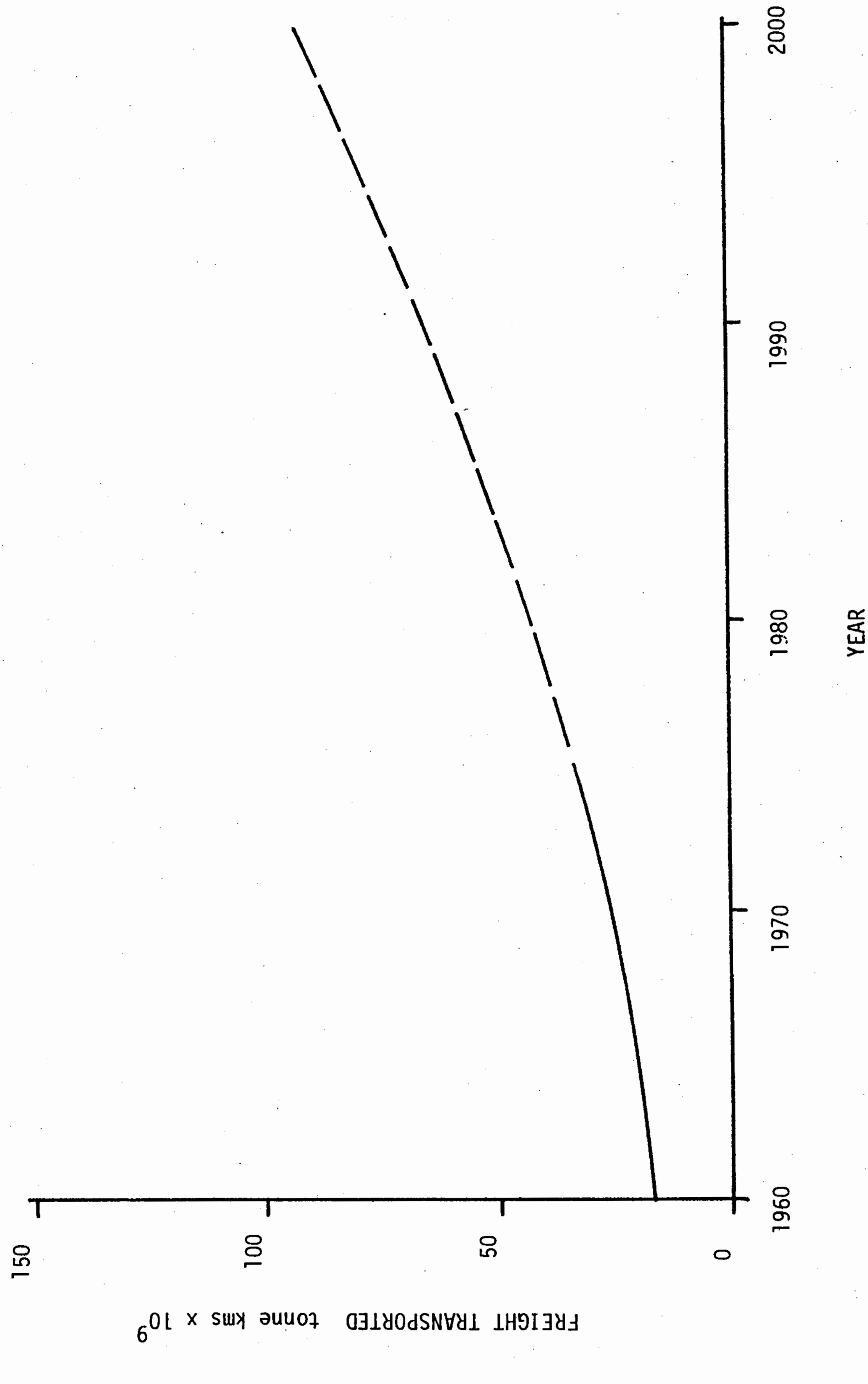
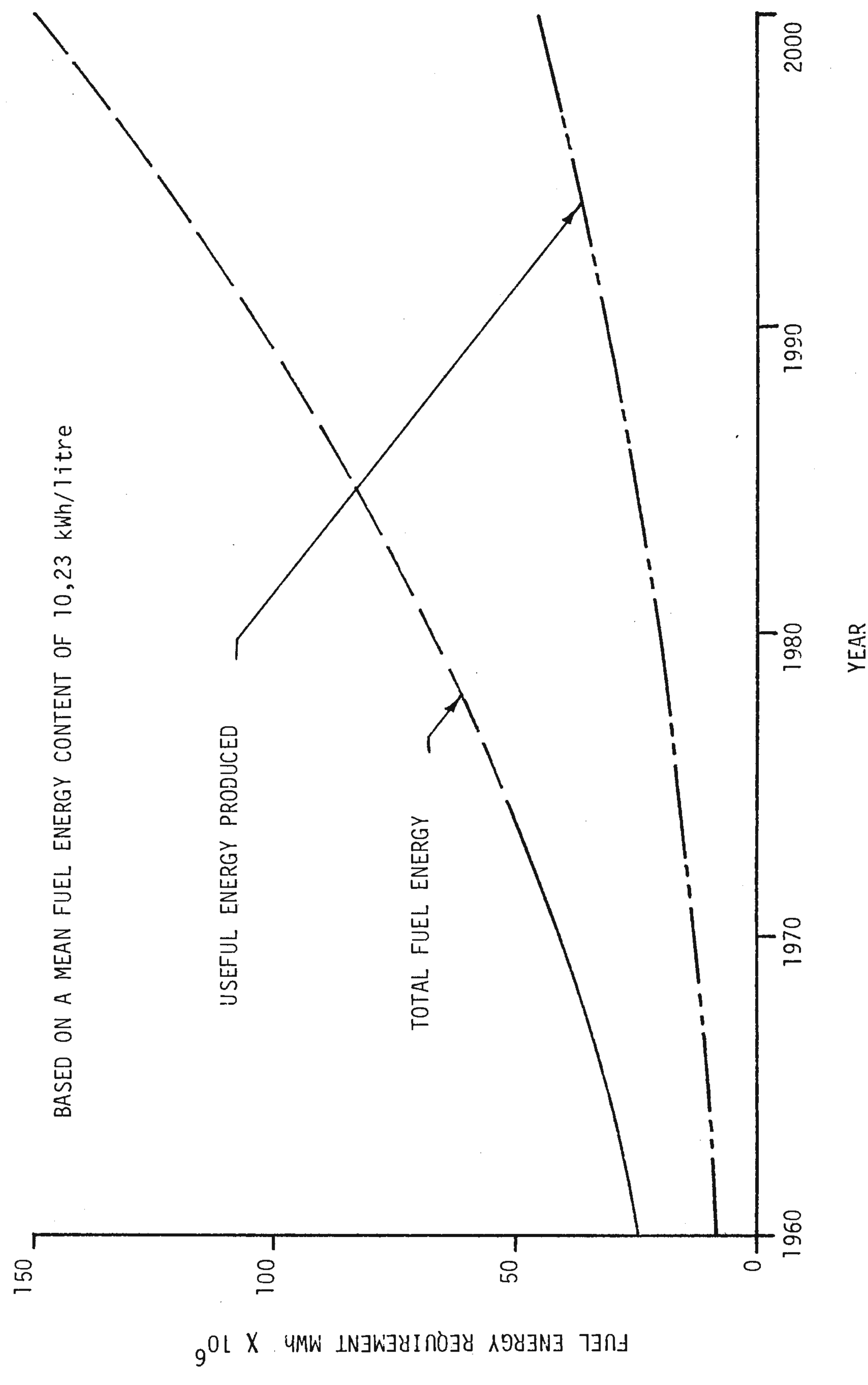


FIGURE 4.5 : ROAD FREIGHT TRANSPORT FUEL ENERGY REQUIREMENT



remaining at present levels with no significant changes.

4.2.5 Discussion - Road Freight Transport

The period 1970-1974 shows a marked increase in the number of commercial vehicles registed (Figure 4.4). It is over this period that South Africa underwent a marked upswing in industrial and economic levels, resulting in greater road transport demands. This state of affairs has now largely been reversed with poor economic climate facing the country at the moment, and in the short term future. A recovery from this mild recession should result in a return to the normal expansion rate of road transport, and predictions based on the artificially high levels of the last few years would be unrealistic. For this reason the expansion of the registered commercial vehicle fleet has been continued at the 4% p.a. level (Section 4.2.3) from 1970 levels rather than the actual figures for the period up to 1975. Together with the economic considerations mentioned above, the recent fuel conservation measures are also expected to contribute to a fairly rapid return to the predicted "normal" expansion rate.

4.3 Private Road Transport

4.3.1 Introduction

By far the largest undertaking in the private road transport sector is the use of private motor vehicles for personal travel. Most of this travelling occurs in urban areas over fairly short distances, eithe for commuting to work or for other business travel and also for travelling to recreational activities, the transport of school children and

domestic shopping/..

domestic shopping. Undoubtedly, the private motor car offers the highest level of personal mobility of all transport systems which is the prime reason for the extensive use it enjoys. Being an expensive consumer product in terms of capital outlay and operating costs, its use is restricted to middle and upper income groups. The rise in the cost of petrol and garage maintenance over the past five years has suppressed the growth of the industry which, coupled with the present economic climate in South Africa, has lead to the general recession apparent in the motor trade today (1977). It is doubtful whether Government fuel legislation has contributed to the slackening of the purchase of motor vehicles, but this had had the effect of reducing the total distance travelled per annum by the average car and imposed some measure of the need for fuel conservation on the public.

4.3.2 Motor Vehicle Polulation

Before any analysis of the energy requirements of private road transport could be performed, it was necessary to forecast the number of motor vehicles in South Africa between now and the turn of the century. Other sources (References 17,18) quote the figures shown in Tables 4.1 and 4.2 respectively.

Year	Total Motor Vehicle Population x 10^3
1972	2 456
1980	4 159
2000	10 329

TABLE 4.1 : Source - Reference 17

Table 4.2/.......

Year	Motor Car Population for seven urban areas* x 10^3
1970	989
1980	1 768
2000	4 609

TABLE 4.2 : Source - Reference 18

* Bloemfontein, Cape Town, Durban, East London, Johannesburg and Witwatersrand, Port Elizabeth and Pretoria.

Form Tables 4.1 and 4.2, Table 4.3 was compiled to show what percentage the estimated mumber of cars in the seven major urban areas was of the total number of vehicles in South Africa.

Year	Percentage of Total : Number of cars in the 7 major urban areas
1970	46,6
1980	42,5
2000	44,6

TABLE 4.3

It was noted/.......

It was noted from Table 4.3 that the number of cars in the seven major urban areas maintained a substantially constant ratio to the total number of vehicles (licenced and exempt from licencing) in South Africa.

The estimates contained in Reference 17 and shown in Table 4.1 are based on the correlation between historical data of the number of vehicles and the Gross Domestic Product (G.D.P.) It is felt that, while the method used is satisfactory for predictions over periods when external factors remain similar, it is unrealistic in the present context for the following reasons :

1) Up until the end of 1973 no restrictions existed on the sale and use of petroleum fuel for private motoring. This is not the case now with Government fuel legislation governing maximum vehicle speeds and petrol selling hours.

2) Traffic congestion in central urban areas is reaching levels where further legislation is likely to be enacted in the not too distant future restricting the use of private vehicles in these areas.

3) Petroleum fuel availability was not a limiting factor to private motoring prior to 1973 whereas now and in the future this will definitely be the case, either as a result of financial or political inadequacies or because of the depletion of natural oil reserves.

Since all of/.....

Since all of the factors mentioned above will have an adverse effect on the private motoring sector, predictions based on a simple analogy between G.D.P. and the number of vehicles (based on a historical period with virtually no incumbent restrictions) will reflect unrealistically optimistic figures.

The predictions of Reference 18 shown in Table 4.2 were based on forecast trends for the rate of motor vehicle ownership per head of population. The value quoted for 1970 was 72,5 vehicles per 1000 head of population and for 2000, 147 vehicles per 1000 head of population. This latter figure was arrived at by comparing vehicle ownership rates with those of 25 other developed countries and attempting to equate these to South African conditions. While cognisance of the fact that urban traffic congestion will ultimately depress car ownership rates in these areas was taken, the ability of the petroleum industry to sustain this number of vehicles was not considered. Again it was felt that the figures quoted in this reference were optimistic and that the actual values will be somewhat lower.

One further factor which may have influenced the choice of these values was the fact that the latest historical data available to the authors was probably the 1972/1973 period. This coincides with the peak of a period of exceptionally vigorous industrial and economic growth in South Africa and it is likely that the artificially high annual expansion rates prevalent at the time may have been used to extrapolate historical data. Subsequently, an economic recession (as a result of a fall in world gold prices, the so called "oil crisis" and increasing isolation of South Africa from world trade) has placed industrial and economic rates back in line with long term

historical trends/....

historical trends. Estimates throughout this report have ignored these short term effects (Figures 2.1 and 4.3) and are based on established long term trends, modified where applicable by technological changes, fuel availability, new operational considerations and the interaction of allied or competitive transport modes.

It was on the above lines that the vehicle population was estimated, the figures appearing in Appendix 32 and represented in Figure 4.6.

4.3.3 Transport Work Performed

A personal survey conducted in and around Cape Town over the period 18th to 28th January 1977 in various weather conditions, yielded the following data for mean vehicle occupancy. The survey was performed at both urban and peri-urban points in groups of 50 vehicles at rush hour and off-peak periods.

Vehicle Occupancy	Occurence
1	562
2	285
3	112
4+	41

Total number of vehicles : 1 000
Total number of passengers : 1 632

Mean vehicle occupancy : 1,632 passengers/vehicle

Note : Foreign vehicles, motor cycles and commercial vehicles were deliberately excluded.

The purpose of this survey was to provide approximate data on vehicle occupancy to compare with foreign values. British estimates are in the region of 1,4 to 1,55 passengers/vehicle (Ref.13) so the slightly higher mean occupancy found locally may well be due to the sharing of vehicles by lower income groups, as well as the smaller percentage of public transport services available in South Africa.

A further survey was conducted to give an idea of the annual distance travelled per vehicle in the private sector. Seventeen used vehicle sales premises were visited to ascertain the age and odometer reading of secondhand vehicles up for sale. This covered a total of 227 private cars of all types with individual ages varying from 14 years to just a few months. The survey was conducted in and around Cape Town over the period 31st January to 5th February 1977 and yielded the following results :

Total cumulative vehicle age	:	849 years
Total distance travelled	:	$10{,}29 \times 10^6$ kilometres
Total number of vehicles	:	227

Mean distance travelled per car per annum
= 12 114 km

Other centres (especially Johannesburg) may be quite different in this respect, but as shown below, this figure corresponds well with other national estimates and in any case was only intended as an approximate guide.

Combining the/.....

Combining the data of these two surveys results in a transport work figure of 19 750 passenger kilometres per car year. The value computed from figures given in Reference 18 is 18 813 passenger kilometres per vehicle year (Appendix 33). (This value is unaffected by the optimism of the figure which was analyzed in Section 4.3.2 since the calculation results in an average index rather than an absolute value). Accordingly, a mean value of 19 000 passenger kilometres per vehicle year was chosen as the basis for estimating the total transport work performed. While city congestion will tend to raise the mean vehicle occupancy rate, fuel availability and Government control over sales is expected to reduce the total annual distance travelled by each vehicle and it has been assumed that this figure will remain substantially constant over the period considered. Appendix 34 was prepared and the results given in Figure 4.7 showing the total transport work performed by the private transport sector.

4.3.4 Fuel Energy Requirements

Improving car engine technology, the current trend to smaller vehicles (with improved seating capacity per unit vehicle mass) and the indicated trend of increasing mean vehicle occupancy all have beneficial effects on reducing the energy requirement of private passenger vehicles per person kilometre transported. British estimates (Reference 13) show a 12,5% improvement in this factor from approximately 0,8 kWh/passenger kilometre to 0,9 kWh/passenger kilometre over the period 1960 to 1970. In the absence of any South African data, and because of the similarity of vehicle types in the two countries, it was decided to adopt these figures

FIGURE 4.6 : NUMBER OF PRIVATE MOTOR VEHICLES REGISTERED

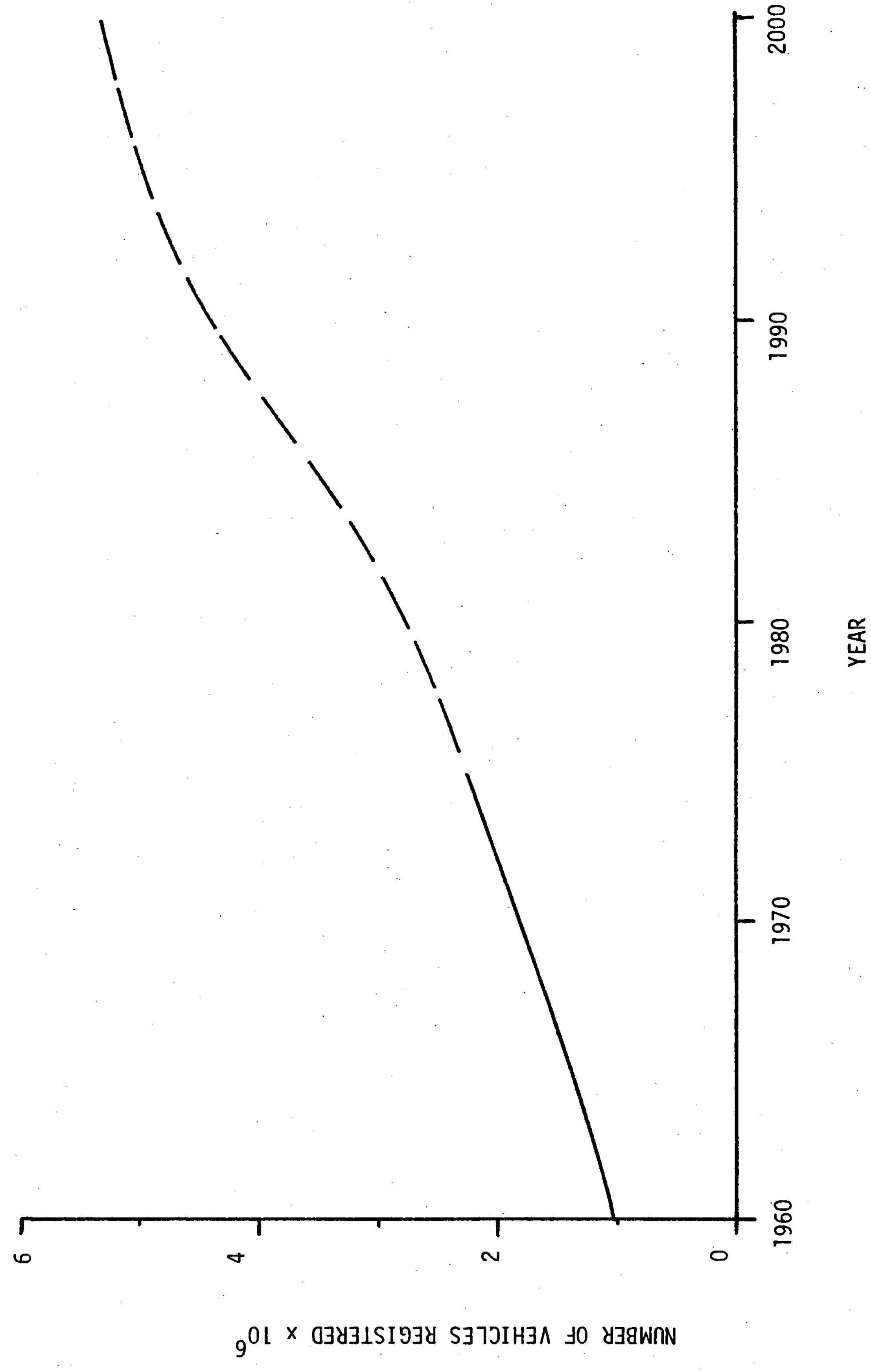


FIGURE 4.7 : PRIVATE MOTOR VEHICLES : TRANSPORT WORK PERFORMED

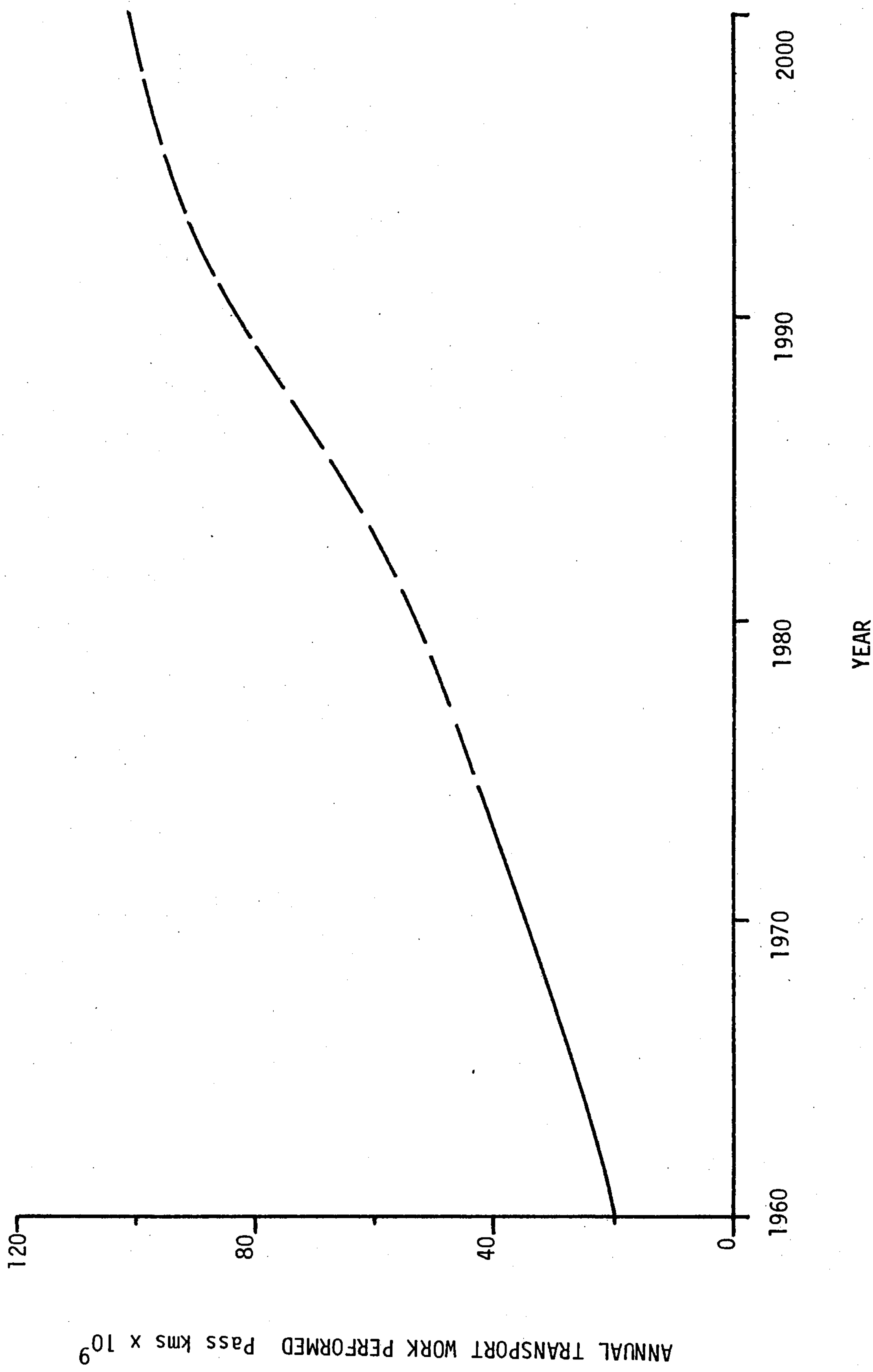


FIGURE 4.8 : SPECIFIC FUEL ENERGY REQUIREMENT : PRIVATE MOTOR VEHICLES

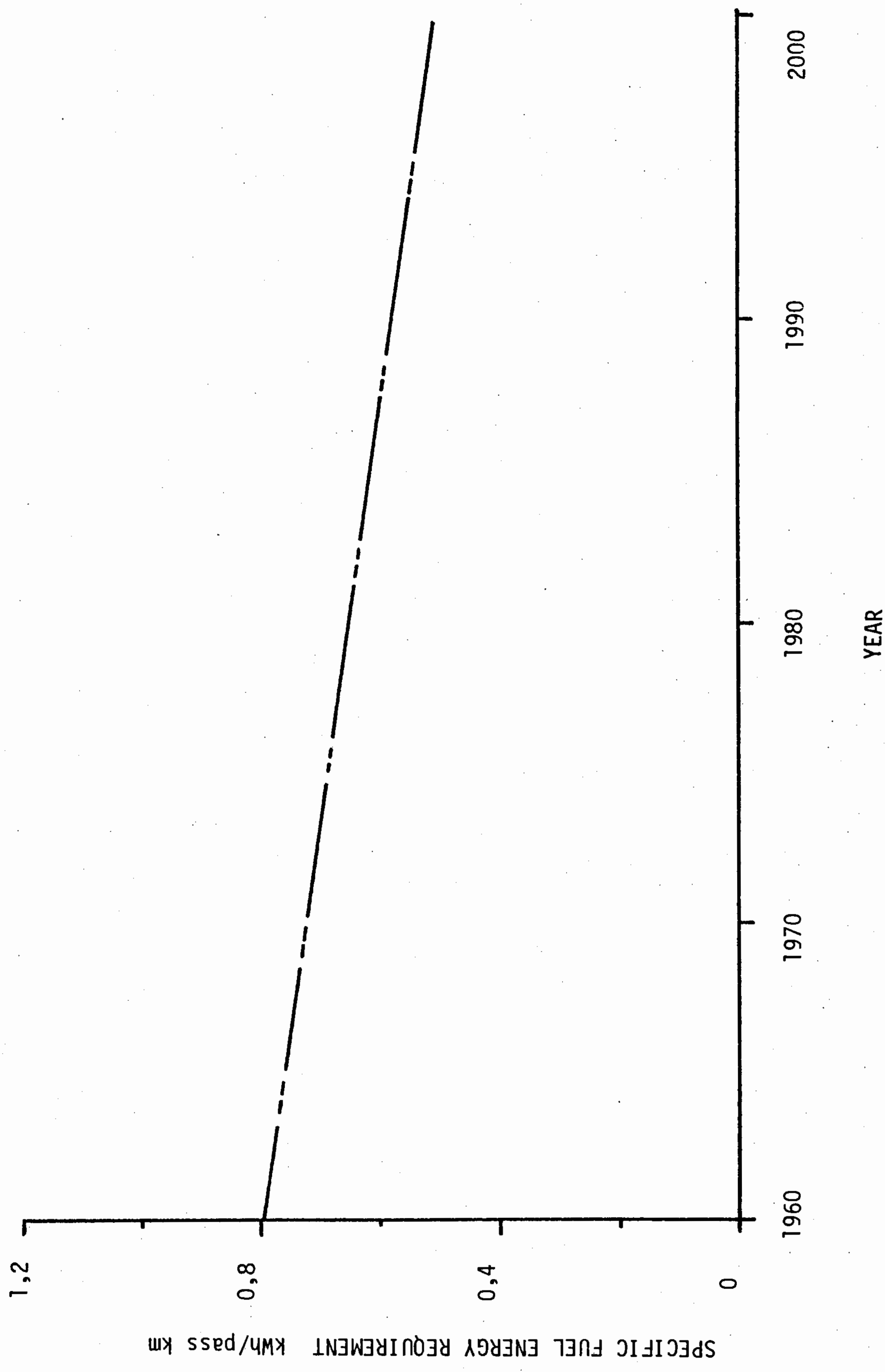
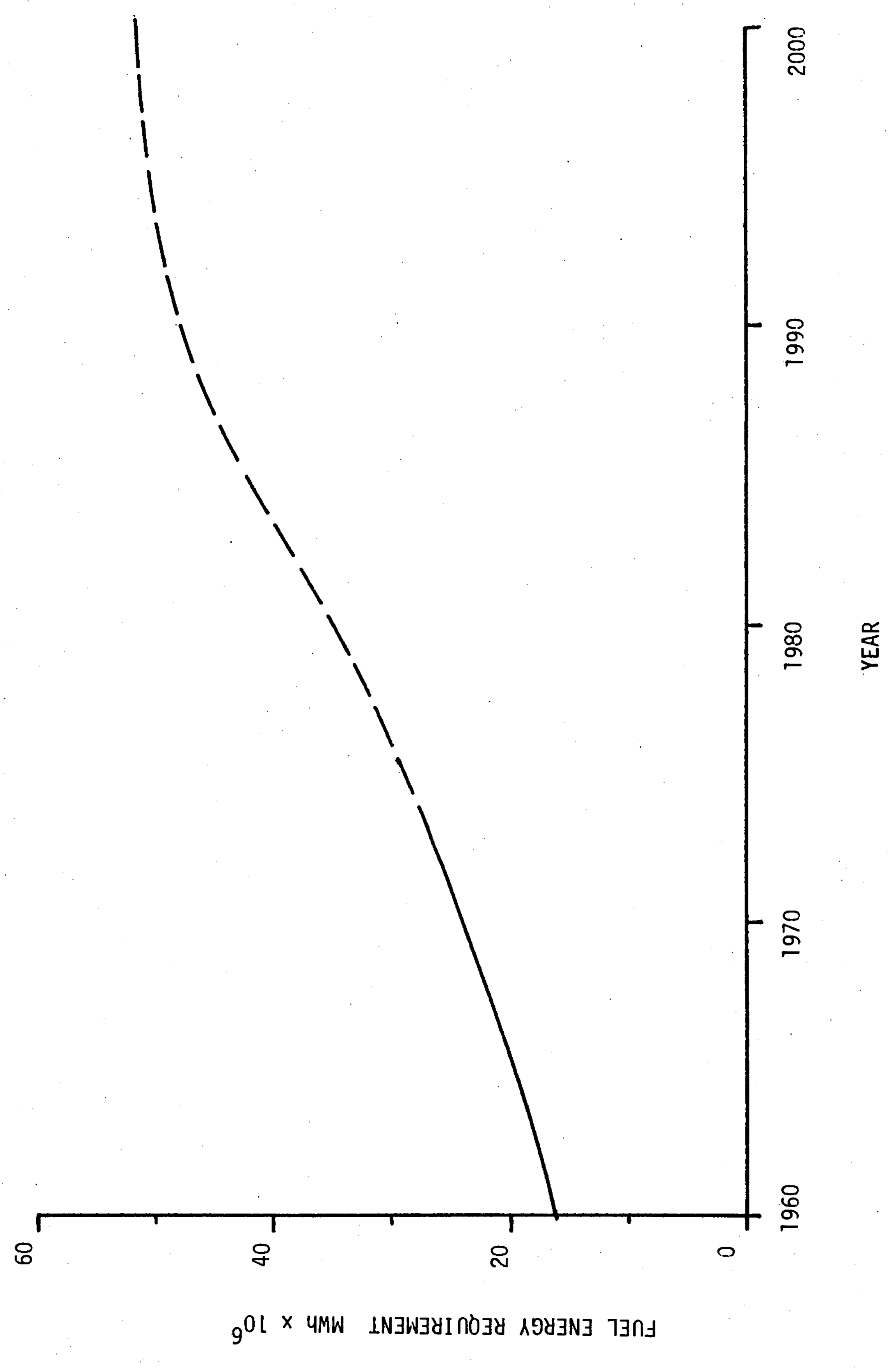


FIGURE 4.9 : ANNUAL FUEL ENERGY REQUIREMENT : PRIVATE MOTOR VEHICLES



as being representative. This is equivalent to a mean vehicle fuel consumption figure of approximately 9,37km/litre (25 miles per gallon) which compares favourably with advertised figures for present medium sized cars. For the reasons given at the head of this paragraph, it has been assumed that this trend will continue fairly linearly until a figure of 0,5 kWh/passenger kilometres is applicable by the turn of the century. These figures are given in Appendix 34 and shown graphically in Figure 4.8.

By using the above figures it was possible to compute the total annual petroleum fuel energy requirement for this sector of the transport industry. The figures appear in Appendix 34 and are represented in Figure 4.9

4.4 Conclusions - Road Transport

The nation's omnibus services, both private and municipal, can look forward to a continued expansion rate well into the future. Although fuel restrictions and traffic congestion levels in South Africa's cities is causing a steady gain in the popularity of bus commuter travel, a continuous rise in the standard of living of the nation's lower working classes has placed many people in a position to own private motor vehicles, and thus reduce the commuter demand at the other end of the scale. American and Western European nations have countered this and further improved the attractiveness of urban bus travel by creating "bus only" areas and traffic lanes and special traffic privileges for omnibuses. Coupled with attractive convenient and weatherproof terminus facilities, these improvements have greatly enhanced the image of bus commuter

travel/.....

travel. However, the degree of personal mobility offered by the private car, and in many cases **the pure status** symbol attached, means that the omnibus service is waging a continual battle to expand. The advantages of increased usage of bus commuter services are numerous; reduced traffic congestion in city and industrial centres; alleviated parking problems and less noise and pollution, but the basic and strong resistance to change by the public must be overcome, perhaps with the aid of government legislation.

As with the railways, road freight transport enjoys an expansion almost directly coupled with the nation's industrial output. From the foregoing chapters, commercial road haulage performed by vehicles with payloads in excess of two tonnes perform roughly one third of the land transport in South Africa, most of this being in the form of short distance goods distribution. The survey incorporates all vehicles in this class, whether commercially operated as transport concerns or as service vehicles by individual companies. With well established service patterns, the fuel efficiency and growth rate of the industry is not expected to undergo any marked change, but to maintain present levels. Should serious fuel shortages threaten the industry as a whole in the future, change-over to an alternative fuel source (probably hydrogen) will maintain the essential service provided at present. Long term industrial expansion if carefully done could reduce the need for road transport per unit of industrial output but this and alternative fuel sources will be long term effects only being felt gradually. This is particularly the case with South Africa's vast oil-from-coal potential and the fact that imported fuel will not have to increase in price much above present levels to ensure the viability of these local fuel sources.

The limiting/......

The limiting factors to the growth of the private car sector will be central urban congestion and the cost and availability of petroleum fuel. Travel by private car constitutes the bulk of non-essential travel in South Africa, and in the face of fuel supply problems, it will naturally be the first to be controlled, as has been witnessed by the recently implemented legislation controlling the sale of petrol to motorists, which has already been altered from the initial restrictions to have further reaching effects. Rising fuel costs will similarly impose artificial restrictions on the private car industry, effectively raising the financial pre-requisites for vehicle ownership and reducing the number of potential users. To a large extent this will be countered in terms of the total transport pattern by causing the mean vehicle occupancy rate to increase, ensuring that a more efficient use of fuel energy is achieved, without drastically altering the service provided.

CHAPTER 5

SOUTH AFRICAN HARBOURS

5.1 Introduction

Of all forms of international freight transport, shipping carries the bulk of long distance transport. South Africa is no exception with harbours situated at Durban, Cape Town, Port Elizabeth, East London, Walvis Bay and Mossel Bay. In addition to these major ports, there is a harbour at Saldanha Bay and the planned development of one at Richards Bay, north-east of Durban. Minor harbours also exist at Luderitz and Port Nolloth.

As at 1970 the register of harbour craft consisted of the following :

19 Tugs
13 Pilot Tugs
2 Pilot Launches
4 Floating Docks
9 Dredgers
2 Hoppers
39 Launches
3 Floating Cranes
97 Miscellaneous Craft
(Lighters, Pontoons, Divers Boats, Dinghies, etc.)

These vessels are distributed among the harbours mentioned above, in accordance with the size of the harbour concerned. Durban and Cape Town are the major ports handling some 75% of all shipping performed in South African harbours. In the 1969/70 financial year 42 017 000 tonnes were handled, 31 880 000 tonnes being handled by Durban and Cape Town. Corresponding figures for 1974/1975 are 60 996 000 tonnes handled, 45 149 000 tonnes at Cape Town and Durban.

This Section deals with the gross energy requirement for handling this cargo in South African ports. The term "cargo handled" includes landed cargo, shipped cargo and transhipped cargo. From this gross energy requirement, the useful energy produced has been estimated in terms of the utilization efficiency of cargo handling equipment and the direct (fuel and electricity) energy requirements.

5.2 Assumptions and Calculations - S.A. Harbours

As a basis for the estimation of energy requirements into the future, it was necessary to establish a prediction of the tonnage of cargo handled at S.A. ports. This was based on historical data (Refs. 8-11) and extrapolated into the future at a mean annual increase of 3%. This figure was chosen by considering the nation's industrial expansion rate, assuming cargo handling to directly reflect industrial activity. This information is contained in Appendix 35 and is represented on Figure 5.1. International estimates of the energy required per tonne of cargo handled (Ref.19) are detailed in Appendix 36 for 1975 and previous years. A study of cargo types revealed that roughly one third of all cargo handled in S.A. is bulk media, the remainder classed as general cargo for the purpose of this report (Refs.8-11) This allowed a weighted mean of the overall energy requirements to be calculated. It has also been estimated, in line with current expectations, that the implementation of containerized cargo transport will halve the direct energy requirement of cargo handling (Ref.19), leaving the remaining requirements largely unaltered. With the relatively long life span of cargo vessels, this reduction is only expected to take effect gradually, beginning now and only being completed by the turn of the century. This is graphically presented in Figure 5.2. The product of these values and the respective quantity of cargo handled yields the gross energy requirements detailed in Appendix 37 and presented in Figure 5.3.

The conversion efficiency of quayside handling facilities varies widely. For example, an electrically operated wharf crane might have an overall efficiency of upwards 80% whilst a coal fired pilot tug may operate at less than 20% efficiency. Considering the relative disposition of this varied equipment, a weighted mean utilization efficiency of 50% was chosen as the figure for a representative value. Using this figure the useful energy produced was added to Figure 5.3. It is stressed that this is an average value over the period 1960 to 2000 and does not account for improvements in the efficiency of harbour equipment. However, changes in this direction will be relatively slow due to to relatively long life-span of this equipment, and other than containerisation and in limited cases, single buoy mooring (SBM) for bulk discharge, no major changes are on the horizon for freight handling in ports.

5.3 Conclusions - S.A. Harbours

As outlined in this report, the harbour energy requirements for cargo handling are obtained from considerations of direct energy requirements and those for harbour construction, plant and equipment, and floating craft. Direct energy requirements (fuel, coal electricity) make up the major share of this gross energy value as shown in Figure 5.3. The slackening gain in annual energy requirements is a result of the introduction of container shipping and the corresponding reduction in the power requirement **per tonne of cargo** handled.

Beyond this normal change, no untoward tendencies are apparent in the results. The useful energy produced represents roughly 25% of the gross energy requirements of running and maintaining cargo handling harbours. As the major transport mode of all imports and exports from S.A., her harbour trade will be in direct accordance with the nation's economic and industrial productivity and with this assured, the future of her sea ports are secure and guaranteed.

FIGURE 5.1 : TOTAL ANNUAL CARGO HANDLED IN SOUTH AFRICAN PORTS

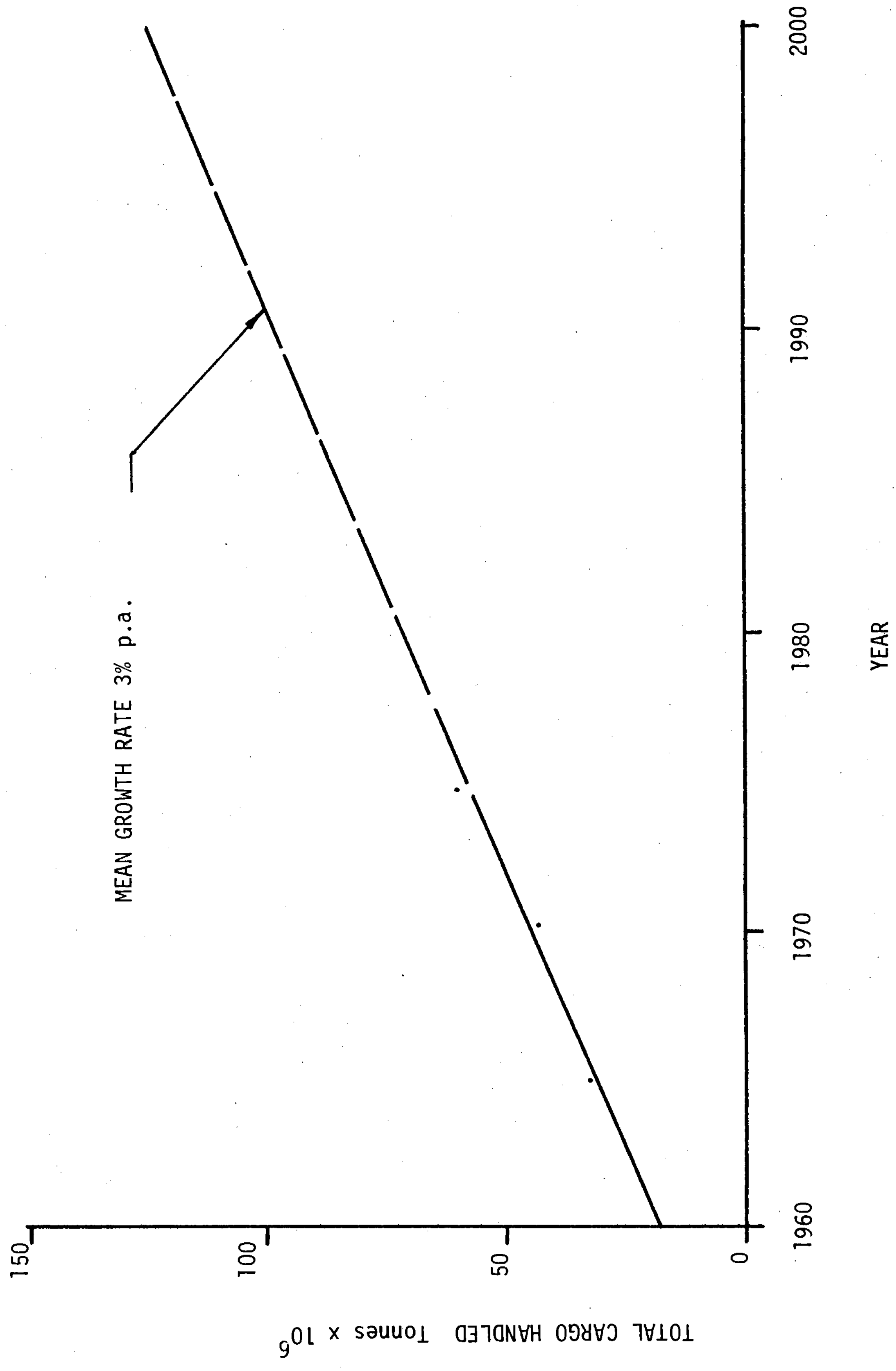


FIGURE 5.2 : ESTIMATED ENERGY REQUIREMENTS FOR CARGO HANDLING : S.A. PORTS

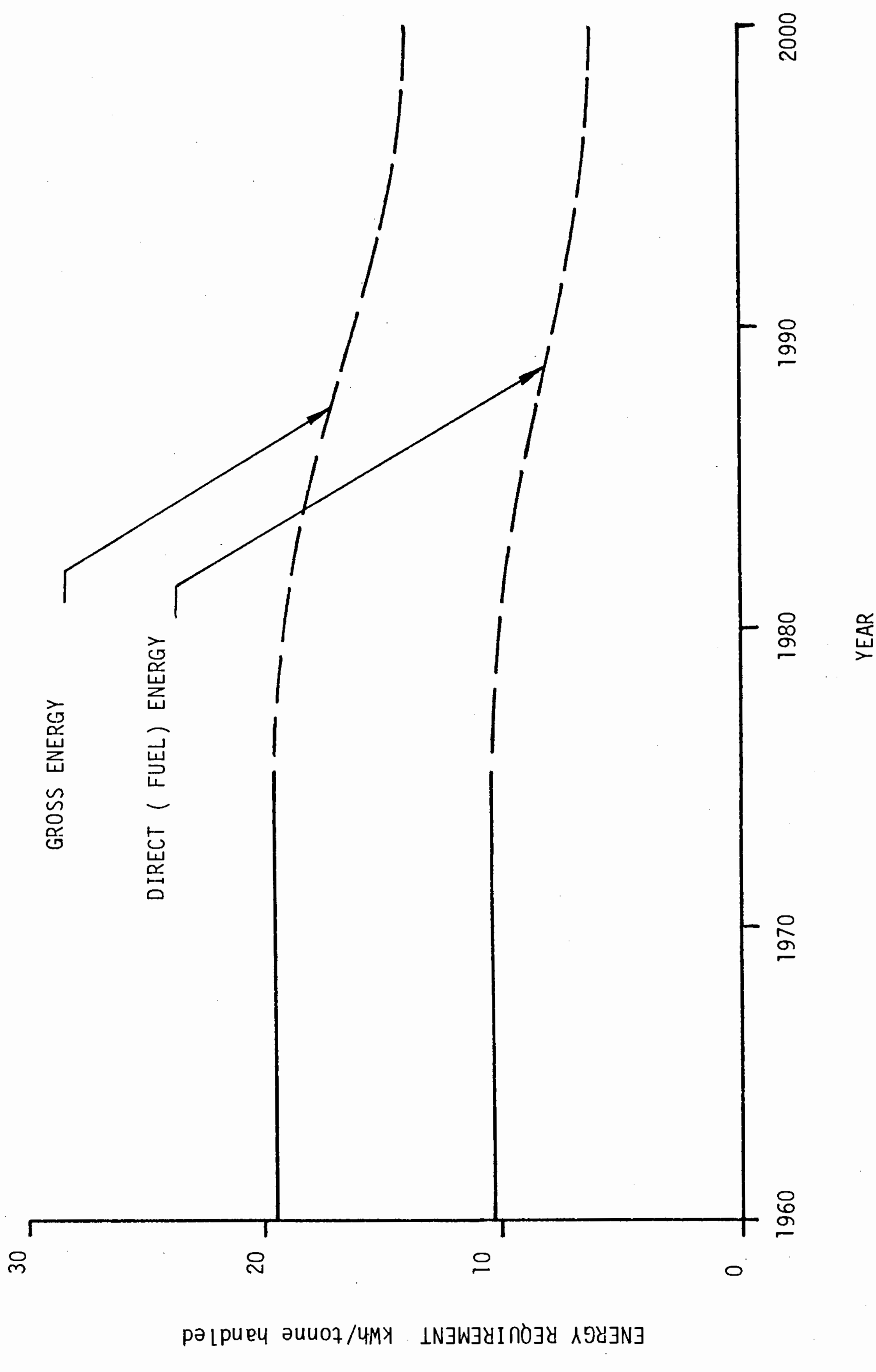
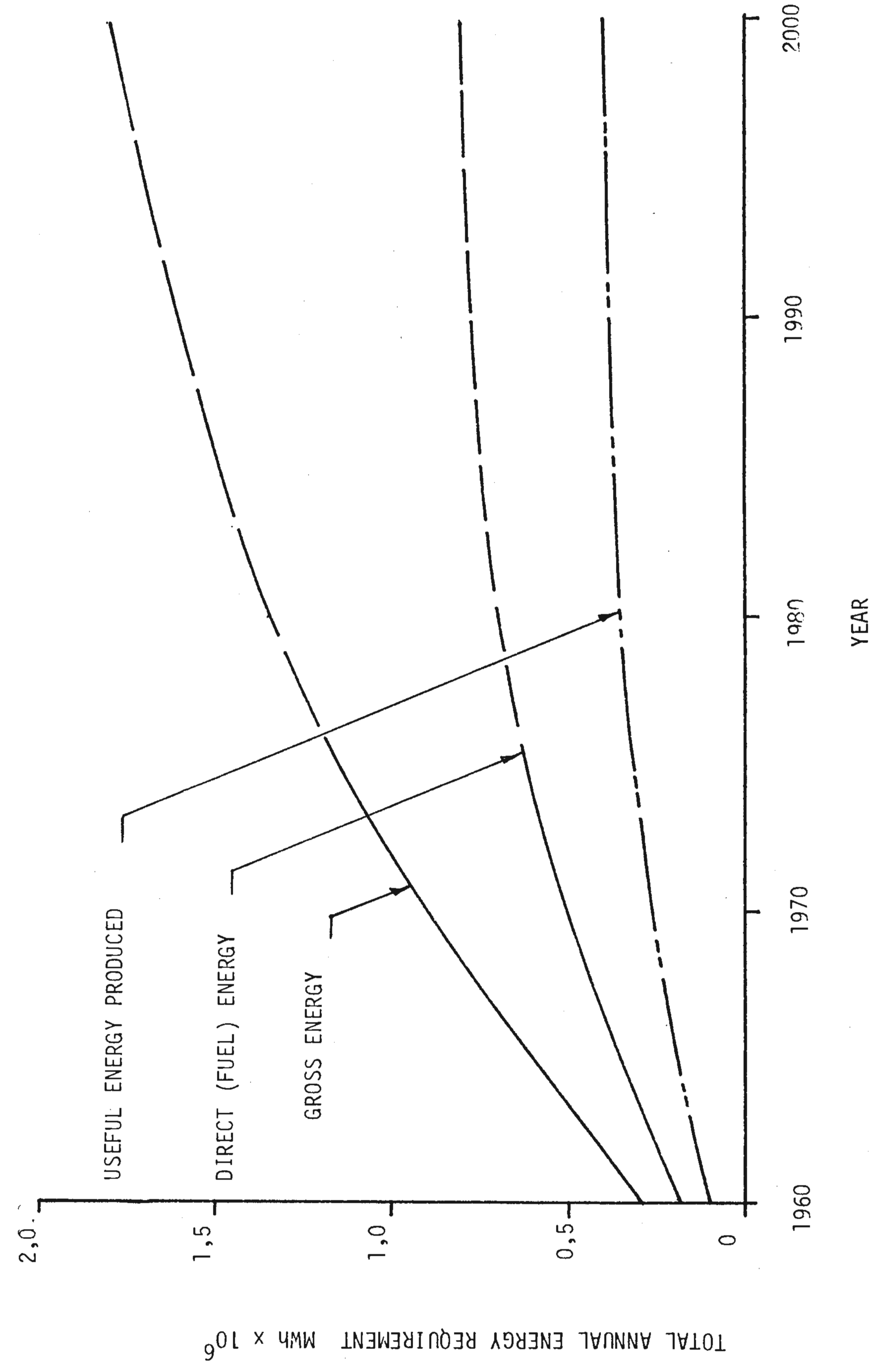


FIGURE 5.3 : ANNUAL S.A. HARBOUR ENERGY REQUIREMENTS FOR CARGO HANDLING



CHAPTER 6

SOUTH AFRICAN SHIPPING

6.1 Introduction

As South Africa has trade dealings with several foreign nations and controls the major harbours around the Cape sea route, ships from all over the world make use of these facilities. Vessel size varies a great deal from small coasters to giant bulk oil carriers in excess of 300 000 tonnes deadweight. In Chapter 5, estimates have been made of the growth of shipping movements in terms of the tonnages of goods handled at South African ports which imply that 1975 levels will double by the end of the century, an indication in itself of the value of this form of transport. Isolated as it is, South Africa is almost totally reliant on sea transport to provide the industrial outlets to the other countries in the world who trade with her.

6.2 Shipping Services and Energy Requirements

Due to the international flavour of South African shipping movements, it becomes very difficult to analyse exact energy requirements for fuel oil (marine diesel and bunker oil) which provides the vast majority of transport power to the shipping sector. The first step was to ascertain the mean vessel size of ships using South African harbours. This was done in Appendix 38 using data from References 8-11 inclusive. It was noted that the mean vessel size increased steadily with a marked rise over the period 1970-1975, probably due to the closing of the Suez Canal, coupled with the trend increasing vessel size throughout the world. Over this latter period the total number of **ships calling** at South African harbours decreased by more than 20%. It has been assumed that this trend will stabilize at a weighted mean vessel size of 25 000 tonnes gross registered weight because of harbour draught considerations (already many of the larger ships can only enter South African ports when lightly loaded or in ballast). Reference 19 quotes a fuel energy requirement of approximately 0,18 kWh/tonne kilometre for vessels in this size range. This is expected to remain fairly constant over the next 10 years but drop gradually thereafter to a value of 0,16 kWh/tonne kilometre by 2000. (Due to the long lifespan of sea-going vessels any improvements are slow in having a beneficial effect on the service's fuel requirement).

A further difficulty arises when attempts are made to estimate mean voyage lengths to determine the fuel requirements of vessels docking in local harbours. Vessel range may well be in excess of 5 000 km or as low as 1 000 km, and a vessel may well arrive requiring less than the total fuel capacity, meaning that the fuel supplied in South Africa will be reduced. It has been very generally estimated that the typical vessel leaving South African ports takes on fuel for 2 000 km, bearing in mind the high percentage of small vessels travelling coastwise over fairly short distances. It has also been estimated that one half of the cargo handled by South African ports arrives at no fuel energy cost to this country, i.e. the last port of call for bunkering was somewhere other than South Africa. Using the above figures, Appendix 39 was compiled to show the transport work performed and fuel energy requirement of domestic shipping movements, represented respectively in Figures 6.1 and 6.2

6.3 Conclusions - Marine Transport

As the nation's major transport system for foreign trade, South African shipping is of vital importance. Energy consumption patterns are slow to change because of the continuance of ship propulsion along classical and well proven lines using primarily marine diesel fuel and bunker oil, but also coal as raw energy sources. In terms of the energy requirement per unit of transport work performed, shipping has the lowest value of all transport forms, although its use is obviously restricted to sea routes in South Africa with the absence of any suitable inland waterways. Out of necessity, the fuel supply for this sector will have to be assured but in all likelihood, this will be possible using the lower distallate fuels which will be available from the production of petroleum and light diesel from crude oil made locally by coal liquifaction. Because of the high capital outlay required and the necessary large vessel size needed, nuclear marine power is not expected to make any inroads on the shipping industry between now and the turn of the century.

FIGURE 6.1 : TOTAL CARGO TRANSPORT : S.A. SHIPPING

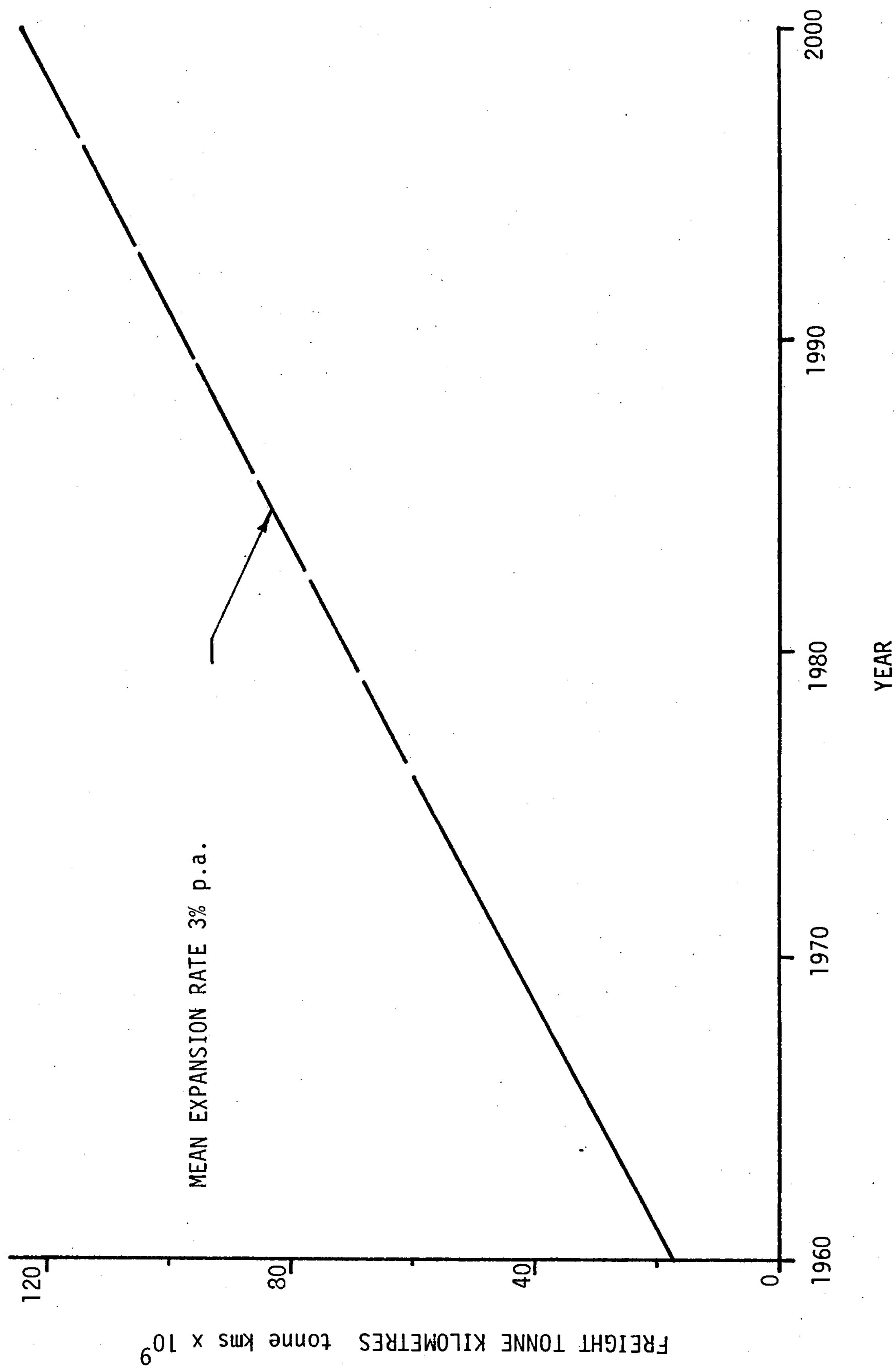
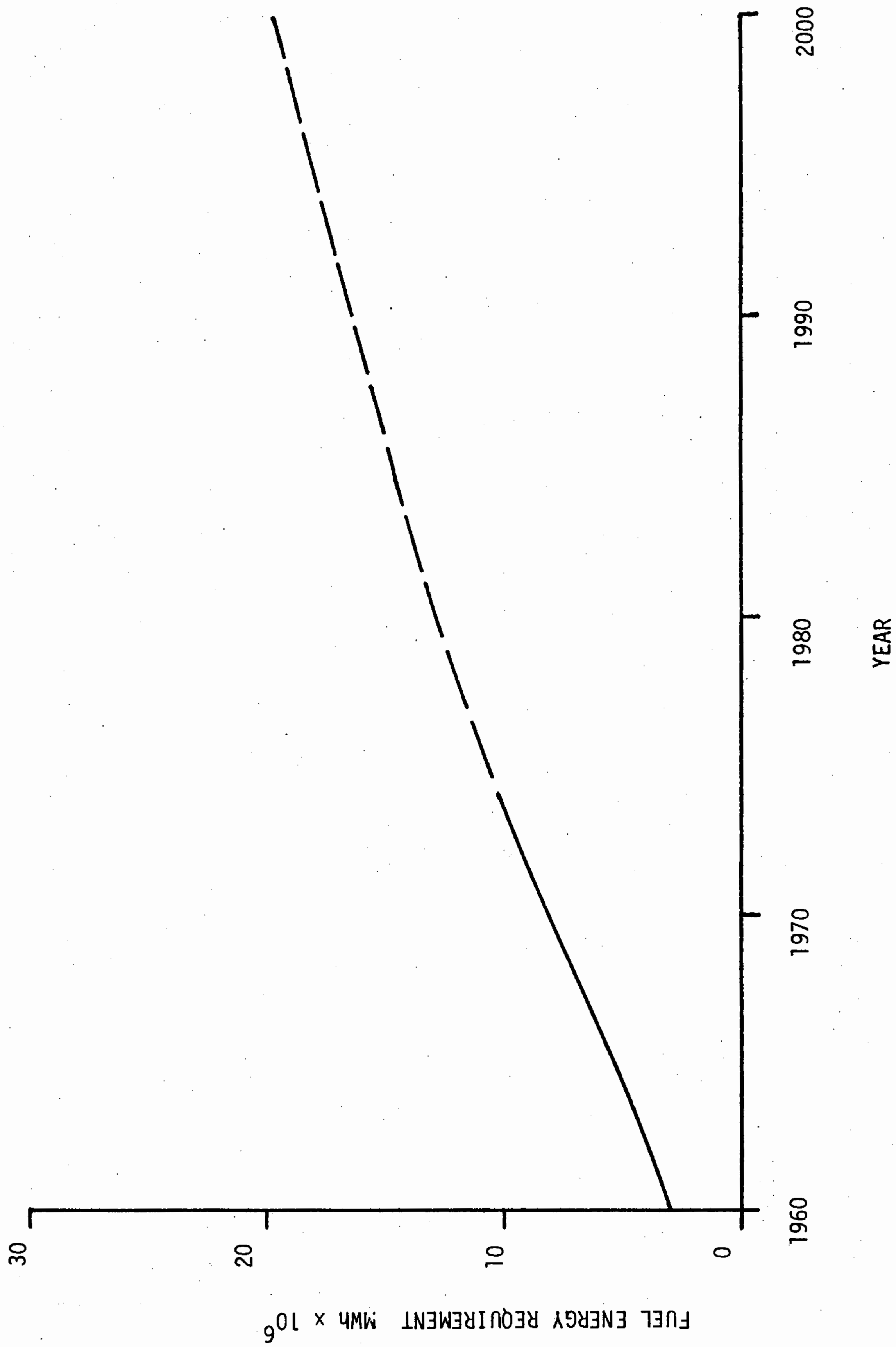


FIGURE 6.2 : S.A. SHIPPING ANNUAL FUEL ENERGY REQUIREMENT



CHAPTER 7

PIPELINE TRANSPORT

7.1 Introduction

The only commercial pipelines for fluid transportation over large distances in South Africa are those operated between Durban and the Gold Reef in the Transvaal by the South African Railways. At present, two main lines exist, one for crude oil from Durban to Coalbrook and a products line (refined petroleum products) from Durban to Johannesburg. These are 18 and 12 inch respectively. In addition to these main lines, there are smaller diameter feeder lines to complement the distribution network on the Reef.

The relatively high capital cost of a large pipeline means that it is only viable when continuous demand can be guaranteed. In South Africa's case with the supply of crude oil arriving by sea in Durban, and the massive demand for oil and by-products on the Reef, the ideal situation exists. The pipelines free a significant percentage of rail and to a lesser extent, road transport vehicles, leaving these services in a position to transport other goods which cannot be pumped.

The pipeline network also provides a second feature in the form of a regular supply of crude oil to the major refineries in Durban and Sasolburg. Should unrefined reserves become depleted at either place, crude oil may relatively easily be piped to the refineries from bulk storage areas. This ensures continued production from the refineries which cannot economically vary or temporarily stop their production.

An additional/.......

An additional crude oil pipeline is proposed which will connnect Durban with Alrode (Johannesburg) and Witbank. Other existing lines connect Sasolburg with Waltloo (Pretoria) and with Klerksdorp and there is a special line for jet fuel from Sasol to Jan Smuts Airport.

All pumping is performed by electrically driven radial flow centrifugal pumps. The pump stages are compounded in series, one motor driving up to four stages. For pumping purposes, these pumps are also series connected, up to the desired number of stages. The selection of the number of stages is based on the desired pressure rise across the pumps in a station.

Pressure throughout the length of the pipeline must remain positive to prevent vapourisation of the product, and in the event of a leak, to prevent contaminants being drawn into the system. The inlet pressure to the pumps of the next station is important since it must be high enough to prevent impeller cavitation. This is regulated by means of control valves downstream of the pumps which are activated by the inlet pressure. Too low a pressure and the valve closes slightly, the resulting restriction increasing the upstream pressure back through the pump until the inlet pressure reaches the necessary value. Major increases in pressure are achieved by increasing the number of stages at the previous station. At present the pipelines are manually controlled from Durban, the necessary information of pressures and valve settings being relayed by radio-telemtry to the control room from the pump stations en route.

The pipeline for refined products (products line) copes with a variety of petroleum products. When the product is changed an inflatable sphere is introduced at the interface of the two products and is transported through the line by the fluids whilst maintaining separation between them. This minimizes intermixing of the products and the obvious contamination that would occur. Cleaning the pipeline is performed by inserting a brush which is propelled by the fluid. Particularly with the crude oil line, fatty deposits in the walls of the pipe can restrict the flow and the brush mentioned above will remove this and keep the line clear. Liquid arriving at a station immediately ahead of a cleaning brush is dumped and decontaminated before being re-introduced to the line.

Accurate metering of the quantities of oil and products transported occurs at inlet and discharge points. Any reasonable discrepency here would indicate that the line is leaking and this will be sought out and repaired. Due to the D.C. electrification of the S.A. Railways, electrical protection must be provided for the pipeline from electrolytic corrosion underground. In certain instances the electric current in the track rails will to a greater or lesser degree also use the earth as a conductor, setting up a potential gradient in the surrounding underground area. Any underground conductor (i.e. a steel pipeline) nearby can also constitute a current path and be severely damaged by external corrosion. This is combatted by maintaining the pipeline at a voltage where this corrosion attack does not occur, by means of rectifier sets which control the potential of the pipeline relative to earth. Severe problems of this nature affected the original pipeline. Additional protection is afforded by suitable epoxy coatings on the outside of the pipe itself.

7.2/.....

7.2 Useful Energy

Note : The performance figures quoted in Section 7.2.1 to 7.4.2 inclusive were supplied by the SAR & H Pipeline Division (Durban)

7.2.1 Crude Oil

Motor efficiency at operating load					95.6%
Pump	"	"	"	"	83 %
Pumping efficiency					79,4%

After leaving the pumps at a booster station the oil passes through a control valve to maintain suction pressure (as discussed in the Introduction). Using data from Appendix 40 :

$$\frac{\text{Pressure drop in Pipeline}}{\text{Total pressure drop *}} = 0,94$$

*Includes pressure drop across control valves

This relates pipeline to station efficiency.

Assuming total power requirements for security lighting and auxillaries not connected with actual pumping consume 2% of the total power supplied :

$$\text{Pipeline efficiency} = (1,00 - 0,02) \times 79,4 \times 0,094\%$$
$$= 73\%$$

7.2.2 Refined Products

Motor efficiency at operating load	94,4%
Pump " " " "	82 %
Pumping efficiency	75,9%

Similarly, pipeline efficiency = 70%

The above indicates that in the crude oil pipeline 73% of all power supplied is consumed in performing useful work while the figure for the petroleum products line is 70%.

7.3 Energy Cost of Transportation

7.3.1 Crude Oil

For the section Durban to Coalbrook
Pipeline length = 659 km

Over an unspecified time*, 369 019 m^3 of crude oil of mean density 0,840 kg/litre was transported for the consumption of 4 643 000 kWh of electricity.

*For security reasons the time cannot be quoted but the duration was sufficient to ensure a representative mean value.

Total mass of oil moved = 309 976 tonnes
Representing 204 274 000 tonne kilometres
Gain in potential energy of the mass of oil in elevating it 1 500 metres (mean altitude of reef outlets)

$$= 1\ 500 \times 9{,}81 \times 309\ 976 \text{ kJ}$$

Representing $\dfrac{1\ 500 \times 9{,}81 \times 309\ 976}{3\ 600}$ kWh

i.e. 1 267 000 kWh

Or/....

Or a mean figure of 4,1 kWh/tonne
Or alternatively, o,00273 kWh/tonne km (1)

Energy required to overcome fluid friction in the pipeline :

= 4 643 000 - 1 267 000 kWh
= 3 376 000 kWh

i.e. An energy requirement of $\frac{3\ 376\ 000}{204\ 274\ 000}$ kWh/tonne km

= 0,01653 kWh/tonne km (2)

Combining (1) and (2) :

Energy requirement = (D x 0,01653) + (H x 0,00273)kWh/tonne ------- (A)

Where D = Pipeline length
H = Altitude change in metres from inlet to outlet
H is positive for uphill pumping

7.3.2 Refined Products

For the section Durban to Sasolburg
Pipeline length = 608 km

As above, 186 966 m^3 of refined products of mean density 0,766 kg/litre was transported for the consumption of 2 066 360 kWh of electricity.

Calculating through in exactly the same manner used for crude oil before gives :

Energy requirement = (D x 0,01701)+(H x 0,00273)kWh/tonne
D and H as above ----- (B)

<u>Example</u> :

200 000 tonnes of petroleum product is transported 720 km from Durban to Johannesburg
(Altitude difference + 1 820 metres)

Energy requirements for equation (B) is :
200 000 (720 x 0,01701)+(1820 x 0,00273) = 3 443 000 kWh

Using the pipeline overall efficiency of 70% derived in the previous section results in an estimate of the useful work performed of 2 410 000 kwh.

Thus, using the network efficiency and expressions A and B, the useful energy expended in transporting crude oil and refinery products may be calculated if the total masses of the products transported is known. Note that for uphill pumping (against a pressure head) H in both expressions is positive, while for downhill pumping, it will assume a negative value.

7.4 Conversion Efficiency

7.4.1 Crude Oil

Rated motor efficiency at operating load : 95,6%
Rated pump efficiency at operating load : 83 %
Overall pump efficiency : 79,35%
Assuming total power requirements for
lighting and auxillaries = 2% of the power supplied

Conversion efficiency = (1,00 - 0,02) x 79,35%
= 77,8%

i.e. 77,8% of supplied electricity is converted to useful energy for the pumping of crude oil.

7.4.2 Refined Products

Rated motor efficiency at operating load = 94,4%
Pump efficiency at operating load = 82%
Pump system efficiency = 77,4%
and similarly conversion efficiency = 75,9%

i.e. 75,9% of supplied electricity is converted to useful energy for the pumping of refined products.

With the total quantities of crude and refined oil moved being of the same order of magnitude, the figure for the entire network would be of the order of 77% of total electricity consumption being converted into useful energy.

This differs from the values given in Section 7.2 as losses are incurred in the control valves downsteam of each pump station. The figures in this section refer to conversion efficiency of energy at the actual pumps while the figures in Section 7.2 considers the useful work done by the overall system including control valve losses.

7.5 Discussion

The total quantities of oil and petroleum products transported could be estimated in terms of the outputs of the refineries at Durban and Sasolburg, but with strategic oil storage and the obvious secrecy surrounding this information, the results would be circumstantial. Any existing pipeline may only be boosted a certain amount beyond its design capacity so consideration of the pipeline size and material would yield an estimate of the system's total transport ability. Again this would be relatively meaningless in terms of gauging the actual quantities transported and the annual expansion rate.

However, with the pipeline system firmly established and in the process of being further expanded, it is reasonable to expect that it will handle by far the most major share, if not all the oil and petroleum movements between Durban and the Witwatersrand.

The concept of pipeline transport is unique in that the movement of the product occurs without the movement of packaged containers. In road and rail transport for example, the mass of the transport vehicle as well as the goods it contains has to be propelled, thus energy is expended merely moving the container itself. In a fluid pumping system, only the fluid itself is transported and no energy is wasted in moving the dead weight of containers and mobile power sources. Once the fluid leaves the pumps the only loss of energy occurs in overcoming fluid friction in the pipeline. Also, since the size and mass of motors and pumps **is irrelevant** (as these are static installations) these can be designed to yield optimum efficiency regardless of power to weight ratio. The removal of this restraint and the fact that the national electricity grid may be used to provide power allow the high efficiencies indicated in the section "USEFUL ENERGY". The above factors combine to yield the high overall transport efficiency of the oil pipeline system. (Values of the order of 40 tonne kilometres per kilowatt hour of supplied electricity).

7.6 Conclusions - Pipeline Transport

The South African pipeline system has already proved its worth in terms of savings in rail transport, energy consumed and transport efficiency. The relatively high capital cost of the pipeline system can be recovered fairly quickly, the system then providing a subsidy for unprofitable but essential services provided by the Railways and Harbours in supplying goods transport to smaller centres throughout the Republic. Added to its high efficiency a pipeline has an ecological impact on the countryside of only a fraction of that of road and rail transport. However, to be viable, the need must exist for substantial and continued movement of bulk fluids over fairly large distances. If these conditions do not exist then, except in a few very special applications, a pipeline is not a practical proposition.

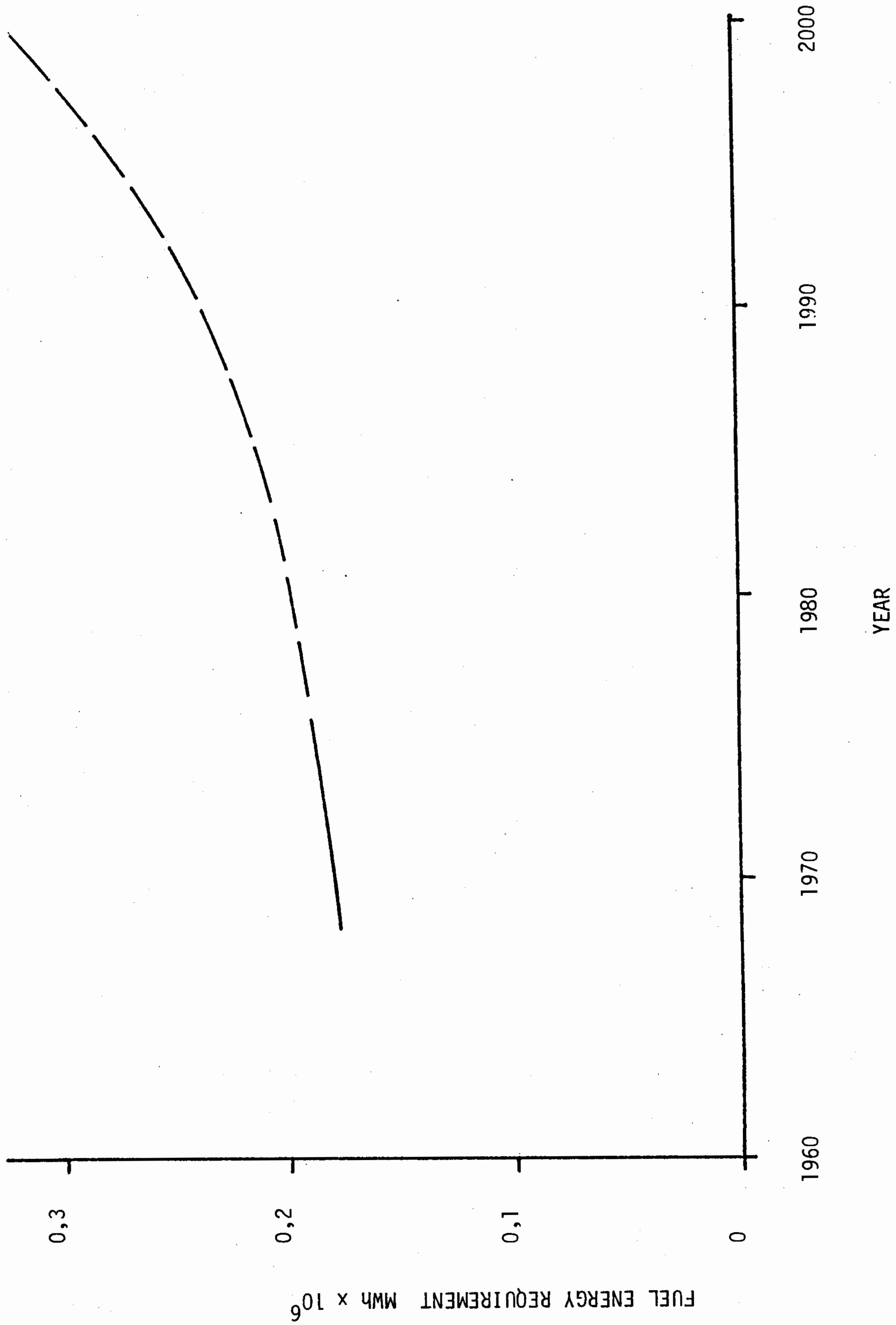
Oil and its derivatives is by no means the only product which lends itself to pipeline transportation. Other bulk fluids, gases and even coal in the form of fine slurry with water are already being piped in other parts of the world. With South Africa's industrial expansion rate,

it is/.....

it is more than likely that similar substances will be transported by pipeline on a national scale by the turn of the century.

Due to the precautions accorded to the divulgence of actual quantities of crude oil and petroleum products moved by the pipeline system, it was not possible to ascertain the transport work performed by this sector. Appendix 44 was prepared to estimate the quantities moved, basing 1975 figures on a 6 hour working day. As the pipeline at present carries imported oil and refined products from Durban up to the Reef, expansion is expected to be limited by the level of oil imports. Ultimately, the service will change to distribute locally made oil (syncrude) from the Sasol complex, but being centrally placed, this keeps the total transport work down to a smaller level. It has been estimated that, due to the foregoing effects, 1975-1985 expansion will be of the order of 1,5% per annum, rising to 3,5% per annum thereafter up to the year 2000. The current energy requirement of 0,16 kwh/ tonne kilometre is expected to reduce gradually over this whole period to 0,14 kWh/tonne km as a result of improved pump and control technology and the installation of larger diameter pipes which will reduce friction head losses. The total energy requirement was calculated and this is represented in Figure 7.1.

FIGURE 7.1 : PIPELINE TRANSPORT ANNUAL FUEL ENERGY REQUIREMENT



CHAPTER 8

TRANSPORT INDUSTRY ENERGY REQUIREMENTS

8.1 Current Energy Requirements

Table 8,1 details the specific fuel energy requirements (electricity, coal and petroleum products) for the various modes of South African transport applicable during 1975, using information from the foregoing chapters.

Mode	Specific Energy Requirement kWh/pass km	kWh/tonne km
Airways	0,74	7,4
Railways	0,18	0,55
Road freight	-	1,62
Omnibus	0,23	-
Shipping	-	0,18
Pipeline	-	0,16
Private car	0,7	-

TABLE 8.1 : Specific Fuel Energy Requirements South Africa - 1975

Note : Raw energy inputs considered as coal, petroleum products and national grid electricity.

From Table 8.1 it is apparent that there is a marked difference in the energy requirement per unit of transport work between the various transport modes. From a pure energy utilization viewpoint it would be simple to select the most economical means of transport. However, social demands and the needs of present industries superimpose

other/....

other factors which have resulted in the present transport network.

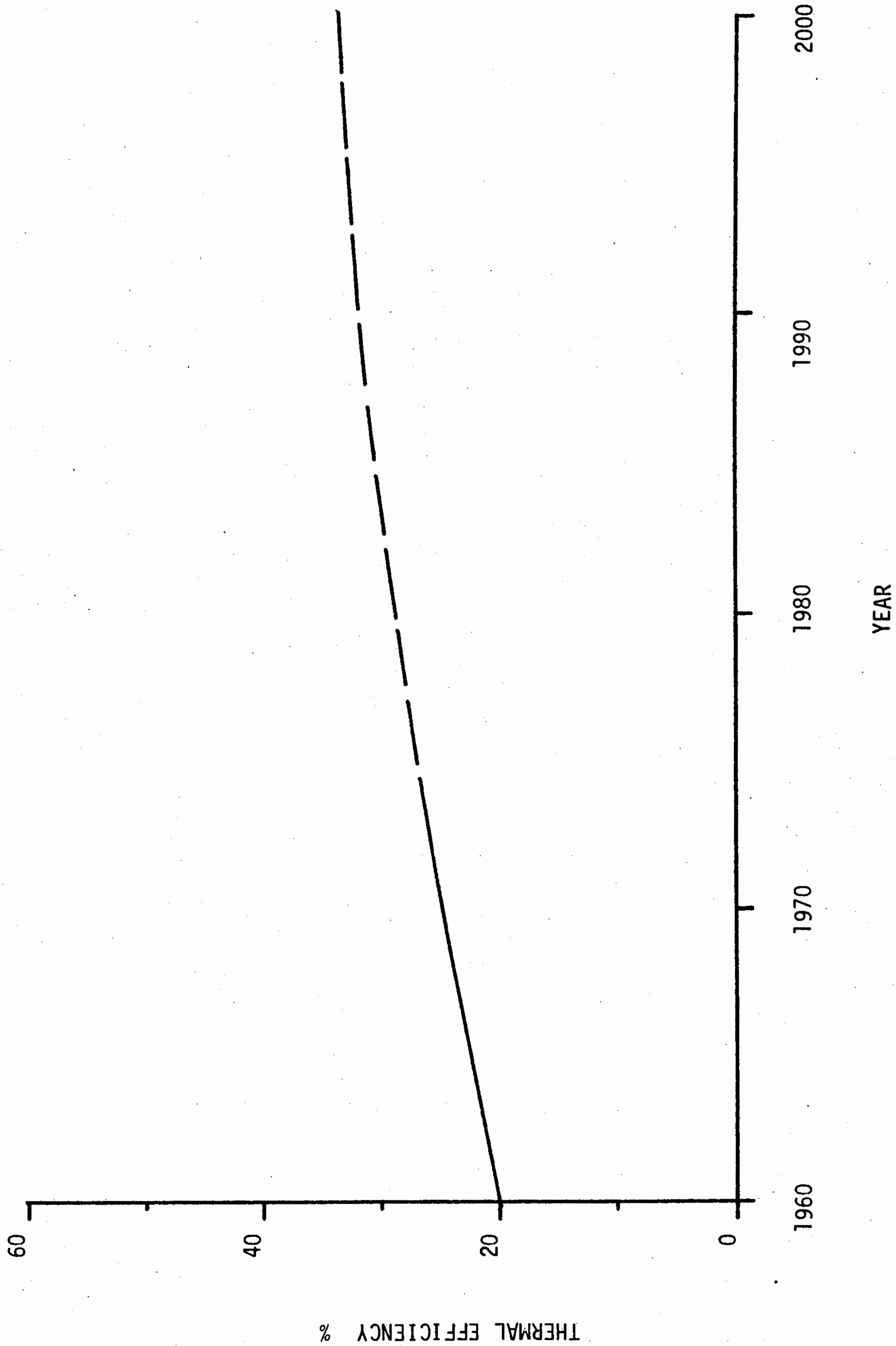
A further consideration necessary for realistic comparison is that, although considered as a fuel input from a pure transport standpoint, national grid (ESCOM) electricity has been primarily generated from coal fired power stations. For 1975 the thermal efficiency of coal fired stations for electricity at the point of sale was approximately 26,8% (Ref.21). Converting the values given in Table 8.1, to include electricity consumption as actual coal consumption resulted in the values indicated in Table 8.2. The values given in both these tables apply only to 1975 conditions, as improvement in vehicle thermal efficiencies and operating methods modify these figures for predictions into the future.

8.2 Future Energy Requirements

For the reasons given in Section 8.1 it was necessary to estimate the thermal efficiency of national grid electricity into the future to enable energy inputs to be broken down into coal and petroleum products only. Using information contained in Reference 22, Appendix 45 was prepared to show historical data on the improving thermal efficiency of coal generated electricity. This data was placed on Figure 8.1 and extrapolated to yield approximate values for the future up to 2000. The principle of diminishing returns was used, showing a slackening in the improvement rate with time until a thermal efficiency of 34% was estimated by the turn of the century. Nuclear and hyro-electric power have been specifically excluded since it is unlikely that these systems will do any more than supplement coal generated electricity over the

period/......

FIGURE 8.1 : ESTIMATED THERMAL EFFICIENCY : ESCOM COAL FIRED POWER STATIONS



period considered, and the energy supply to these systems is not likely to become critical. The primary concern has been to estimate the demand made on coal and petroleum fuels by the transport industry.

Mode	Fuel Energy Requirement (Coal and Oil fuels) kWh/passenger km	kWh/tonne km
Airways	0,74	7,4
Railways	0,22	0,67
Road Freight	-	1,62
Omnibus	0,23	-
Shipping	-	0,18
Pipeline	-	0,59
Private Car	0,7	-

Note : The same sources and considerations as for Table 1.1 apply except "fuel"defined as coal and petroleum products only.

TABLE 8.2 : Transport Fuel Energy Requirements Coal and Oil Fuels - South Africa 1975

Using the information on electricity generation, Tables 8.3 and 8.4 were prepared to indicate specific fuel energy requirements in South Africa for the years 1985 and 2000 respectively

Mode	Fuel Energy Requirement (Coal and Oil fuels) kWh/pass. km	kWh/tonne km
Airways	0,4	4,0
Railways	0,16	0,5
Road freight	-	1,6
Omnibus	0,23	-
Shipping	-	0,18
Pipeline	-	0,49
Private car	0,6	-

TABLE 8.3 : 1985 Transport Fuel Energy Requirement

Mode	Fuel Energy Requirement (Coal and Oil fuels) kWh/pass. km	kWh/tonne km
Airways	0,35	2,9
Railways	0,14	0,41
Road freight	-	1,55
Omnibus	0,22	-
Shipping	-	0,16
Pipeline	-	0,38
Private car	0,5	-

TABLE 8.4 : 2000 Transport Fuel Energy Requirement

8.3 Total Energy Requirements

By considering the energy cost per unit of transport work performed and the total trsnsport work expected it was possible to predict the values given in Table 8.5 of the total energy cost of South AFrican transport.

Mode	Total Annual Fuel Requirement MWhx10^6 1975	1985	2000
Airways	6,1	8,2	14,1
Railways	55	48	56
Road freight	55	83	143
Omnibus	1,2	1,6	2,1
Harbours	1,1	1,5	1,7
Shipping	9,4	15	19,5
Pipelines	0,7	0,7	0,9
Private Car	30	40	51
TOTAL	158,5	198	288

TABLE 8.5 : Total South African Fuel Requirement 1975 - 2000

As may be seen from these figures, the Railways fuel energy requirement falls over the period 1975-1985, a direct result of the phasing out of steam locomotives, leaving diesel electric and electric traction to cope with the increasing rail transport demand. The remaining transport sectors increase in fuel requirement with increased transport demand, this being slightly tempered with technological improvements in the therma-efficiencies of the various transport vehicles and improved utilization factors.

Compounding/....

Compounding the values in Tables 8.2 to 8.5 inclusive to obtain weighted mean values of energy **requirements per** unit of transport work for freight and passenger travel results in the data contained in Table 8.6, graphically presented in Figure 8.2.

		1975	1985	2000
Energy Requirement	kWh/pass. km	0,54	0,44	0,37
" "	kWh/tonne km	0,78	0,67	0,65

TABLE 8.6 : Gross Transport Fuel Energy Requirement

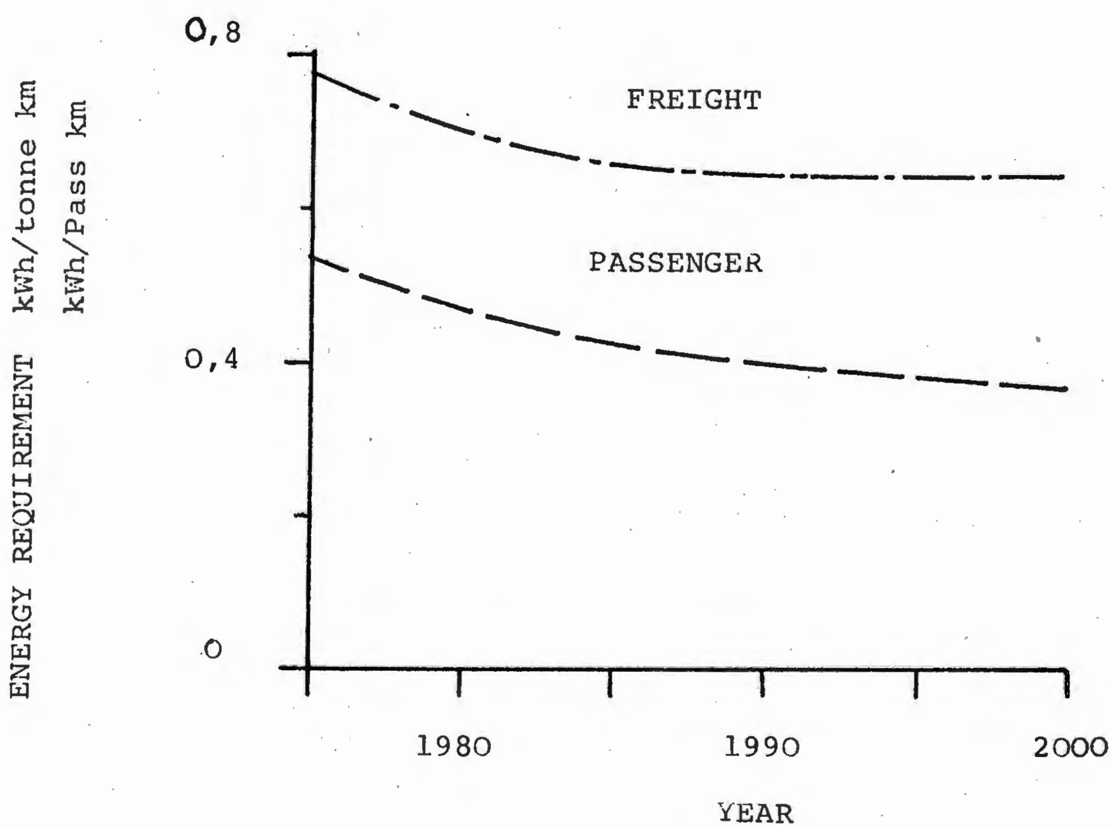


FIGURE 8.2 : Projected Gross Transport Fuel Energy Requirement

As may be seen from Figure 8.2, the improving thermal efficiency of transport vehicles and **better utilization** results in a gradual decline in the gross fuel energy requirement for the overall transport industry in South Africa. The biggest single reason for this decline is from the Railway sector which reduces by half its total fuel energy requirement with the removal of steam locomotives from service, while providing a continually expanding service.

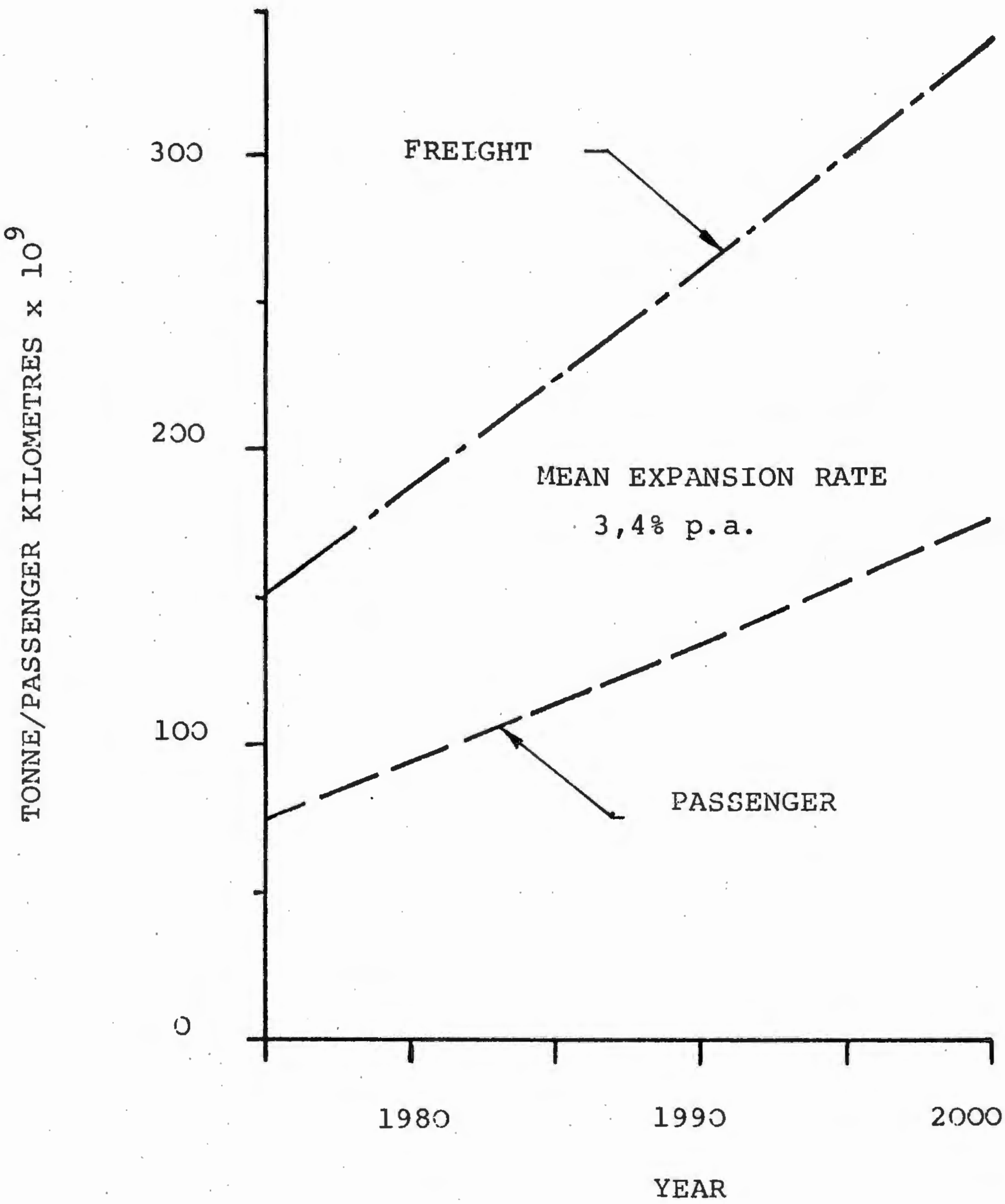
8.4 Total Transport Performed

Using current and predicted data from Chapters 2 to 7, it has been possible to compile Table 8.7 showing the total transport work performed within South Africa up until the turn of the century.

Year	Freight Tonne kilometres	Passenger kilometres
1975	$152,5 \times 10^9$	$75,5 \times 10^9$
1985	$224,7 \times 10^9$	$114,5 \times 10^9$
2000	$340,3 \times 10^9$	$176,0 \times 10^9$

TABLE 8.7 : Total Transport Work Performed South Africa

Figure 8.3/.....



<u>FIGURE 8.3</u> : <u>Total South African Transport Movements</u>

Figure 8.3 is a graphic representation of the total transport work performed in South Africa, and for both freight and passenger transport, the annual expansion rate over the period 1975 to 2000 for the entire transport industry averages at 3,4% per annum. This estimate has been based on the predicted expansion rates of the

various/......

various transport sub-systems (Chapters 2-7) which have been summed to find the transport industry total expansion over this period.

By considering the values given in Table 8.5, Figure 8.4 was compiled to indicate the relative demands made by the transport industry on coal and petroleum products for basic energy requirements into the future. Historical data was extracted from Chapters 2-7 for the period 1960-1975, but as for Table 8.2, electricity inputs were converted to coal energy inputs.

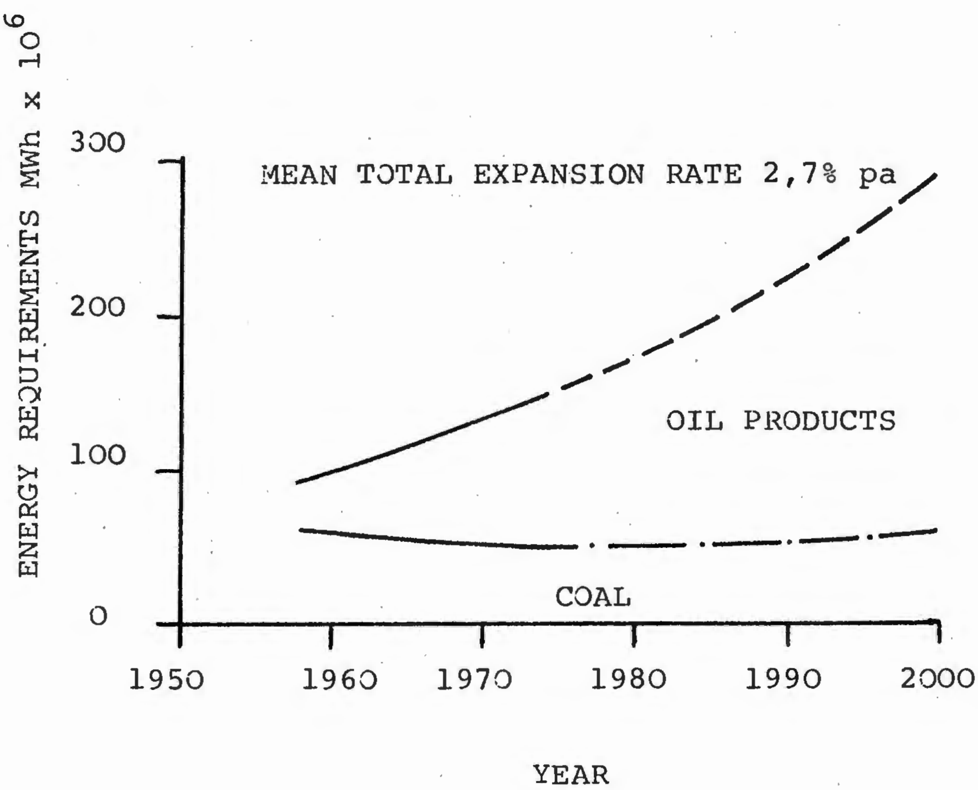


FIGURE 8.4 : Raw Fuel Energy Requirements.

It will be noted that the transport industries dependence on coal as a power source remains substantially constant, while its dependence on oil based fuels rises markedly. The use of oil based fuels actually increases at a mean rate of 3,2% per annum over 1975 levels according to the estimates made in this report.

CHAPTER 9

PRINCIPAL TRANSPORT ROUTES

In South Africa four distinct metropolitan areas can be distinguished as focal points of industrial development These are the Witwatersrand area between Pretoria and Vereeniging, the Cape Peninsula, the Durban-Pietermaritzburg complex and the Port Elizabeth-Uitenhage area. The primary long distance transport routes connect the Witwatersrand with each of these areas, the Johannesburg-Durban link being by far the most significant. These are shown schematically in Figure 9.1 below.

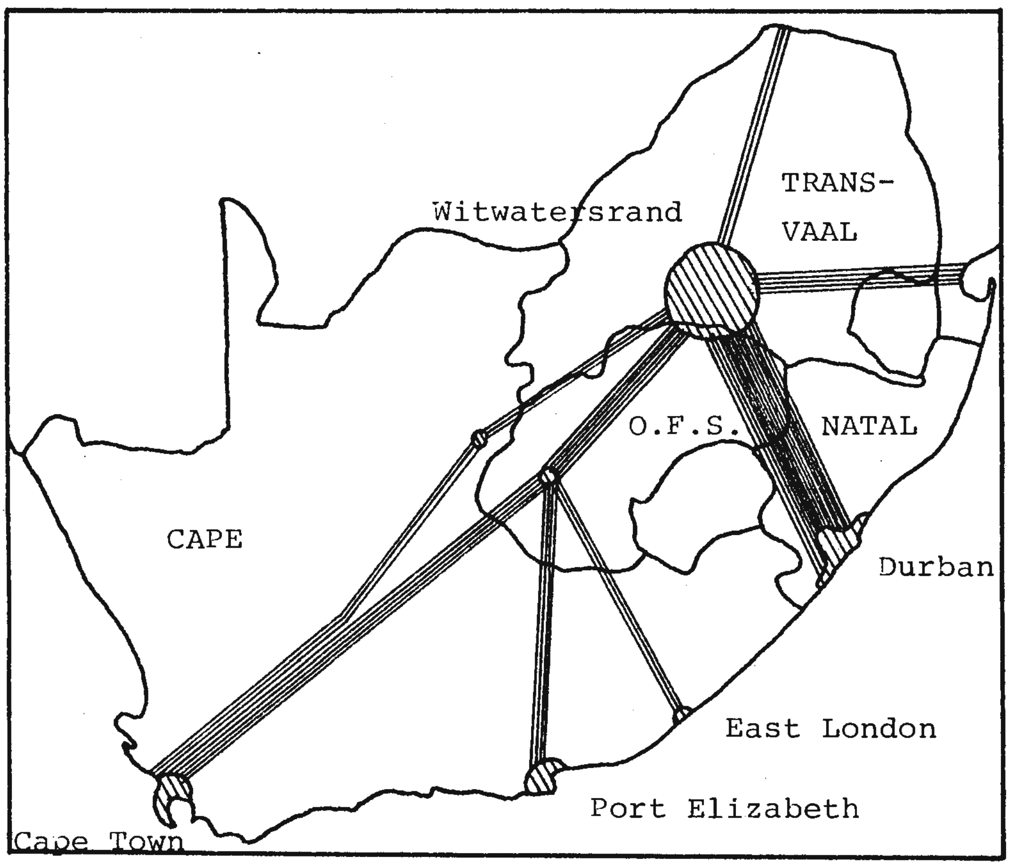
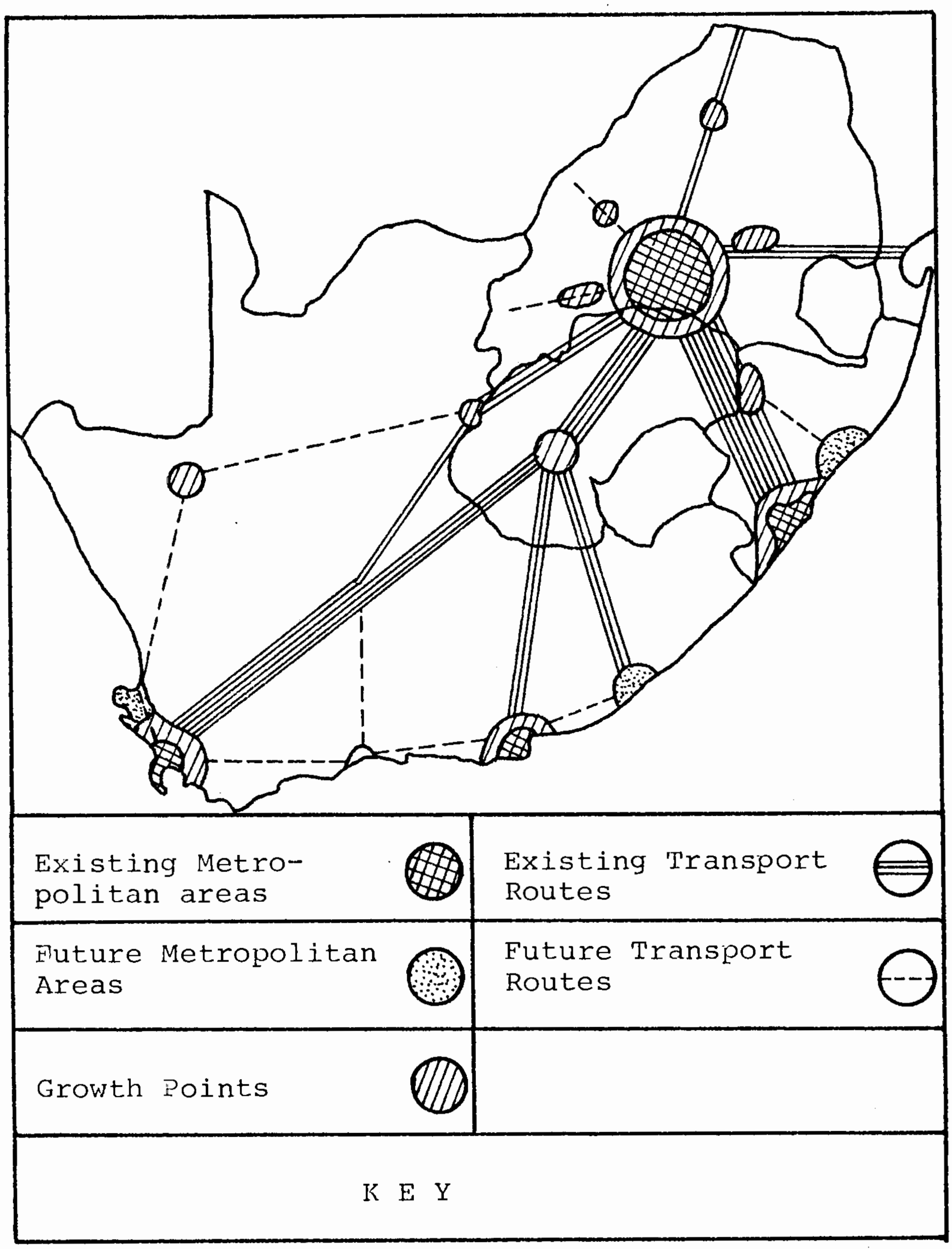


FIGURE 9.1 : South Africa's Prime Transport Routes.

With the/.....

With the economic development of the nation, new industrial and metropolitan areas will gradually appear and the likely future development will be as shown in Figure 9.2 below.



<u>FIGURE 9.2</u> : <u>Future Metropolitan Areas and Transport Routes</u>

(Source : Reference 24)

New metropolitan areas are envisaged at Saldanha Bay, East London and Richards Bay, as well **as development** in the Bloemfontein area. The growth point in the North-Western Cape is envisaged as a by-product of the development of the mineral resources in the area. The primary processing of local minerals would provide the economic base around which related industries and the labour force would centre. A metropolitan area around Saldanha will be formed on the basis of an export harbour and processing nucleus for sea produce and the minerals of the NW Cape. Development at Saldanha will eventually merge into expansion from the Cape Town metropolitan area. A further growth point in the Cape is the George-Mossel Bay area, ecomically based on agriculture, forestry and recreation, and forming the only region between Cape Town and Port Elizabeth where any major development is foreseen. East London is also expected to become a metropolitan area with good harbour facilities and the labour pools of the adjacent Transkei and Ciskei and an already established level of industry. It is also situated in an established agricultural area and is advantageously sited for the shipping of agricultural produce from the O.F.S. This area is expected to develop rapidly into a large metropolis.

Richards Bay, north-east of Durban is an ideal alternative harbour and export/import route for merchandise produced and processed on the Witwatersrand. Agriculture and a measure of industry have contributed to the economic development of the area, which, coupled with its potential as a harbour which is marginally closer to the Gold Reef than Durban, will result in rapid development in the area. Bloemfontein, and to a lesser extent, Kimberley, with their already well established mining and agricultural

activities/.....

activities form the epicentre of goods movements from the entire Cape Province to the Witwatersrand. Both town are scheduled as growth points as a result of the foregoing and by virtue of their central position in South Africa, will feature significantly in the transport network.

Centred around the Witwatersrand and its already massive development are the following growth points. The Witbank Middleburg area with coal mining as the growth factor. The Pietersburg area on the access route to the North based on agriculture, Rustenburg to the west and the mining and agricultural areas of Potchefstroom and Klerksdorp to the South West. Development is also expected in the region between Johannaesburg and the sea outlets of Durban and Richards Bay.

Note : The foregoing information was extracted from Reference 24.

On the basis of the foregoing, Figure 9.3 overleaf was compiled to indicate the likely pattern of development of the internal transport network.

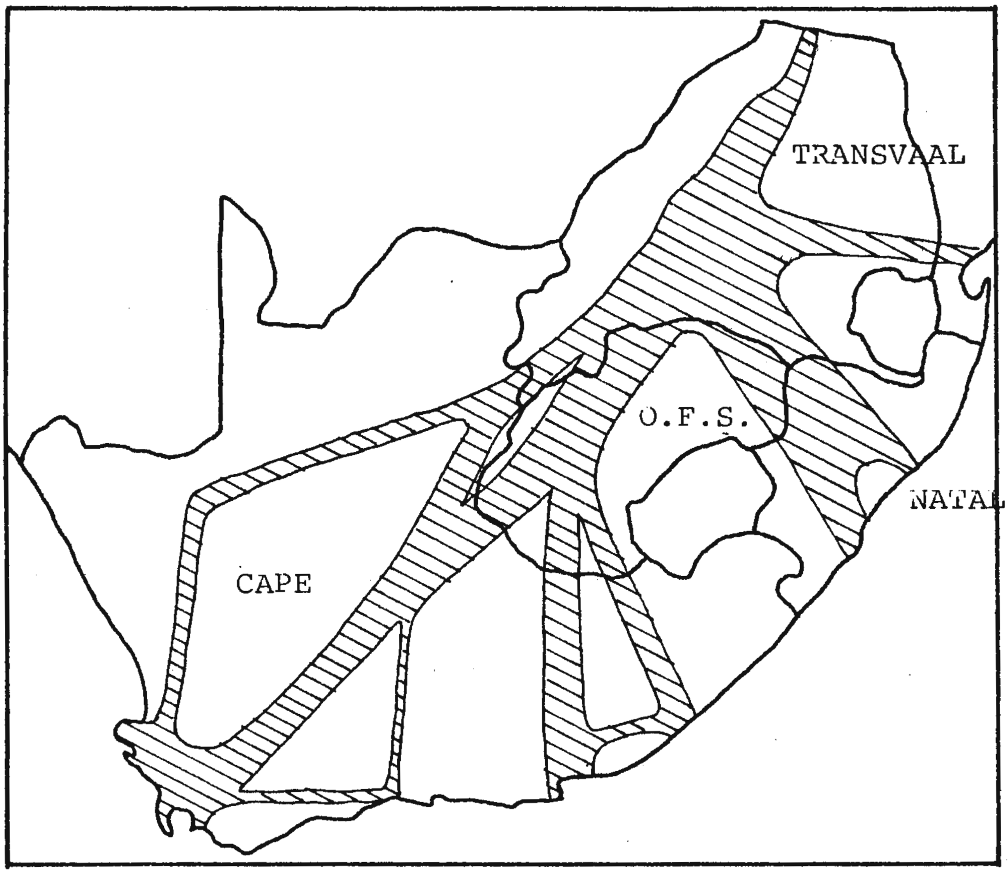


FIGURE 9.3 : PREDICTED NATIONAL TRANSPORT NETWORK MAJOR ROUTES

The Johannesburg to Durban/Richards Bay route will remain as the largest and best developed one, followed by links to Cape Town, Port Elizabeth and East London, routed via Bloemfontein. Routes which will become established with the development of other major centres include Saldanha - North West Cape - Kimberley, Cape Town - George - Bloemfontein and Port Elizabeth - East London of which the former will probably assume the most importance with time. The actual transport network will remain substantially the same, but rather improved with alternative and sometimes better situated outlets. With the political uncertainty of the availability of Maputo in Mozambique as an outlet for Witwatersrand produce, it is unlikely that any development of this route will be undertaken in the foreseeable future. This factor will further enhance the value of the coastal areas of Durban and Richards Bay. The development of Saldanha and Richards Bay will supplement the existing major harbours in South Africa, bringing the total number to six and increasing the convenience of any transport from inland requiring port facilities.

The biggest change in the domestic transport network will be the development of the North Western Cape mineral reserves, and the assured water supply from the Orange River Project for agricultural use. The Saldanha/Sishen project is already well under way, and the Cape Peninsula has a large labour pool to draw on for manpower requirements. It is likely that initial processing of natural minerals will occur on site, and the extract sent to Saldanha for further processing and export, or inland to the Witwatersrand for national use. All of the above factors will result in a steadily increasing transport demand to and from the N.W. Cape area for the movement

of minerals/....

of minerals, mineral produce, agricultural produce and manpower. The opening up of the area on the above basis may well result in a new series of towns and villages with interests related to the natural reserves, and this may compound the growth of a new transport branch serving the produce both to the coast at Saldanha and Cape Town, and inland to the Witwatersrand.

The foregoing discussion is applicable to road, rail, coastal shipping and in certain cases, pipeline transport for the movement of goods and people. Air transport, by virtue of its independance from fixed travel routes, relies only upon the establishment of suitable airport facilities to be able to provide the service required. Furthermore, with the large distances between major centres and (by American and European standards) low air traffic density, air transport has plenty of scope for an intensification of services even with present equipment and airports.

Rail transport is of primary importance in the long distance conveyance of bulk (usually mineral) produce. The advent of high capacity liner trains and semi-automatic loading and unloading of wagons in recent times have further enhanced the attractiveness of rail transport over other forms. The possibility of transporting crushed produce (i.e. coal) in slurry form by pipeline over long distances is a reality in some foreign countries and may well have valuable applications in this country. However, its use is restricted to suitable products, and for the development of new industrial or mining areas the more versatile rail and road transport will invariably precede any pipeline installation.

Consider the/.......

Consider the development of mineral extraction on a large scale in the North West Cape. Initially, mining equipment will have to be moved from the Reef or imported via Saldanha or Cape Town, together with cement, steel for fabrication and a host of other products to establish mine townships. In the early stages, food and household necessities will have to be moved in from some established centre. Once mining operations begin on any scale whatever, the minerals or extracts must be transported for export or domestic use. With the distance between the mineral deposits and any established centre, rail transport is the only service which can economically provide the transport capacity and variety required. When the deposit is well established and the volume of mineral produce to be moved become particulary large, then, and only then, will pumped slurry transport become a consideration and this still depends on the suitability of the mineral or extract for pipeline transport.

The existing oil pipeline network connecting Durban and Richards Bay with the Witwatersrand only became feasible because of the large and consistent demand between fixed areas and the suitability of petroleum products for pipeline transport. The economic threshold for pipeline transport is elevated above that of a rail or road system since at best a limited range of similar products only can be transported, and this must be in large quantities between concentrated supply and delivery points with little or no seasonal fluctuation in demand. A rail or road system can economically handle lower bulk transport demands since the service is in effect subsidised by the simultaneous conveyance of a wide range of other products and/or passengers.

CHAPTER 10

10. ENERGY AVAILABILITY

As was shown in Section 8.4 (Fig.8.4), the situation for South African transport at the present moment is a 65% reliance on petroleum products and 35% dependance on coal as primary energy sources. By the year 2000 this has been estimated to change to 80% and 20% respectively indicating a steadily increasing dependence on oil products, the absolute oil demand being more than twice current levels. Therefore, from the transport viewpoint, the supply and cost of oil and refined products is of paramount importance.

10.1 Oil Sources

At the present moment the bulk of South Africa's crude oil is imported from the Persian Gulf, and the final supply supplemented by the Sasol oil-from-coal plant situated in the north of the Orange Free State. Due to the current sensitivity over the strategic importance of oil supply and production, exact figures are not available. Consequently, estimates have been used, based on pre-1973 data as well as published predictions from other sources (Ref.25).

Table 10,1/......

	Possible Oil Consumption Barrels per day	Sasol Production (est) bpd	Sasol % of Total
1975	300 000	11 000	4%
1980	392 000	111 000	28%
1985	512 000	211 000	41%
1990	639 000	311 000	49%
1995	795 000	411 000	52%
2000	922 000	500 000	54%

TABLE 10.1 : S.A. OIL FROM COAL PRODUCTION (Source : Reference 25)

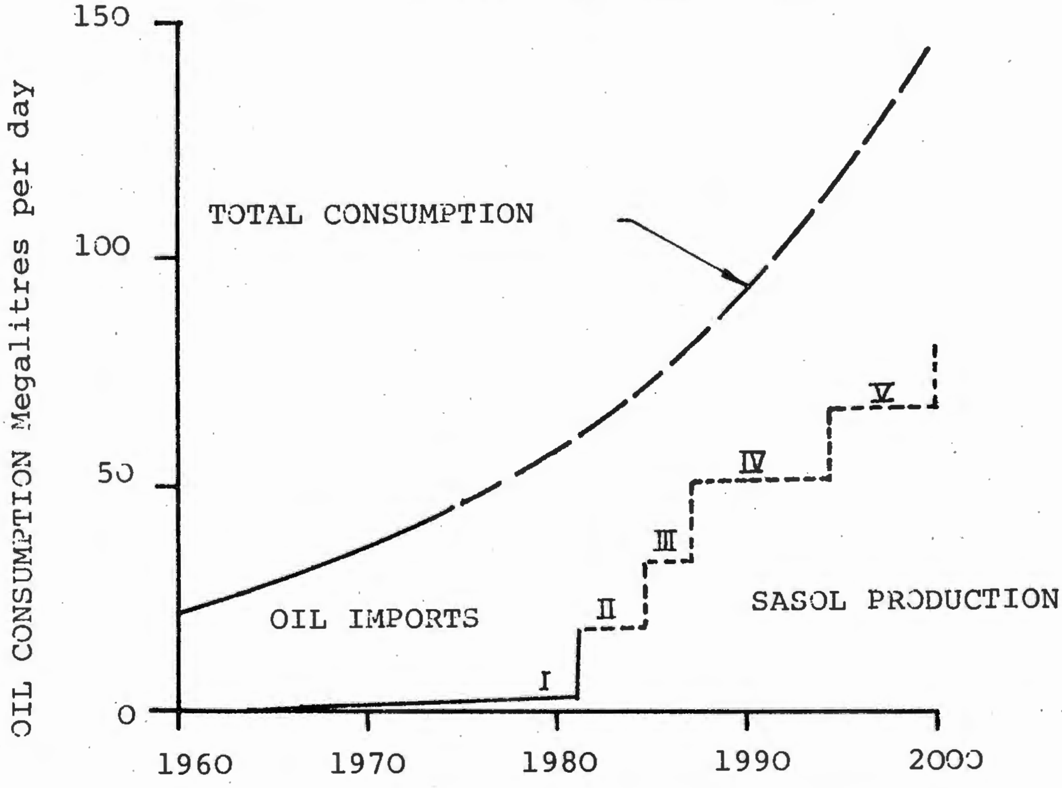


FIGURE 10.1 : OIL CONSUMPTION AND LOCAL PRODUCTION PATTERNS

Table 10.1/.....

Table 10.1 and Figure 10.1 show the expected trends in South Africa's total oil consumption and local oil from coal production. This has been compiled on the basis of a vigorous and continued expansion of Sasol type projects for the production of synthetic crude oil. As can be seen from Figure 10.1, it would be possible using such a scheme to maintain South Africa's oil imports at a fairly constant level. Several factors have been considered in this estimate and it is not the purpose of this report to investigate the nation's oil supply, rather merely to given an outline to the fuel supply situation facing the transport industry over the next quarter decade. This information was extracted from Reference 25, which also quotes the above production rates as being the maximum feasible values considering the enormous capital expenditure involved for domestic coal liquifaction.

Translating the values given in Table 10.1 to actual amounts of petrol and diesel fuels produced results in the values given in Table 10.2.

Year	1975	1985	2000
Total petrol production tonnes p.a. x 10^6	6,13	8,81	13,08
Petrol fuel energy produced x 10^6 MWh (1)	82	118	175
total diesel production tonnes p.a. x 10^6	7,48	10,75	15,96
Diesel fuel energy produced x 10^6 MWh (2)	92	132	197

TABLE 10.2 : PROJECTED S.A. PETROL AND DIESEL FUEL CONSUMPTION

Note(1)/....

Note (1) Based on Fuel calorific value of 11500 kCal/kg
(2) " " " " " " 10600 kCal/kg

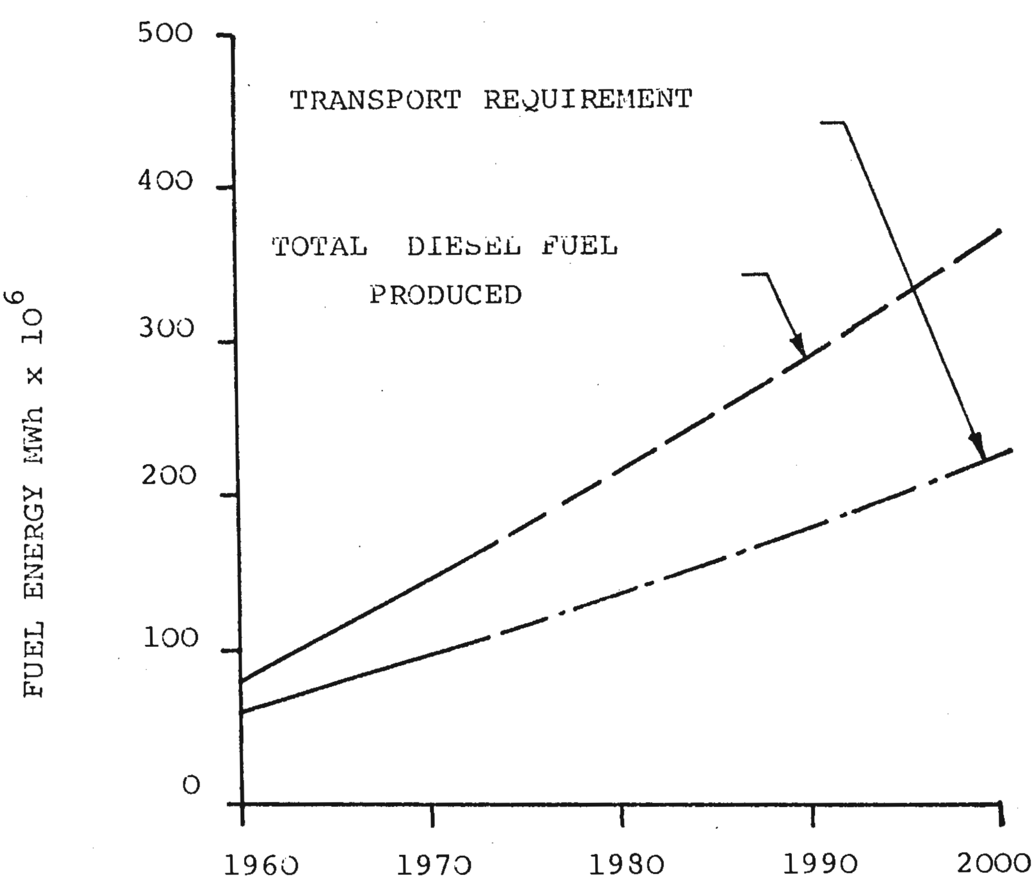


FIGURE 10.2 : TOTAL TRANSPORT REQUIREMENT FOR PETROLEUM BASED FUELS

The information contained in Table 10.2 was based on current and projected values of refinery yield by weight for the various products by distallation (cracking) of crude oil. (Ref.26) This information was used to produce Figure 10.2. From this it is apparent that the transport sector accounts for approximately 60-70% of all refined petroleum and diesel fuel produced, and this fraction will remain substantially constant with time.

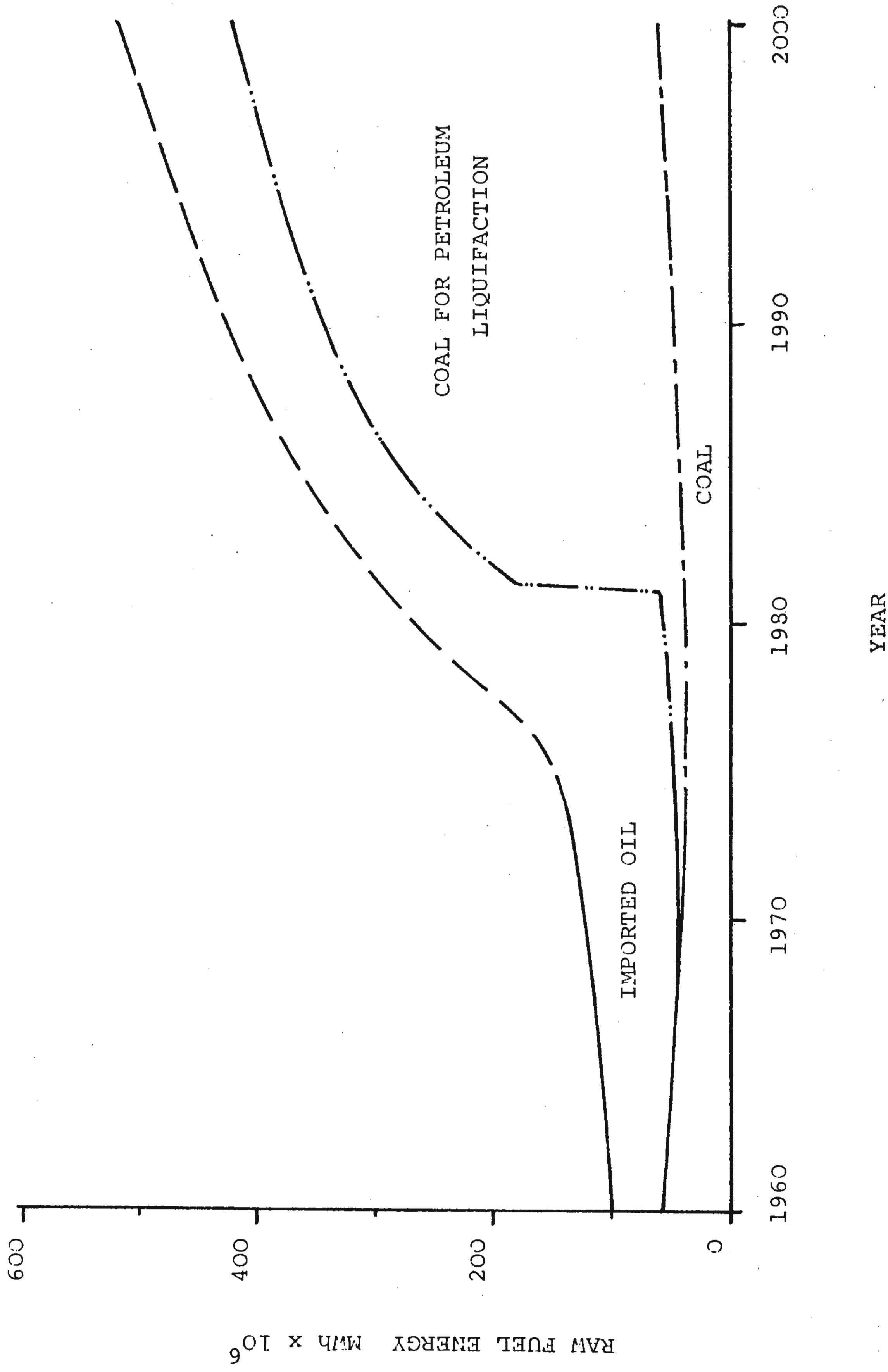
Considering/.........

Considering now the values shown in Figure 10.3 for raw fuel energy requirements, what was considered as pure petroleum (oil based) fuel inputs will now have a proportion of this raw energy attributable to coal as a fuel source. Estimates of the yield of synocrude (synthetic crude oil) are of the order of 0,8 to 1,5 barrels per ton of coal for the Sasol process* with recent modifications to the plant probably placing production in the higher bracket (Ref.26) From above the refinery yield of products usable by the transport industry (petrol, diesel) is of the order of 60% from crude oil by weight. This can now be converted giving a figure of approximately 115 kg of Petroleum products/tonne of coal or 235 kWh petroleum fuel energy from 1 MWh coal fuel energy**. It has been assumed that with improvements in refining technology this will increase steadily to approximately 350 kWh petroleum fuel energy per 1 MWh coal fuel energy by the turn of the century. (Technology on a pilot scale has already proved this.Ref.26) The above information was used to compile Figure 10.3 overleaf to show the true energy consumption pattern, in terms of the anticipated raw fuel energy requirement of the entire transport industry (fuel oil for marine use has been neglected since sufficient lower distallates from the cracking of crude oil for petroleum are produced to more than cover the requirements of this sector). It is stressed that the foregoing is largely dependant on the programme adopted for the production of syncrude but it is felt that the above production is attainable and, if South Africa is to gain any measure of independance from world oil sources, it is in fact essential.

* Coal gasification plus Fischer-Tropsch synthesis

** Coal calorific value 22,5 MJ/kg;
Mean petroleum product 46 MJ/kg

FIGURE 10.3 : ABSOLUTE RAW FUEL ENERGY REQUIREMENT FOR TRANSPORT



10.2 Coal Sources

As a result of the foregoing discussion, it becomes apparent that coal reserves in the Republic will have a very large part to play in the supply of power to the transport industry. Translating the values shown in Figure 10.3 for coal consumption results in the following demand for coal expressed in millions of tonnes per annum.

Year	1960	1970	1980	1990	2000
Coal Consumption $\times 10^6$ tonnes p.a.	9,5	7,0	29	53	66

TABLE 10.3 : ESTIMATED ANNUAL COAL CONSUMPTION - TRANSPORT SECTOR

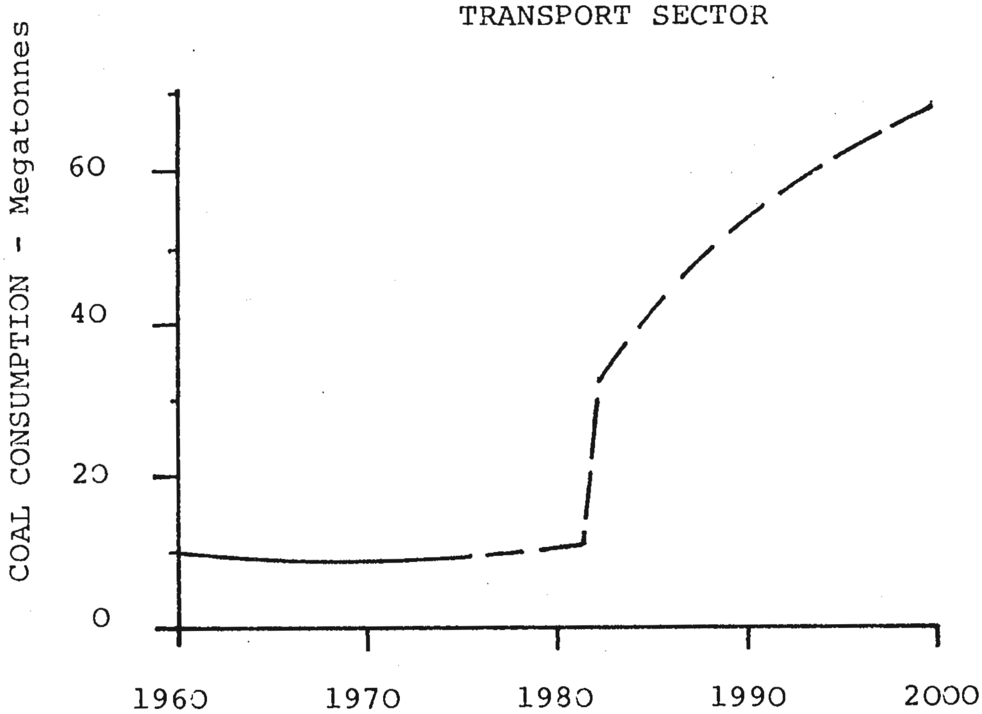


FIGURE 10.4 : ESTIMATED ANNUAL COAL CONSUMPTION - TRANSPORT SECTOR

Using/.....

Using information contained in Reference 27 regarding total coal demand expected in the future, Figure 10.5 was prepared. The figures for coal use by Chemical, Electricity and other industries on this graph were extracted directly from Reference 27 and plotted with the transport sector usage from Figure 10.4. The figures of coal consumption for transport quoted in reference were derived from an estimate of total vehicle population from Reference 17 by the author and used to formulate the total petrol, and hence coal requirements. From estimates derived in this report by agglomorating data from all transport sectors and in terms of the other published estimates (Ref.26) the coal consumption quoted for transport use was rather high (121×10^6 tonnes compared with 66×10^6 tonnes for the year 2000), and the lower value has been inserted in Figure 10.5

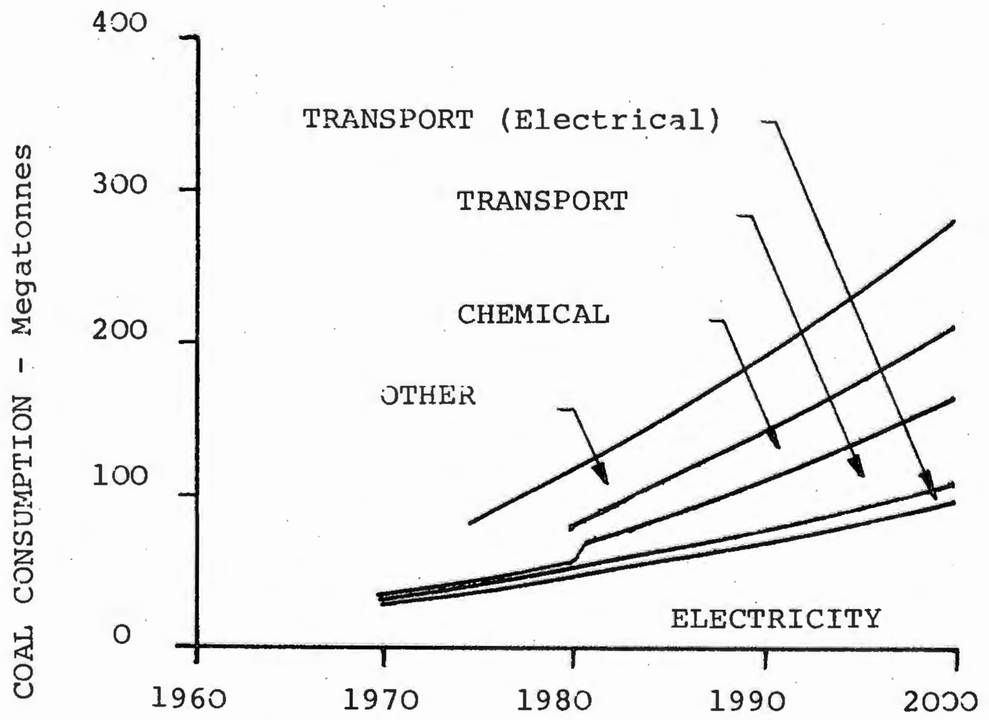


FIGURE 10.5 : TOTAL PREDICTED S.A. COAL CONSUMPTION

It is also/.....

It is also apparent that some of the electricity generated is directly used for transport work (electric trains, pipelines, etc). The demand for coal placed by the transport industry appears to be of the order of 20-23% of the total coal demand over the period 1980 - 2020, a relatively small figure compared with the coal demand for electricity. Consequently, the transport sector, by not placing an overburdening demand on local coal supply can be guaranteed the required quantities of coal until well into the 21st Century.

From the foregoing it is apparent that South Africa has both the resources and the financial means at her disposal to ensure energy supplies for the transport industry to continue expansion along classical (oil based) lines until well after the turn of the century. In a nation where, by virtue of the distance between major centres and harbours as well as the peri-urban spread of its industrial workers,transport is of primary importance so it is reassuring that demands on the industry will be met without excessive sacrifices. However the importance of an economic and well developed oil from coal project cannot be overstressed. Sasol 11 is the first stage in expanding the domestic oil supply and it is apparent that this is still just a small step in relation to the requirements estimated by the year 2000.

CHAPTER 11

11. ALTERNATE ENERGY SOURCES

In the current climate of the so-called "energy crisis" an increased world wide awareness of energy conservation has led to the publishing of a great deal of literature regarding alternative energy sources and in several instances, particulary in the popular press, over-enthusiastic claims have been made regarding certain energy sources and their ability to completely solve all power supply problems. Nuclear, solar and wind power along with hydrogen and natural gas systems are particularly frequently referred to with various claims made as to their suitability. In this section it is proposed to analyze most of these alternatives with a view to their possible impact on South African transport and suitability for transport systems in general. For the sake of uniformity and simplicity, transport systems will be treated as either of two types : DEPENDANT, if the system requires external power sources, or INDEPENDANT, if each transport vehicle carries its own power source : See Table 11.1 below :

TRANSPORT SYSTEM		CLASSIFICATION
Airways		Independant
Railways -	Steam traction	Independant
	Diesel traction	Independant
	Electric "	Dependant
Road Freight		Independant
Omnibus		Independant
Trolleybus		Dependant
Private Car		Independant
Shipping		Independant
Pipeline		Dependant

TABLE 11.1 : TRANSPORT SYSTEM CLASSIFICATION

Without/.....

Without exception the dependant systems rely on electricity as the energy source, **no doubt due to the** ease of transmission over large, but relatively inflexible routes. In general, the independant systems provide a far greater flexibility, constrained only by the availability, where applicable, of track or roadway (fixed route) facilities.

11.1 Nuclear Power

Up to now the civil applications of nuclear power have been exclusively directed towards the generation of electricity. Generation figures for Britain and the U.S.A. approach 10% of these nations' total installed capacity (Ref.28). In terms of direct power sources for transport only, current application is in large shipping vessels where power plant size and power demands are sufficiently large not to be limiting factors.

Several types of power reactor are currently in use and these are enumerated below :

1. Light Water Reactors (LWR)
2. Heavy Water Reactors (HWR)
3. Graphite Moderated Reactors (GMR)
4. Fast Breeder Reactors (FBR)
5. Advanced Gas Reactors (AGR)

Other types such as the Molten Salt Reactor have been tested and investigated on a model scale along with several variations of the main types already mentioned (Ref.28) Types 1 and 2 however, are the most numerous

in commercial/.......

in commercial operation, some of them making use of pressurised water systems for steam generation.

To date the world-wide emphasis has been on fairly high powered static reactors where high capital outlay is effectively neutralized by low fuel costs. Small reactors below about 10 MW (electrical) cannot effectively compete with fossil fuelled plants on an economic basis, with the situation deteriorating rapidly for smaller types.

The Electricity Supply Commission's Koeberg Power Station in the Cape will supply 1800 MW (electrical) due in the early 1980's which will represent some 15% of the installed power station capacity in South Africa. This will evidently ease the demand made on coal for electrical generation and represents a total potential saving of the order of 10×10^6 tonnes of coal per annum.(Roughly 5% of the estimated 1985 coal demand). Additional nuclear stations in the future will enhance this not inconsiderable saving of South Africa's coal, and hence indirectly the oil-from-coal potential.

At present no form of reactor appears suitable for any form of propulsive power other than in large ships. High capital costs and the relatively insignificant fraction of transport power requirements from the marine sector limit the direct application of this power source for local conditions. Any breakthrough in the technical field of small reactors suitable for say large road trucks is considered remote and,due to the sophistication of equipment likely to be required,will be excessively expensive. A further consideration is the safety aspect where it is deemed unlikely that a completely fail-safe and accident proof unit could be developed to the stage that it is acceptable for urban or even long distance road or rail transport. Similar considerations apply to air transport applications where the size and weight penalty of existing and proposed reactors would completely discount any application. There does exist remote possibilities that military nuclear technology may produce commercially viable spin-offs but it is unlikely that these will have any transport applications.

It appears that the benefits of nuclear power to the transport industry will be restricted to the indirect saving of petroleum and coal reserves, enabling more of these products to be channelled into applications which do not rely on generating electricity. Outside of electricity generation, the transport sector places the largest demand upon local coal reserves (Section 10.2) and thus will be the most important benefactor from any large scale use of nuclear power generation.

11.2 Solar Energy

Perhaps the most topical of all solar energy applications at the moment is the use of direct radiation from the sun to heat water (or some other fluid) with a simply insulated radiation absorbing plate. Most commonly known as a flat plate collector, this system is already economically in use for domestic and small scale industrial water heating. Other applications include space heating and the possibility exists for adaption to air conditioning and process heating. With the primary energy source being absolutely cost free, the only economic consideration is the capital cost of the equipment and maintenance and replacement cost. For domestic water heating, annual electricity savings on an average S.A. home could be as high as R90 per annum (Ref.29) for an initial outlay of approximately R500. Thus for small applications the capital redemption rate may be as much as 20% per annum, making the system financially attractive in certain instances.

A more complex arrangement involving focussing or concentrating the sun's rays on a collector surface make possible the generation of steam which could be used for electricity generation. Costs appear to be more than double that of contemporary coal and nuclear stations according to estimates made in 1975 (Ref.29), although possible applications exist in peak load power stations.

A further alternative source of power from the sun is in the form of high energy photons. Photoelastic cells are the most common form of "collector" although the cost of such silicon cells is exorbitant in terms of their power output potential. Commercially available cells for ground level use have efficiencies somewhat less than 15%. One advantage of the system however is that electrical power is produced directly with no need for any energy conversion and on very large scale applications energy costs may ultimately be sufficiently reduced to enable this near perfect energy source to be exploited.

Ocean thermal power is yet another potential energy source, whereby temperature differences between water at the sea's surface and water at depth is used to produce power. The development of such projects could ultimately lead to fairly large power stations but the cost and low energy intensities involved will make this a rather lengthy process. If exploited on a large scale there are also marine ecology problems which may prove insurmountable. Ammonia production from ocean power is another alternative, again dependant on economic considerations.

With the exception of photo-voltaic energy production, none of the currently considered solar energy systems are suitable for independant type transport vehicles. For ideal South African conditions, at noon during summer the peak thermal (direct) radiation at ground level is of the order of 1 KW/metre^2. Typical collector efficiencies are in the region of 60% resulting in a maximum practical collection rate of 0,6 KW/metre^2. Thus for an engine requiring say 30 KW of thermal power some 50 metres^2 of collector area would be necessary. This is rather impractical since this area would be the minimum needed to power a small car, and only under ideal conditions. Also a suitable engine would have to be developed to exploit this power economically and cheaply. This appears to be rather a tall order by any current technology and even with 100% conversion efficiencies such a system would be too large for use on small transport vehicles i.e. road trucks and cars.

The photo-voltaic cell does appear to have certain applications for trickle charging batteries in an electric vehicle. Costs at this stage price this system right out of the market and at best the system would only be a back-up to conventional battery charging from an outlet supplied by normally generated electricity. Cost considerations aside, the major drawback to direct solar energy utilization is its periodic and totally weather dependant nature and under the best conditions it can only produce power for less than 30% of the time.

In the transport context then,the only likely benefit is of the same form as that of nuclear power, namely to reduce the burden made on coal for national electricity generation. However, at this stage it is considered highly unlikely that solar energy will be used to any degree at all in South Africa before the turn of the century for power generation. Indirectly the solar heating of water for domestic applications will reduce the burden on national grid electricity. Utilization of this method is primarily dependant on the ratio between the cost of conventional electricity and heating systems and the cost of an installed solar water heater over its useful lifetime. It is felt that with rising conventional fuel costs that the system will be gradually implemented, especially in new buildings, with the cummulative electricity saving gradually becoming apparent.

11.3 Wind Energy

Strictly speaking, this is an offshoot of solar energy, global temperature differences causing the primary wind movements, but as the methods of utilization are different it will be considered separately. Like wave energy, wind energy is a low intensity power source requiring large structures to collect relatively small amounts of power. As with solar energy this precludes its use in independant transport vehicles and unreliability of wind movements is a further drawback. Research is currently underway in America and some of the problems inherent in wind generators may well be reduced, although the suitability of wind energy as a large scale power source is questionable even with advanced technology.

One more/....

One more unusual possibility is the return of the days of sailing ships, but using modern aerofoil section vanes or perhaps large rotating cylinders to power ocean going vessels. In the South African context, even a complete reversion to wind for marine propulsion would have only a small effect on the total transport energy consumption pattern. Again, unreliability and the consequent difficulty in maintaining scheduled voyage times would limit exploitation to special cargoes and the nett effect then would be negligible and not worthy of consideration for the South African energy situation solely for the sake of fuel conservation.

11.4 Hydrogen

As the earth's most abundantly occurring element, and as a "clean" fuel, hydrogen has many advantages for supplementing the more conventional energy sources at present being used for primary power throughout the world. Hydrogen can be used in several different ways for power generation, as a heat source in the same way as coal is used, in internal and external combustion engines and in gas turbines.

For static applications hydrogen can be simply supplied by pipeline, but the problem of fuel storage occurs where a vehicle must carry its own fuel supply. Hydrogen may be stored as a compressed gas in a suitable pressure vessel, as a liquid or as a chemical compund, usually a hydride. Hydrogen has a heat of combustion of approximately 120 MJ/kg compared with 48 MJ/kg for petrol, so 1 kg of hydrogen is equivalent to roughly 2,5 kg petrol, but the problem of increased storage volume precludes its use in gaseous storage vessels (approx. 1,2m^3 to be equivalent to a tank of petrol in an average sized car (Ref.30). Hydrogen in liquid form does not suffer from this drawback, but the problems of high vapour pressure, low temperatures and evaporation make safe and convenient storage equally impractical. The remaining alternative, storage as hydride appears to be the most practical solution.

Metallic hydrides which can be reversibly formed have been the basis of most research done on hydrogen fuel storage. Basically the process of hydride formation is performed as follows. A suitable metal is exposed to pressurized hydrogen at reduced temperature, forming the hydride which can then be used as a storage medium. The process is reversible on the application of heat, and hydrogen gas is liberated. Metals with low atomic numbers have the potential to absorb larger percentages of hydrogen than those with high atomic numbers, and Magnesium appears to be a good compromise (Ref.30). In a conventional vehicle, waste heat from the engine may be used to liberate hydrogen gas from the hydride storage tank. Such a system has been proven and test vehicles have been constructed in the U.S.A. which have operated successfully.

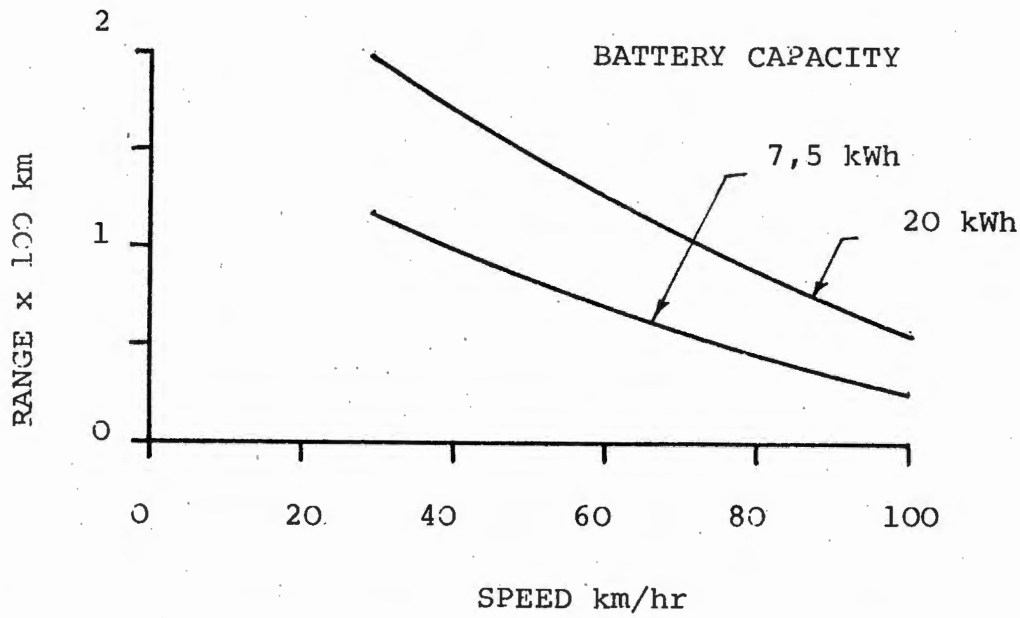
The large scale development of hydrogen fuelled vehicles would have to take very great care in the final choice of any fuel storage system because of the difficulties outlined above and in ensuring the availability of any carrier substance used for hydride fuel shortage. With South Africa's low overall dependance on petroleum and good oil from coal potential, it is unlikely that any research or development of hydrogen fuelled vehicles will occur on a large scale in this country, but rather any overseas lead is likely to be followed. It is certainly considered unlikely that any implications arising from this fuel source will have any effect before the turn of the century in the local transport or power generation industry.

11.5 Battery Powered Vehicles

Battery stored electrical energy has long been considered as an alternative power source especially for road vehicles. Battery technology itself has been the primary limitation to this concept with even new generation batteries having poor power to weight ratios, and usually high initial costs. From a practical view-point the most serious drawbacks to battery powered vehicles are the limited range of operation and the high ratio of battery mass to total vehicle mass. Although the concept of battery storage as a vehicle power source has been well tried successfully, the range limitation has been the primary drawback to the attractiveness of such vehicles as replacement for the conventional automobile.

The most common type of accumulator, the lead acid battery, has a rather poor storage capacity to mass ratio but is however the cheapest and one of the most convenient to use. This type of battery, if designed specifically for electric vehicles, would show only small improvements over conventional types but is however probably the only commercially made battery which will be available over the next decade. (Ref.32)

Figure 11.1 shows an approximate relationship between vehicle speed, battery capacity and possible range.



Source : Reference 31 for steady speed driving : Medium sized car.

FIGURE 11.1 : ELECTRIC CAR - APPROXIMATE RANGE

It is apparent that range falls off rapidly with increased operating speeds, and the more usual stop/ start driving under urban conditions worsens this appreciably. Regenerative braking can improve this performance but only marginally and at the expense of added weight and increased initial costs. Thyristor control has greatly improved the smoothness of operation while reducing electrical losses, but again the expense factor for heavy current semi-conductors is relatively high. Combined battery/flywheel systems do afford some improvements in vehicle performance by reducing peak battery currents but the system is

complicated/.....

complictated and improvements are marginal (Ref.31).

The primary problem inherent in electric vehicle development is the battery itself. A recent British project used industrial lead/acid batteries with a mass of 1672 kg and a storage capacity of 58 kWh (Ref.31) for a vehicle with a payload of only 1780 kg and a range in urban conditions of 65 km. Nickel/Cadumium batteries are lighter and can accept a more severe service cycle than can Lead/Acid types but their cost is prohibitive. A further point to be borne in mind is the availability of the elements needed in propulsive batteries, since implementation on a large scale may result in more severe supply problems than those of natural oil itself.

Looking at the concept of battery powered cars (or trucks) in the South African context, it is difficult to see their successful implementation on a large scale even over the next quarter century for the following reasons. Firstly, the vast coal reserves and hence oil-from-coal potential, already established and expanding, makes the continuation of oil based transport feasible and even attractive in the face of a complete (or large scale) transition to electric power. The second important consideration is the limited range of current and projected electric vehicles compounded by the larger transport distances involved compared with the U.S.A. or Europe, where development in this field is most likely to occur. Lastly, the implementation of electric vehicles would gradually increase the electricity demand of the transport sector. Since battery recharging will mostly be done in the off-peak periods (especially at night) this may not be a serious drawback.

Briefly considering the following :

ESCOM efficiency	≏28%	(Thermal efficiency at the point of sale)
Charging system efficiency	75%	(estimated)
Battery charging efficiency	50%	(output versus input under ideal conditions)
Electric motor efficiency	90%	(typical)
Control circuit efficiency	90%	(typical)

Source : Reference 31

results in an overall thermal efficiency for mechanical power in the vehicle motor from coal generated electricity of approximately 8.5% Current petrol and diesel engined vehicles have thermal efficiencies for mechanical power in the vehicle motor in the range 20 -35%. Crude oil (syncrude) is produced from coal at 60-65% thermal efficiency (Ref.26) and with typical conversion figures of 60%, syncrude into petrol and diesel results in the following figures :

Internal Combustion Engine Efficiency	25%	(thermal average)
Oil from Coal Conversion Efficiency	60%	(typically)
Petrol from Oil Yield	60%	(typically)

This leads to an average thermal efficiency for an internal combustion engine on coal produced fuel of the order of 9%, or roughly the same efficiency as that of an equivalent electric vehicle.

It is stessed that the foregoing is by no means an attempt at an accurate analysis of the efficiencies of either battery or internal combustion powered vehicles, but rather to indicate the approximate figures by which these systems

may be compared/....

may be compared. On the basis of these figures it is apparent that neither form of motive power has any distinct power consumption advantage over the other, indicating similar raw fuel (coal) requirements and thus no nett gain in transport performance to merit, or condemn, one or the other.

As there appears to be no positive ground for a changeover to electric powered vehicles, the only incentive would be an economic or operational one. With the high initial cost of current electric vehicles and their range limitations, it is considered unlikely that these types will make any inroads to the South African transport scene within the next two decades. The improved air pollution features of electric vehicles may well be the sole factor resulting in their use in America and Europe in the future, but, although becoming pollution conscious South Africa does not experience problems on the same scale, so this factor is also not likely to become a crucial consideration in the near future.

CHAPTER 12

12. TRANSPORT PLANNING FOR ENERGY CONSERVATION

Chapters 8 and 10 have dealt with the predicted energy consumption patterns (coal and natural oil) up until the end of this century for the current transport types. In other words, this estimation has been formed on the basis of roughly equal growth rates of all the transport sub-sectors. In this section it is proposed that changes in the utilization of the various modes may beneficially modify the energy demands whilst retaining the same level of urban and long distance transport activity.

12.1 The Predicted Transport Pattern

Figures 12.1-12.4 show the expected distribution of freight and passenger transport over the period 1975-2000 for urban and long distance travel in terms of the passenger or freight tonne kilometres carried by the various transport modes.

These figures are based on the following intuitive estimates of the fractions of the total services performed under urban or long distance operation (Table 12.1)

MODE	URBAN	LONG DISTANCE	TOTAL
Private car	80%	20%	100%
Omnibus	90%	10%	100%
Rail freight	5%	95%	100%
Rail passenger	20%	80%	100%
Road freight	40%	60%	100%

TABLE 12.1 : URBAN/LONG DISTANCE BREAKDOWN OF VARIOUS TRAVEL MODES

Figure 12.1/....

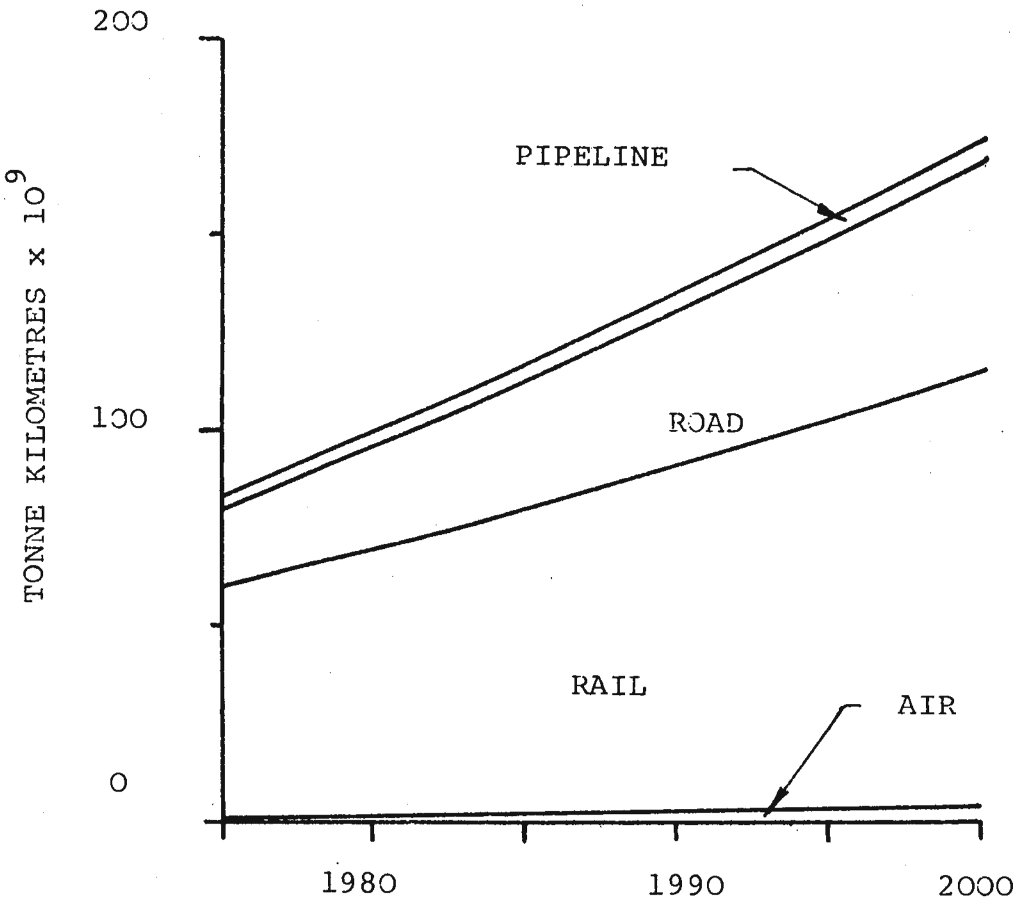


FIGURE 12.1 : LONG DISTANCE FREIGHT TRANSPORT

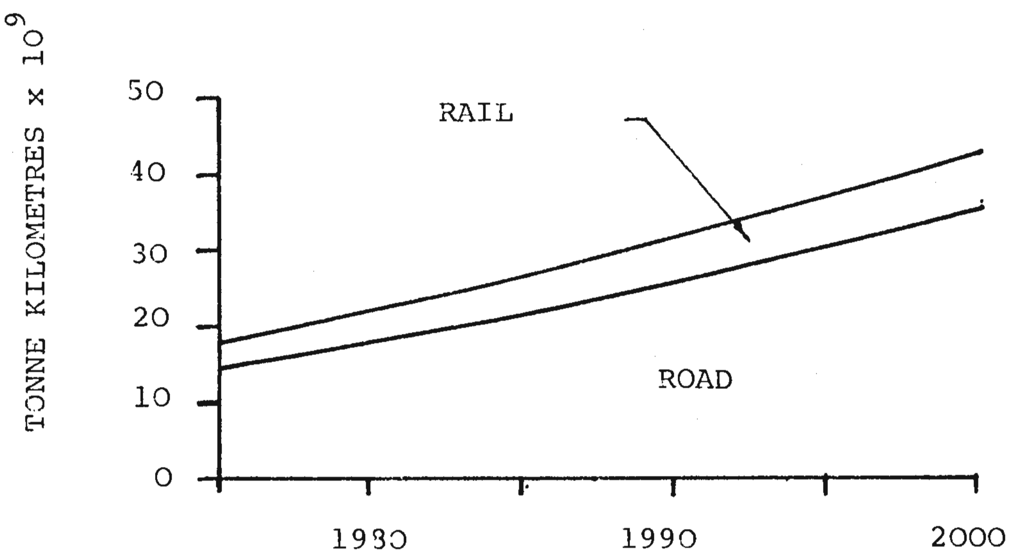


FIGURE 12.2 : URBAN FREIGHT TRANSPORT

figure 12.3/....

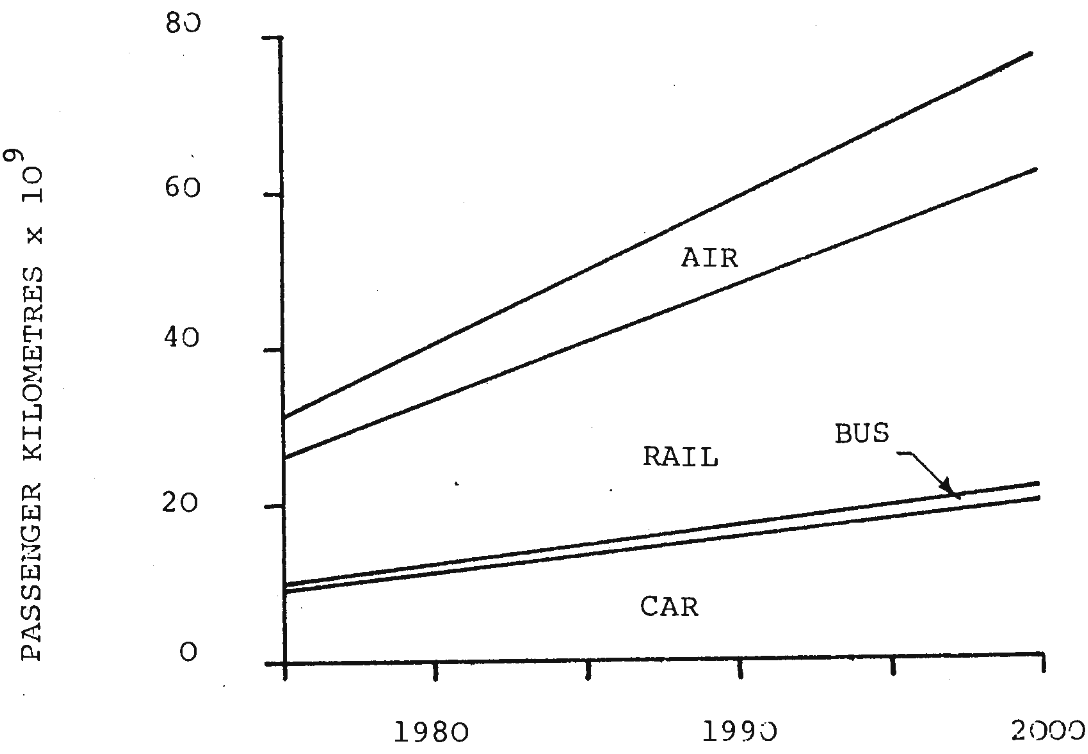


FIGURE 12.3 : LONG DISTANCE PASSENGER TRANSPORT

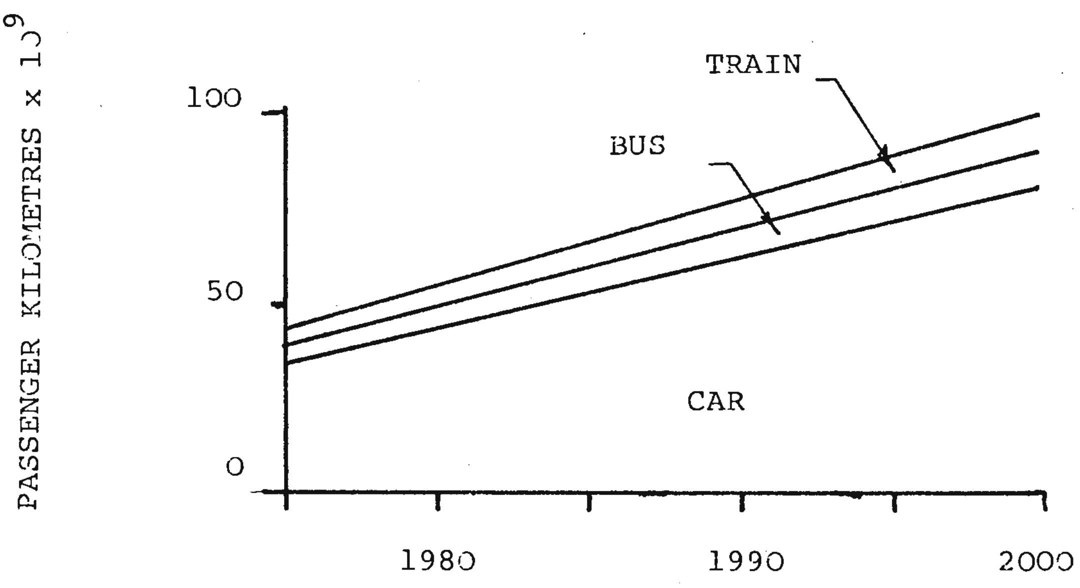


FIGURE 12.4 : URBAN PASSENGER TRANSPORT

Insufficient/.....

Insufficient information exists for an accurate analysis of the fractions of transport work performed under urban and long distance conditions, however it is felt that Figures 12.1-12.4 reflect realistic estimates of South African conditions with present transport systems, and into the future based on the normal expansion of these systems. Hopefully, with it being the stated intention of the National Institute for Transport and Road Research to conduct specific research aimed at analysing urban transport in this country (Ref.33), more precise information will become available in the near future. Until such time as this information is forthcoming, the only alternative is the formation of estimates (as has been done in this report) to apportion the urban and long distance shares of the various transport modes.

The Report of the Committee of Inquiry into Urban Transport Facilities in the Republic (Driessen Committee Report) Reference 18, details estimates for the contributions of the various modes of transport to urban passenger movements for the seven major urban areas within South Africa over the period 1970-2000. For the 1975 estimates, fairly close correlation is noted with figures contained in this report. Predictions beyond 1980, while maintaining similar percentage contributions of the different modes, differ in that the estimates quoted in Reference 18 are greater than those quoted here for the total urban transport work performed and this difference increases progressively up to the year 2000. This was discussed in Section 4.3.2.

As the basis of the transport pattern indicated in Figures 12.1-12.4 it is now possible to analyse the energy consumption patterns in the future with various different options in the form of changed transport mode contributions, the total transport task remaining the same. This has been done in the following sub-sections.

12.2 Long Distance Freight Transport

Four modes of transport are applicable to inland transport in this section i.e. pipelines railways, road freight and air freight in ascending order of raw fuel energy intensiveness. With the specialised service afforded by air transport a guaranteed demand exists and will continue to exist for the service, and while it is highly energy intensive, its contribution to the total energy demand is small, as the service offered constitutes less than 2% of the total transport work even in the year 2000. Consequently, it is deemed unrealistic to assume any deviation from its predicted expansion. Pipeline transport also only contributes a small fraction of the total transport work, roughly the same level as the airways for petroleum product transport only over the period considered. However, with advances being made in the transport of crushed solids in slurry form by pipeline (Ref.34) and this coupled with steadily increasing demand for the movment of certain products (coal, mineral ores) will lead to the situation where it would be possible to extend pipeline services over other major routes. Assuming this is the case, it is reasonable to expect the pipeline sector to double and even treble estimated 2000 services beginning in say, 1985.

It is also considered possible that with the necessary control, road freight operations could be maintained at 1980 levels up to 2000, by transferring this sector to rail transport. This measure is not necessarily as harsh as it may sound, since a reasonable proportion of road transport operates in direct competition with the railways.

Gradually removing this type of road service would still enable road transport to maintain the required services to centres without railheads, but still maintain total operations at a constant level. Figure 12.5 shows the modified transport pattern for long distance freight movements adopting the foregoing measures (Option 1).

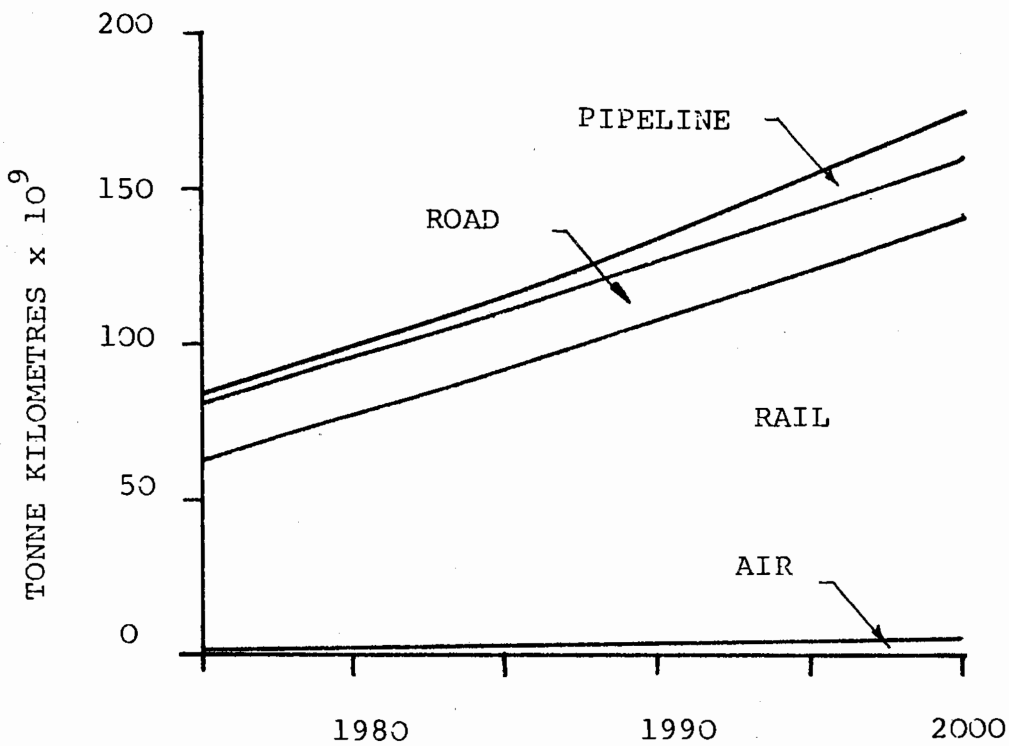


FIGURE 12.5 OPTION 1 - MODIFIED LONG DISTANCE FREIGHT TRANSPORT

12.3 Urban Freight Transport

This is predominantly performed by road transport, rail freight accounting for the small remaining service. As with long distance transport, pipelines for certain products may find an increasing application, the present

domestic gas/.....

domestic gas distribution contributing a negligible fraction of the urban transport requirement. Consider the implementation of urban distributional pipelines for certain products beginning in 1985 and ultimately handling 5% of the total estimated transport in 2000. This becomes more feasible with the intensification of industrial areas, particularly if grouped according to commonality of raw materials, etc. On a similar basis, consider the rail freight service to urban areas embarking on an expansion scheme, beginning in 1985 which will ultimately double the normally expected service by the year 2000. Labelled "Option 2", this is presented in Figure 12.6

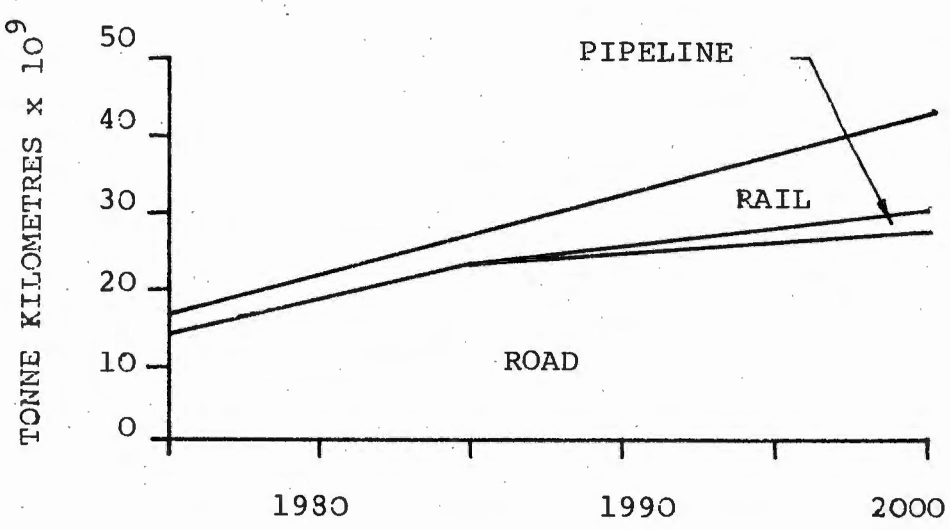


FIGURE 12.6 : MODIFIED URBAN FREIGHT TRANSPORT OPTION 2

12.4 Long Distance Passenger Transport

This sector is shared between air, rail, omnibus and private car transport with rail and private vehicle movements providing the major portion. As discussed in Section 12,2, air transport does cater for specialized demand and a reduction in this service would be at the expense of other factors, i.e. executive travel time - a certain sector of the business world is totally dependant on the airways for long distance high speed transport; tourist convenience - other transport systems require more travel time and reduce the attractiveness of certain types of holiday. If air transport is accepted as a necessity at predicted levels,the only energy savings possible are in the fields of rail, omnibus and car travel, the latter being the most energy intensive form. A large portion of car travel over long distance is for pleasure purposes, or for extended stays in other centres where the vehicle is needed. However, it is felt that a scheme whereby a vehicle may accompany the owner on a train for a very nominal fee would attract a certain amount of long distance car travel. At present the tariff rates for accompanied vehicles is quite high and entails a certain amount of owner inconvenience, although the latter could be obviated by a drive-on system, in much the same way as a ferry might operate. Omnibus transport cannot offer this service, and is expected to remain within the levels predicted. It has been assumed that Option 3 (Fig.12.7) consists of a gradual changeover, beginning in 1980, of ultimately 10% of private vehicle travel by the year 2000 to rail travel with the car being accompanied by the driver/family.

Figure 12.7/.....

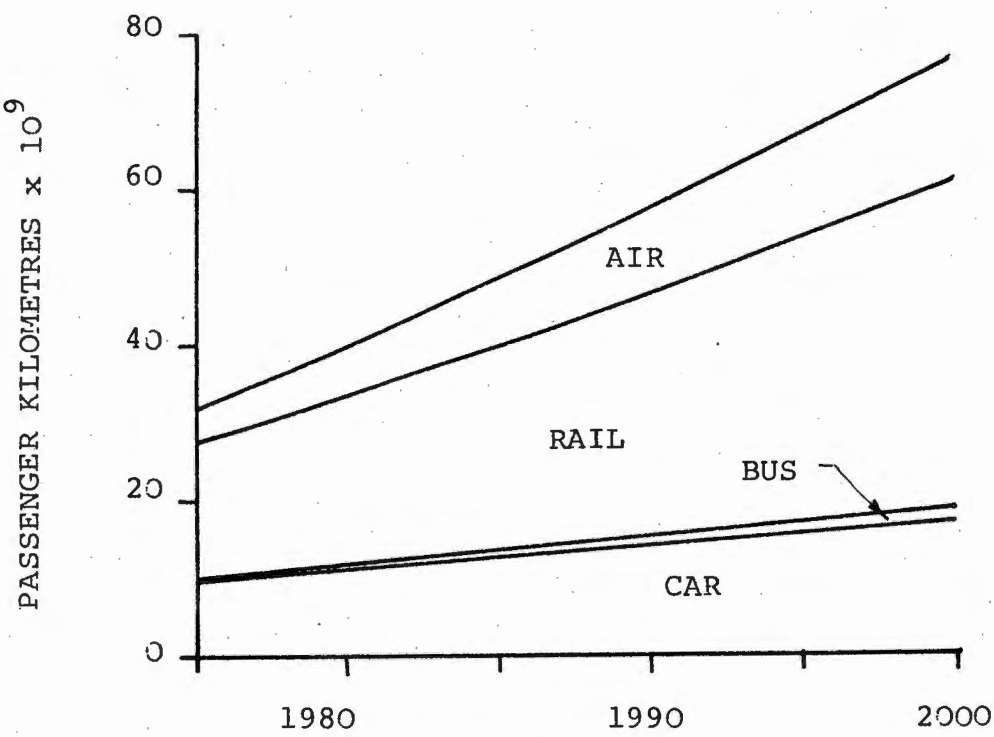


FIGURE 12.7 : OPTION 3 - MODIFIED LONG DISTANCE PASSENGER TRANSPORT

12.5 Urban Passenger Transport

Three primary modes of passenger transport exist for urban travel, namely private car, omnibus and suburban train services. The largest section of transport in this category is performed by private motor vehicles, the most energy intensive of the three types. Train and omnibus services account for smaller and roughly equal shares. The inflexibility and capital outlay required for suburban rail services has restricted its use to the large South African centres. With the growth of new centres in the future, it is reasonable to expect the rail services to maintain the same fraction of the total urban transport structure as shown in Figure 12.4. However, with a view to energy conservation and the decongestion of urban centres, and the advent of more comprehensive services it is considered that it would be possible to increase the level of transport work undertaken by undercutting private car usage. With the help of suitable legislation and a gradual change in the attitude of the motoring public, it is felt that an increase of predicted services, beginning now and ultimately increasing originally predicted 2000 levels by 50%, would be feasible.

Similar reasoning applied to omnibus services but due to the increased system flexibility, gains of 100% over the orginally predicted 2000 service levels are possible particularly if the attractiveness of the facility can be increased. Attractive in this sense would imply rapid, reliable and above all, cheap (in comparison with car travel). A further factor which would promote the rail and bus services would be the introduction on a large scale of flexible business hours. This would reduce traffic peaks and allow more effective use to be made of train and bus units, as the demand would be spread out over longer periods at the beginning and end of ordinary working days. Figure 12.8 is a graphic representation of the abovementioned improvements labelled Option 4.

Figure 12.8/....

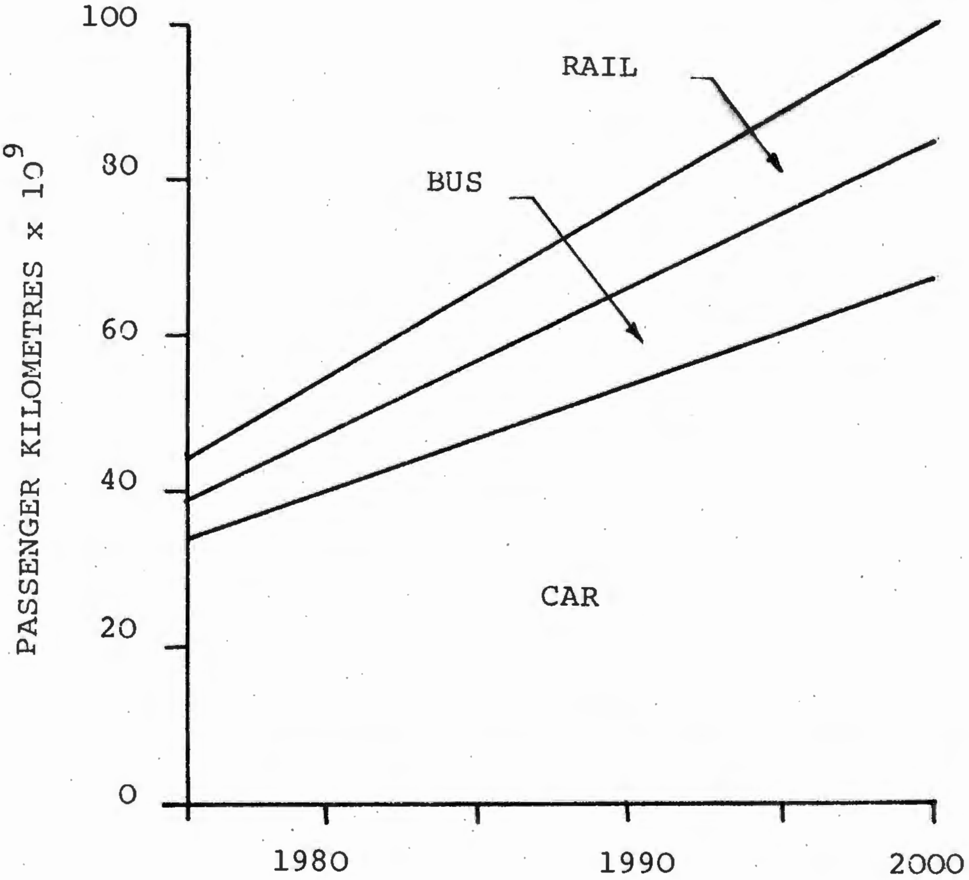


FIGURE 12.8 : OPTION 4 - MODIFIED URBAN PASSENGER TRANSPORT

Using the Options 1-4 mentioned in this chapter, it has been possible to estimate the savings in raw energy for the transport sector should these options be implemented. This is represented in Figure 12.9 showing the saving in imported petroleum and a slight increase in the quantity of coal burnt for direct traction and electricity generation. As shown, this represents a total saving between now and the year 2000 of approximately 465 million barrels of refined petroleum product by increasing the consumption of coal by 28 million tonnes over the same period. This latter figure is very small when it is considered that this represents less than 1,5 million tonnes per annum average over the period considered and

that current/.....

that current coal consumption is already in excess of 30 million tonnes per annum and rising rapidly. The saving has been represented purely on imported petroleum, but may of course reduce the demand for petroleum produced from coal locally instead, or a balance between the two, economic considerations being the deciding factor.

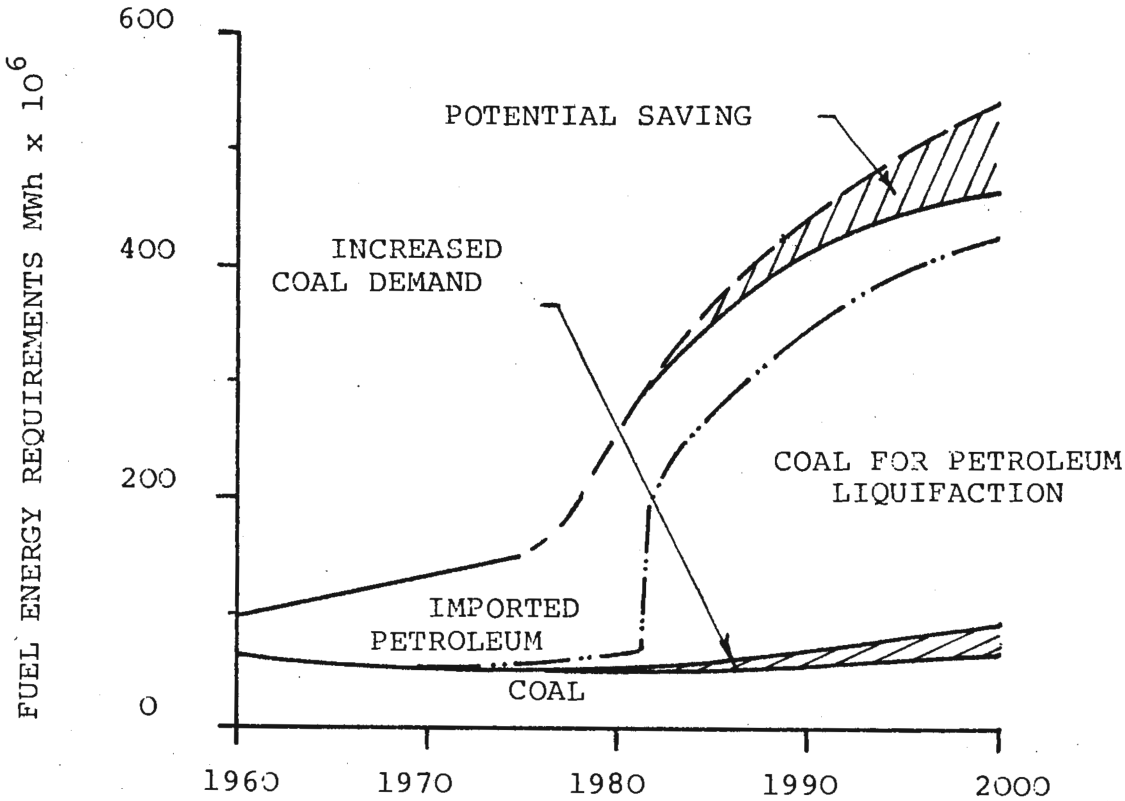


FIGURE 12.9 : MODIFIED ENERGY CONSUMPTION PATTERN

It must be stressed that the foregoing is an indication of the potential for energy saving by adopting realistic and practical transport planning measures alone, and not an attempt to dictate actual transport policy. Necessity might require that even stricter control may have to be exercised over the more energy intensive transport modes should the petroleum based fuel supply become critical. However, it is felt that, with an industrial sector so dependant on long distance transport, South Africa can ill afford any sacrifice to the total transport service in the future, and the measures proposed in Options 1-4 are thought to be the limit before actual service volume will be adversely affected.

It is apparent that the potential for energy conservation is somewhat limited, despite fairly far reaching measures to optimise transport utilization, if the total transport service provided in the future is not to suffer. Further restrictions and enforced control of transport sub-sectors is likely to create socially or economically unacceptable conditions, ultimately limiting the nation's industrial output (and even these severe measures are not capable of reducing energy requirements much more than the savings shown possible in the foregoing chapter). If the nation as a whole is not to suffer artificial economic restrictions caused by suppressed transport services, the availability of sufficient fuel must be assured.

CHAPTER 13

DISCUSSION

The forecasting of any system and its performance into the future entails a good deal of risk to the author's reputation, regardless of how well historical data correlates with the hypothetical model. If the system to be simulated is also dependant on several external and unpredictable variables, the phrase "sticking one's neck out" is enhanced in its implications. Consequently a good number of past predictions have been somewhat conservative in outlook and approach.

In the context of this report and its study of South African transport systems, one of the major assumptions has been of smooth and balanced industrial development in the country throughout the future periods under discussion. It is well known that South Africa has exceptionally good mineral reserves convering a wide range of materials, as well as excellent weather and farming conditions over a large portion of the country. Consequently the potential for development is enormous. However oppresive the current economic recession seems at the moment, it is likely that this will be of negligible effect when seen in retrospect in, say, ten years time.

A further disadvantage is the inability to foresee new developments and concepts which could supercede current transport modes. The development of new fuels and energy converters may well result in currently impossible thermal efficiencies. It is not entirely unlikely that, for example, nuclear power may be refined to the extent of small, self-contained motors suitable for small vehicles. Far fetched as it may sound, perhaps even the discovery of a fourth dimension will completely remove the need for transport as we know it.

In many /.....

In many ways, lack of imagination may be the main cause of conservative estimates which fall short of actual occurrences. It is not possible however to put quantitative values to imaginative concepts and as a result this report is concerned with the classical transport modes and their most likely development. As far as possible cognisance has been taken of technological advances which are currently in the conceptual or actual development stage, with a view to determining their implications on the whole transport industry.

Bearing in mind the foregoing limitations, it is sincerely felt that the transport model presented here does represent a reasonable picture of the South African situation up until the turn of the century. As far as it is possible to ascertain at the moment, major new developments will be unlikely to occur during the next ten years, anything beyond this being impossible to forecast.

CHAPTER 14

SOUTH AFRICAN TRANSPORT INTO THE FUTURE : CONCLUSIONS

The basis of this report has been the forecasting of South Africa's transport network and the raw energy requirements of this sector up to the end of this century. The results indicate that, over the period considered, the transport industry will continue to use processed oil products as the prime energy source and so will be dependant on the supply of crude oil for processing into petroleum fuels. South Africa is in the fortunate position of having good coal reserves and a proven coal liquifaction process which has the potential of isolating this nation from the world natural oil market. This is especially important since none of the currently available alternate energy sources are likely to provide viable transport power over the next quarter decade. (Chapter 11)

Despite the valuable potential of locally produced petroleum, the expense involved in the establishment of large-scale coal liquifaction plants is considerable. If the transport industry is to develop normally and be able to fully meet the demands of the nation, action must be taken now to start raising the necessary funds to achieve local independance from natural oil sources. The recently implemented levy imposed by the Government on fuel sales is a step in the right direction. It is only since about 1970 that fuel availability has become a criterion in the expansion of South Africa's transport industries and it is apparent from this report that this will become the prime limiting factor in the near future.

Accordingly/.....

Accordingly the estimates given in the foregoing Chapter have been made with the ultimate fuel availability in mind. The limitations of other forecasting methods for the transport industry rapidly become apparent when the energy implications of these predictions are analysed. Granted, social economic and environmental factors must also be considered, but ultimately it will be the ability to sustain these systems, from an energy consumption viewpoint, that will dictate the permissible levels of operation of the different sectors.

It is therefore recommended that maximum priority be given to improving the currently inadequate supply of energy utilization data for the transport industry and that all the necessary steps are taken to ensure the availability of sufficient quantities of coal-produced crude oil over the forthcoming years. Similarly, current forecasting methods for the transport industry and allied sectors should be reviewed to allow for the inclusion of energy availability considerations, as it is evident that these will become of crucial importance within the next decade.

It is also apparent that the potential for fuel energy conservation is rather limited, even when fairly stern measures are enforced to redistribute the transport pattern over the more energy effective transport modes. Thus the early and vigorous change-over to local fuel sources is imperative if the nation's full potential is to be effectively realised in the future.

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APPENDIX 1

SAA RECORD OF HOURS FLOWN AND PASSENGER/FREIGHT SERVICE

Year	Hours Flown	x 1000 Pass. kms	x 1000 kms flown	x 1000 tonne kms (freight)
1962	37 368	719 475	15 852	
1963	39 995	849 465	17 864	
1964	45 212	1 042 438	20 788	
1965	44 416	1 144 414	21 949	140 290
1966	45 073	1 458 478	25 553	
1967	47 487	1 654 354	26 846	
1968	50 373	1 837 739	28 180	
1969	56 829	2 167 764	33 037	
1970	65 831	2 817 588	41 262	
1971	73 722	3 071 769	47 866	328 534
1972	68 332	3 536 119	45 966	
1973	69 255	4 436 176	47 850	
75/6	80 470	4 049 767	-	686 346

Source : SAA

Appendix 2/......

APPENDIX 2

DETERMINATION OF HOURS FLOWN FROM PREDICTED DATA

$$K_p = K_A \times N_{sm} \times F_L$$

$$= H_A \times V_{om} \times N_{sm} \times F_L$$

$$\therefore \quad H_A = \frac{K_p}{V_{om} \times N_{sm} \times F_L}$$

Where K_p = Passenger kilometers

K_A = Aircraft kilometers

N_{sm} = Mean Number of Seats/Aircraft

F_L = Load Factor

H_A = Aircraft Hours Flown

V_{om} = Mean Average Operating Speed

World trend of operating load factors is tending to the 0,65 (65%) level, generally considered to be the optimum value (Ref 1).

Mean operating speed 700 km/hr. Based on study of aircraft kilometers and hours flown 1975/76, with aircraft already flying at maximum practical operating speeds. Note - flying time is recorded from engine start up to shut-down, taxiing and holding on the ground thus being termed flying time together with the actual time spent airborne.

Appendix 3/....

APPENDIX 3

SAA:TABLE OF PREDICTED VALUES FOR FUTURE SERVICES

YEAR	PASS. KMS x 10^9	LOAD FACTOR	MEAN NO. OF SEATS	MEAN OPERATING SPEED km/hr	ANNUAL HOURS FLOWN (estimated) hr	ACTUAL
1960	0,52	0,45	50	670	(34 500)	(35 487)
1970	3,02	0,60	100	670	(75 124)	(68 089)
1980	5,2	0,50	180	700	82 500	-
1990	10,5	0,65	250	700	92 300	-
2000	15,0	0,65	300	700	110 000	-

NOTE: Jet Fleet only.

Based upon a mean annual expansion rate of 6% per annum.

Appendix 4/....

APPENDIX 4

SAA SPECIFIC AIRCRAFT PERFORMANCE DATA

(See Confidential Appendices)

APPENDIX 5

SAA PERFORMANCE OF FLEET AIRCRAFT

(See Confidential Appendices)

APPENDIX 6

PROJECTED SAA FLEET FOR 1980

TYPE	NUMBER	EFFICIENCY (EST.) %	HOURS FLOWN (1)	FUEL CONS. x 10^3 TONNES (2)
B707A	-	21	-	-
B707B, C	6	24	13 750	82,5
B727	9	28	20 625	77,2
B737	6	28,5	13 750	39,9
B747B	5	30	11 458	128,3
B747SP	6	30	13 750	120,3
A300	4	32	9 167	53,2
TOTAL	36	29% (3)	82 500	501,4

1. Estimated hours flown from Figure 23.
2. Estimated fuel consumption from quoted performance figures. (SAA)
3. Estimated fleet fuel efficiency (weighted mean). Based on specific performance figures (Appendix 4) and estimates in References 1 and 5.

APPENDIX 7

SAA - JET FLEET MEAN FUEL CONSUMPTION (EXCLUDING HIRED AIRCRAFT)

YEAR AND TYPE	HOURS FLOWN	FUEL CONSUMED*	AVERAGE CONSUMPTION
	hours	x 10^3 tonnes	tonnes/hr
1960/61			
B707	2 581	15,5	
TOTAL	2 581	15,5	6,000
1965/66			
B707	11 844	71	
B727	6 366	24	
TOTAL	18 210	95	5, 217
1970/71			
B707	27 625	165	
B727	17 826	67	
B737	10 377	30	
TOTAL	55 828	262	4,693
1975/76			
B707	21 658	130	
B727	22 167	83	
B737	11 435	33	
B747B	17 014	190	
TOTAL	72 274	436	6,033

*Estimated from quoted fuel consumption figures App (8)

Appendix 8/....

APPENDIX 8

SAA CURRENT AIRCRAFT DATA

(See Confidential Appendices)

Appendix 9/.....

APPENDIX 9

SAA - AIRCRAFT FLYING TIME UTILISATION

YEAR	FLEET SIZE	HOURS FLOWN	TIME AIRBORNE %
1967	23	47 487	23,55
1968	26	50 427	22,13
1969	29	56 829	22,35
1970	32	65 831	23,47
1971	35	73 722	24,03
1972	31	68 332	25,15
1973	31	69 255	25,49
1974	31	-	-
1975	31	80 470	29,61
1976	37	-	-
		WEIGHTED MEAN:	24,76%

Source : Ref (4)

For calculation purposes a utilization time of 25% has been assumed, in the light of the above results, and this is not expected to change radically with future technology. Ref (3).

APPENDIX 10

SAA - EXTRACTED FIGURES : 1974 SOUTH AFRICAN STATISTICS

Averages for 5 year period 1969 - 1973.

	Unit	Regional & Domestic Flights	Overseas Flights
Hours flown/annum	hrs	38 560	28 233
Aircraft dist. travelled	x 1000 km	21 534	21 662
Number of flights	No.	35 063	6 202
Number of passengers	No.	1 493 176	212 940
Passenger kilometers	x 1000	1 267 442	1 938 441
Tonnes of freight carried	tonnes	17 078	5 752
Freight tonne kilometers	x 1000	15 658	55 073
Tonnes of air mail carried	tonnes	2 693	715
Air mail tonne kilometers	x 1000	2 572	7 034
Tonnes of excess baggage	tonnes	290	54
Baggage tonne kilometers	x 1000	275	452

Source : Reference 4

Appendix 11/.....

APPENDIX 11

SAA MEAN FLIGHT VALUES - AVERAGE FIGURES FOR FIVE YEAR PERIOD 1969 - 1973

		REGIONAL AND DOMESTIC	QUANTITY	OVERSEAS
	(1)	38 560	Hours Flown	28 233
	(2)	21 534 x 10^3	Aircraft kms	21 662 x 10^3
	(3)	35 063	No of take offs	6 202
	(4)	1 493 176	No of pass.	212 940
	(5)	1 267 442 x 10^3	Passenger kms	1 938 441 x 10^3
(5) ÷ (4)	(6)	850 km	Trip length/pass.	9 100 km
(5) ÷ (2)	(7)	58,86	Pass/Aircraft	89,49
(2) ÷ (1)	(8)	558,45 km/hr	Mean aircraft speed	767,26 km/hr
(6) ÷ (8)	(9)	1 hr 31 mins	Mean flight time/pass.	11 hr 52 mins
(11) x (8)	(10)	615 kms	Mean stage length	3 495 kms
(1) ÷ (3)	(11)	1 hr 6 mins	Flying time/stage	4 hrs 33 mins
	(12)	17077,8	Freight tonnes	5725,5
	(13)	15658 x 10^3	Freight ton kms	55073 x 10^3
	(14)	2693	Air mail tonnes	715
	(15)	2572 x 10^3	Air mail ton kms	7034 x 10^3
	(16)	290	Excess baggage tonnes	54
	(17)	275 x 10^3	Baggage ton kms	452 x 10^3
(12) ÷ (21)	(18)	673 kg	Freight/trip	2418 kg
(14) ÷ (21)	(19)	106 kg	Mail/trip	300 kg
(16) ÷ (21)	(20)	11 kg	Baggage/trip	23 kg
(2) ÷ (6)	(21)	25368	No of trips	2379
(13) ÷ (12)	(22)	920 km	Freight trip length	9575 km
(15) ÷ (14)	(23)	955 km	Mail trip length	9840 km
(17) ÷ (16)	(24)	950 km	Baggage trip length	8370 km

Appendix 12/....

APPENDIX 12

SAA JET FLEET FUEL CONSUMPTION (ESTIMATED)

YEAR	CRUISE tonnes x 10^3	CRUISE + 10% tonnes x 10^3	CRUISE Ml(1)	CRUISE + 10% Ml(1)	MEAN HOURLY CONS/AIR-CRAFT l x 10^3
1960	15,5	17	19,5	21	7,5
1965	95	105	120	130	6,5
1970	262	290	325	360	5,9
1975	436	480	545	600	7,5
1980	500	550	625	690	8,4
1985	570	625	710	780	8,4
1990	630	695	790	870	8,6
1995	700	770	875	960	9,0
2000	760	840	955	1 050	9,5

(1) At s.g. = 0,80 Jet A.1

Appendix 13/.......

APPENDIX 13

AIR TRAFFIC MOVEMENTS

To obtain an idea of the frequency of services and correspondingly, the density of air traffic movements for air travel until the end of the century it is necessary to consider the following factors.

Passenger kilometers moved/annum . . . . (K)
For a given fleet the number of passengers conveyed over established routes will directly affect the number of aircraft movements.

Passenger load factor . . . . (F)
This will inversely affect the frequency of services

Aircraft size (Number of seas) . . . . (S)
Will also inversely affect service frequency

Let N denote the frequency of services and the suffix the year considered.

$$N_{2000} = \frac{N_{1975} \times K_{2000} \times S_{1975} \times F_{1975}}{K_{1975} \times S_{2000} \times F_{2000}}$$

$$N_{1975} \; \frac{15 \times 10^{9} \times 170 \times 0{,}50}{4 \times 10^{9} \times 300 \times 0{,}65}$$

$$1{,}6 \times N_{1975}$$

i.e. the frequency of services will be 1,6 times the present level by the year 2000.

However the size of the passenger handling facilities will have to increase in direct proportion to the passenger kilometers flown if the service routes remain the same. Thus air terminal facilities will have to increase fourfold over present levels by the turn of the century, while runways and air traffic control facilities will probably be able to handle the 60% increase in aircraft movements mentioned in the previous paragraph,

without/......

without a substantial increase in size or number. A similar increase may be expected in the freight handling facilities as those for passenger handling.

Considering N_{1975} as the numberof landings performed in South Africa during 1975 by SAA aircraft on commercial services

$$N_{1975} = 9\,400$$

$$\text{so} \quad N_{2000} \simeq 15\,000$$

APPENDIX 14

STEAM LOCOMOTIVE FLEET

YEAR	NUMBER OF LOCOS	FLEET TRACTIVE FORCE kN	TRACTIVE FORCE PER LOCO kN	TOT. DIST. TRAVELLED km	COAL CONSUMED TONNES
1959/60	2 742	436 467	159	n/a	n/a
1964/65	2 572	417 952	162,5	130 047 867	6 048 892
1969/70	2 473	406 895	164,5	103 116 603	5 120 249
1974/75	2 087	351 984	168,5	61 927 049	3 332 269

YEAR	MEAN DISTANCE TRAVELLED/LOCO km	MEAN COAL CONSUMPTION km/tonne	MEAN COAL CONSUMPTION kg/km
1959/60	n/a	n/a	n/a
1964/65	50 560	21,5	46,5
1969/70	41 700	20,1	49,8
1974/75	29 670	18,6	53,8

n/a = not available

Source : South African Railways

NOTE: FIGURES INCLUDE ALL LOCOMOTIVES, BROAD AND NARROW GAUGE.

Appendix 15/....

APPENDIX 15

DIESEL LOCOMOTIVE FLEET

(See Confidential Appendices)

APPENDIX 16

ELECTRIC LOCOMOTIVE FLEET

YEAR	NUMBER OF LOCOS	FLEET TRACTIVE kN	MEAN TRACTIVE FORCE/LOCO kN	TOT. DIST. TRAVELLED km	ELECTRICITY CONSUMED kWh
1959/60	471	57 540	122	n/a	923 929 807
1964/65	746	97 316	130,5	82 664 374	1 606 093 943
1969/70	1111	150 327	135,5	130 405 177	2 316 373 804
1974/75	1467	252 705	172	152 447 492	3 158 823 201

YEAR	MEAN DISTANCE TRAVELLED/LOCO km	MEAN POWER CONSUMPTION km/1000 kWh	MEAN POWER CONSUMPTION kWh/km
1959/60	n/a	n/a	n/a
1964/65	110 800	51,5	19,42
1969/70	117 400	56,5	17,70
1974/75	104 000	48,0	20,83

n/a = not available

Source : South African Railways

NOTE: FIGURES INCLUDE ALL LOCOMOTIVES, BROAD AND NARROW GAUGE

Appendix 17/.....

APPENDIX 17

LOCOMOTIVE ENERGY CONSUMPTION

STEAM LOCOMOTIVE

1975	Mean coal consumption	53,8 kg/km (Appendix 14)
	Calorific value	7,5 kWh/kg

Mean energy consumption = 403,5 kWh/km
(for a loco of 168,5 kN tractive effort)

DIESEL LOCOMOTIVE

1975	Mean fuel consumption	4,01 l/km (Appendix 15)
	Calorific value of diesel fuel	12,2 kWh/kg
	Density of diesel fuel	0,835 kg/l

Mean Energy Consumption 40,9 kWh/km
(for a loco of 191,0 kN tractive effort)

ELECTRIC LOCOMOTIVE

1975	Mean electricity consumption	20,8 kWh/km (Appendix 16)
	Mean energy consumption	20,8 kWh/km

(for a loco of 172,0 kN tractive effort)

Appendix 18/.....

APPENDIX 18

S.A.R. SYSTEM ENERGY CONSUMPTION 1974/75

(See Confidential Appendices)

Appendix 19/....

APPENDIX 19

ANNUAL LOCOMOTIVE POWER REQUIREMENTS 1960 - 2000

(See Confidential Appendices)

APPENDIX 20

LOCOMOTIVE TRACTIVE EFFORT

YEAR	ANNUAL GOODS TONNE KMS x 10^9	ANNUAL LOCO KMS x 10^6	MEAN TRAIN LOAD TONNES	MEAN LOCO TRACTIVE EFFORT kN (1)
1960	34	200	170	135
1970	53	280	190	150
1980*	76	340	224	177
1990*	98	420	233	185
2000*	120	490	245	195

* Projected values

(1) Based on a linear increase in loco size with increases in train goods load

Source 1960 figures : Reference 8

Source 1970 figures : Reference 10

Appendix 21/...

APPENDIX 21

SOUTH AFRICAN RAILWAYS

SYSTEM EFFICIENCY

YEAR	1960	1970	1980	1990	2000
Steam efficiency %	3%	3%	3%	-	-
Steam loco kilometres x 10^6	155	100	40	0	0
Diesel efficiency %	30%	30%	30%	30%	30%
Diesel loco kilometres x 10^6	15	48	115	160	90
Electric efficiency %	60%	60%	60%	60%	60%
Electric loco kilometres x 10^6	25	130	185	260	400
Total loco kilometres x 10^6	195	278	340	420	490
Mean efficiency %	12%	34%	43%	49%	54%
% of total energy consumption	98%	95%	91%	80%	77%
Estimated efficiency other servies %	30%	30%	30%	30%	30%
Weighted system efficiency %	12%	34%	42%	45%	48%

Appendix 22/......

APPENDIX 22

NON-TRACTION ENERGY REQUIREMENTS

YEAR	NON-TRACTION ENERGY CONSUMED x 10^6 MWh
1960	1,0
1970	1,7
1980	2,5
1990	3,2
2000	4,1

NOTE: Scaled off a 1975 requirement of 2,2 x 10^6 MWh at an annual increase rate of 2,5% p.a.

APPENDIX 23

SOUTH AFRICAN RAILWAY
TRANSPORT ENERGY CONTENT

YEAR	SYSTEM ENERGY REQUIREMENTS MWh x 10^6	GOODS TONNE KILOMETRES x 10^9	POWER PER TON km kWh/ton kilometres
1960	55	34	1,62
1970	43,8	53	0,83
1980	27,8	76	0,37
1990	16,1	98	0,16
2000	17,2	120	0,14

Appendix 24/.....

APPENDIX 24

S.A.R. ROAD TRANSPORT 1975

(See Confidential Appendices)

Appendix 25/....

Appendix 25

Omnibus Services 1974/1975

Municipalities : Alberton, Benoni, Bloemfontein, Brakpan, Durban, East London, Germiston, Johannesburg, Kempton Park, Ladysmith, Nigel, Pietermaritzburg, Pretoria, Roodepoort, Springs, Welkom, Windhoek.

Other :

City Tramways	(Cape Town and Port Elizabeth)
Putco	(Transvaal and Natal)
United Transport	(Transvaal)

Combined Totals :

1.	Passengers carried	440 150 000
2.	Bus distance operated	234 795 000 km
3.	Number of buses	4 400
4.	Fuel consumed per annum (est)	86 322 000 litres
5.	Mean bus fuel consumption	2,72 km/litre
6.	Transport energy requirement* (ref 13)	0,23 kWh/pass. km
7.	Passenger kilometres transported (est.)	3 860 554 000 pass. km
8.	Mean distance per passenger journey	8,77 km
9.	Passengers embarking per bus kilometre	1,8746 pass/km
10.	Mean bus seating capacity	78,4 seats
11.	Mean bus occupancy	16,44 pass.
12.	Load Factor	21%
13.	Total income from fares and subsidies	R68 000 000
14.	Income per passenger kilometre moved	1,76c
15.	Average income per passenger (Incl. subsidies)	15,45c

Appendix 26/.......

* At diesel fuel calorific value = 10,23 kWh/litre

Appendix 26

South African Bus Services - Totals

		1974/1975
Buses accounted for in Appendix 24		4 400
Other*		1 120
	Total	5 520

Passengers carried	552 000 000
Distance operated	295 000 000 km
Fuel consumed (est)	108 000 000 litres
Passenger kilometres transported (est)	4,85 x 10^9 pass.kms

Note: Estimates based on extrapolation of data in Appendix 2 in terms of the number of buses operated.

	1964/1965
Passengers carried	331 000 000
Distance operated	177 000 000 km
Fuel consumed (est)	65 000 000 litres
Passenger kilometres transported (est)	2,9 x 10^9 pass.kms
Total number of buses	3 310

Bus defined as a passenger carrying vehicle with a seating capacity in excess of 40 seats operating over specified routes for reward.

Appendix 27/........

* Estimates of small companies: Durban, East London, Kimberley and Pretoria.

Appendix 27

Trolleybus Services 1973/74 (Reference 12)

Sole operator : Johannesburg Municipality

Passengers carried	17 924 544
Trolleybus distance operated	3 119 104 km
Number of trolleybuses	81
Electricity consumed per annum	11 098 499 kWh
Mean bus power consumption	3,5582 kWh/km
Transport energy requirement	0,15 kWh/pass.km
Passenger kilometres transported	73 990 000
Mean distance per passenger journey	4,13 km
Passengers embarking per bus kilometre	5, 7467 pass/km
Mean bus seating capacity	73,53 seats
Mean bus occupancy	23,72 pass.
Load factor	32,26%
Total income from fares and subsidies	R1 577 405
Income per passenger kilometre moved	2,13c
Average income per passenger (incl. subsidies)	8,80c

1964/1965 Totals (Reference 12)

Number of trolleybuses	360
Distance operated	11 500 000 km
Paasengers carried	7 510 000
Power consumed	26 100 000 kWh
Passenger kilometres transported*	273 000 000 pass. kms

Appendix 28.......

* Estimated from 73/74 figures in terms of distance operated

Appendix 28

Omnibus Power Plants
(Figures quoted from City Tramways Limited)

Maker	Serial	Cubic Capacity (litres)	Estimated in-service fuel consumption km/litre
Leyland	L600	9,8	2,7
Gardner	6Lx30	10,45	2,6
Leyland	680	11,1	2,7

Appendix 29.......

Appendix 29

Commercial Vehicles Registered
(excluding tractors)

YEAR	VEHICLES REGISTERED
1940	49 470
1945	63 519
1950	123 549
1955	163 000
1960	211 525
1965	300 000
1970	393 841
1973	572 581
+ 1980 (est)	590 000
+ 1990 (est)	870 000
+ 2000 (est)	1 290 000

\+ Based on a mean annual increase of 4% p.a. over 1970 levels.

Appendix 30/....

Appendix 30

S.A. Road Haulage Fleet

1975

Number of vehicles	165 000 (est)
Annual distance travelled/vehicle	45 000 km (est)
Mean vehicle payload	4,5 tonnes
Annual tonne kilometres transported	33,4 x 10^9 tonne km
Transport energy requirement (Appendix 24)	1,64 kWh/tonne km
Total fuel energy required (est)	54,7 x 10^6 MWh
Diesel fuel required*	5,36 x 10^3 Ml
Useful work produced at 30% efficiency	16,4 x 10^6 MWh

* At fuel energy content of 10,23 kWh/litre

Appendix 31

Estimated Road Transport Energy Requirements

Year	No of Commercial Vehicles registered x 10^3	Freight Tonne Kms transported tonne kms x 10^9	Fuel Energy Requirement MWh x 10^6	Useful Energy Produced MWh x 10^6
1960*	74	15	25	7,4
1965*	105	21	35	10,5
1970*	138	28	46	14
1975	(est) 170	34	55	17
1980	(est) 206	42	68	21
1990	(est) 304	62	101	30
2000	(est) 450	91	150	45

* Source : Reference 4

Appendix 32/....

5. References/.........

APPENDIX 32

PRIVATE MOTOR VEHICLE POPULATION

Year	Number of Private Vehicles Registered
1960	1 033 000
1965	1 357 000
1970	1 800 000
1975	2 250 000
1980	2 810 000
1985	3 520 000
1990	4 390 000
1995	4 830 000
2000	5 300 000

Note : Figures for 1960-1975 are based on actual figures of private vehicles registered plus 65% of commercial vehicles to cover light vans, private trucks, etc. (See Section 4.2.3)

Figures 1980-1990 based on 4½% annual growth rate over 1975 value. Values for 1995 and 2000 based on 2% annual growth rate over predicted 1990 value.

APPENDIX 33

VEHICLE TRANSPORT WORK PERFORMED

Year	No. of cars (7 major urban centres)x 10^2	Passenger kilometres moved (All races) Pass kms x 10^9	Passenger kilometres per vehicle year Pass kms/ vehicle year
1970	989	14,332	14 491
1980	1 768	28,688	16 232
2000	4 609	95,547	20 730
WEIGHTED MEAN VALUE			18 813

Source : Reference 18

Appendix 34/.....

APPENDIX 34

PRIVATE VEHICLE TRANSPORT WORK AND FUEL ENERGY REQUIREMENT

Year	No. of vehicles registered x 10^3	Total transport work performed Pass km x 10^9	Fuel Energy Requirement kWh/pass km	Est.Total fuel energy requirement MWh x 10^6
1960	1 033	19,7	0,8	16
1970	1 800	34,2	0,7	24
1980	2 810	53,4	0,65	35
1990	4 390	83,4	0,57	48
2000	5 300	101	0,5	51

Appendix 35/...

APPENDIX 35

GOODS HANDLED AND GROSS ENERGY REQUIREMENTS IN SA HARBOURS

YEAR	TONNAGE HANDLED IN SA PORTS TONNES	TOTAL HANDLING ENERGY REQUIREMENTS MWh x 10^3
1960	17 980 000	350
1965	30 494 000	595
1970	42 017 000	819
1975	60 996 000	1 190
1980	70 713 000	1 336
1985	81 977 000	1 484
1990	95 036 000	1 597
1995	110 175 000	1 664
2000	127 726 000	1 757

Appendix 36/....

APPENDIX 36

ESTIMATED ENERGY REQUIREMENTS FOR CARGO HANDLING

1975 and previous years

ITEM	BULK CARGO CARRIERS kwh/ton	GENERAL CARGO CARRIERS kwh/ton
Direct energy	3 - 5	13 - 21
Floating craft	-	0,5
Plant and equipment	0,5	
Dredging and dock construction	2,5 - 3	7 - 9
MEAN VALUE	7,25	25,5

From an analysis of Bulk and General cargo handled at South African ports approximately one third of the tonnage handled was bulk cargo, the rest being general cargo.

Weighted mean of energy requirements for cargo handling =

$$\frac{7{,}2 + 2 \times 25{,}5}{3} = 19{,}4 \text{ kWh/tonne}$$

Mean with direct energy requirements halved for general cargo handling

= 13,75 kWh/tonne

Source: Ref. 19 (est. year 2000)

Appendix 37/....

APPENDIX 37

DIRECT ENERGY REQUIREMENTS FOR CARGO HANDLING (FUEL ENERGY)

YEAR	FUEL ENERGY REQUIREMENTS (INCL ELEC.) MWh x 10^3
1960	190
1970	440
1980	680
1990	760
2000	800

Appendix 38/.....

APPENDIX 38

MEAN VESSEL SIZE

Year	Total Registered Tonnage		Number of Ships (All types)
	NET (tonnes)	GROSS (Tonnes)	
1959/60	32 996 000	58 110 000	13 712
1964/65	41 277 000	72 708 000	15 458
1969/70	72 520 000	124 021 000	20 138
1974/75	n/a	269 244 000	16 395

Year	Mean Vessel Tonnage	
	NET (tonnes)	GROSS (Tonnes)
1959/60	2 406	4 238
1964/65	2 670	4 703
1969/70	3 601	6 158
1974/75	n/a	16 420

Appendix 39/.....

APPENDIX 39

SHIPPING TRANSPORT WORK AND ENERGY REQUIREMENTS

Year	Freight leaving S.A. Ports tonnes x 10^3	Mean voyage length km	Transport work tonne kms x 10^3	Fuel energy req. kWh/ tonne km	Est. total fuel energy req. MWh x 10^6
1960	8 990	2000	18	0,18	3,2
1970	21 008	2000	42	0,18	7,6
1980	35 356	2000	71	0,18	12,8
1990	47 518	2000	95	0,17	16,1
2000	63 863	2000	124	0,16	19,5

Appendix 40/.....

APPENDIX 40

OPERATING FIGURES - DURBAN - COALBROOK CRUDE OIL PIPELINE

Pump Station	Suction Press. kPa	Pump Discharge Press. kPa	Station Discharge Press. kPa	No. of Pump Stages
Fynnland (Durban)	890	9 030	8 540	4 + 4
Empangeni	1 210	9 220	9 050	4 + 4
Mahlabatini	430	8 800	8 080	3 + 2 + 4
Scheepersnek	800	8 830	8 040	4 + 4
Quagga	970	8 110	7 830	3 + 4
Coalbrook	600	-	-	-

Note : Pumped Product - Sassan Crude Oil
Density 0,8440 kg/l
Viscosity 12 Centistokes
Flow Rate 765 000 l/hour

The above represent continuous pumping figures where steady state conditions have been attained throughout the pipeline. Figures supplied by Pipeline Headquarters, Durban.

Appendix 41/....

APPENDIX 41

AVERAGE OPERATING PRESSURES - PETROLEUM PRODUCTS

Source : SAR & H Headquarters.

Station and Distance (km)	DIESEL (kPa)		NAPHTHA (kPa)		PETROLS (kPa)	
	IN	OUT	IN	OUT	IN	OUT
Fuel flow (Dbn) 18,5	500	8 400	550	7 000	600	7 400
Hillcrest 73,5	600	8 100	1 200	6 000	1 300	6 450
Howick 112	900	8 200	1 300	7 200	1 500	7 200
Ladysmith 43	2 000	8 500	3 600	8 000	2 200	7 000
Van Reenen 113,6	750	7 500	3 000	6 800	2 300	6 000
Bethlehem 142,1	2 100	5 500	3 000	6 800	1 600	6 000
Magdala 105,6	3 200	5 200	4 200	7 500	2 000	5 000
Sasolburg	700	8 600	-	-	550	6 400

Appendix 41 continued/.....

Appendix 41 ./continued

OTHER PIPELINE DISTANCES (KILOMETRES)

Sasolburg	-	Alrode	-	70,5
Sasolburg	-	Klerksdorp	-	133
Sasolburg	-	Potchefstroom	-	83
Alrode	-	Langlaagte	-	22,5
Alrode	-	Waltloo	-	78,5
Alrode	-	Jan Smuts	-	20,3
Hillcrest	-	Pietermaritzburg	-	49,5
Bethlehem	-	Kroonstad	-	124,5

Note : Alrode is at Alberton and Waltloo is at Pretoria.

Appendix 42/....

APPENDIX 42

AVERAGE OPERATING PRESSURES - CRUDE OIL PIPELINE

Source : SAR & H Headquarters

Station and Distance (km)	Suction Pressure kPa	Discharge Pressure kPa
Fynnland (Durban) 177	800	8 700
Empangeni 79,2	1 100	9 000
Mahlabatini 85	420	8 100
Scheepersnek 105	950	8 900
Quagga 212,8	900	7 800
Coalbrook	800	-

Appendix 43/....

APPENDIX 43

ANALYSIS OF CRUDE OIL PIPELINE

Product Density = 844 kg/m^3

Pipeline Diameter = 18 inches = 457,2 mm

Product Viscosity = 12 Centistokes = 12 x 10^{-6} m^2/sec

Flow Rate = 765 000 l/hr = 765 m^3/hr

(See Appendix (1))

Pipe Cross Sectional area = $\frac{\Pi D^2}{4}$ = 0,1642 m^2

So mean flow velocity $\frac{765}{0,1642 \times 3600}$ m/sec

= 1,2944 m/sec

Reynolds Number N_{RE} = $\frac{lV}{\upsilon}$

where l is a characteristic length. In the case of flow in a pipe, this dimension is taken to be the diameter of the pipe.

So, N_{RE} = $\frac{0,4572 \times 1,2944}{12 \times 10^{-6}}$

= 49300 (turbulent flow)

From fluid flow tables of Friction Factor f versus Reynolds Number :

f = 0,0095 (Smooth pipe)

For turbulent flow in pipes we have :

$$hf = \frac{4f\ell\bar{u}^2}{2dg} \qquad \text{(Ref. 20)}$$

where :

hf = head loss due to friction

f = friction factor

ℓ = length of pipe

$\bar{u}$ = mean fluid velocity in the pipe

d = pipe diameter

g = acceleration due to gravity

So/.......

So $hf \simeq \frac{4 \times 0{,}0095 \times \ell \times (1{,}2944)^2}{0{,}4572 \times 2 \times 9{,}81}$ metres

$\simeq 0{,}00710 \times \ell$ metres

But pressure loss $P = hf \times \ell \times g$

$\therefore P \simeq 0{,}00710 \times 844 \times 9{,}81 \times \ell \quad N/m^2$

$\simeq 59$ Pa/metre

i.e. Pressure loss = 59 kPa/km

Considering Appendix (1) and summing the pressure losses between stations, a net pressure drop for the entire pipeline is obtained.

$P_{NET} = 37530$ kPa

But pipeline length = 650 km
and pressure loss per km is calculated at 59 kPa :

So calculated total pressure drop = 650 x 59 kPa

= 38350 kPa

which is only 2% in excess of the actual figure.

It may be concluded that the practical values show no marked deviation from the calculated values indicating that standard analysis may be used for the estimation of flow of other products in different sized pipes.

Appendix 44/.....

APPENDIX 44

PIPELINE ENERGY REQUIREMENT

Year	Tonne kilometres moved per annum (estimated) tonne kms x 10^9	Energy Requirement kWh/tonne km (electrical)	Total energy requirement MWh x 10^6 (electrical)
1975	1,2*	0,16	0,19
1985	1,4	0,15	0,21
2000	2,3	0,14	0,32

*Based on estimated 6 hour working day with present capacity

APPENDIX 45

THERMAL EFFICIENCIES - ESCOM COAL FIRED POWER STATIONS

Year	Thermal Efficiency at point of sale %
1967	23,4
1968	24,0
1969	25,0
1970	25,3
1971	25,1
1972	26,3
1973	26,7
1975	26,8

Mean improvement rate = 0,38% per annum

Source : Reference 22

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