COMPARATIVE ECONOMIC EFFICIENCY, OPERATING COSTS AND FUEL CONSUMPTION RATES OF FREIGHT TRANSPORT MODES BETWEEN THE LARGEST INDUSTRIAL CITIES AND SEAPORTS IN SOUTH AFRICA

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Abstract

The paper deals with aspects of efficiency within the five modes of freight transport, with special reference to the operating cost and fuel consumption rates between South Africa's largest industrial cities and seaports. In particular, the paper deals with (a) the opportunities that exist for the achievement of efficiency in freight transport; (b) the subgroups of economies that can enhance efficiency attainment in the freight transport industry; (c) prevailing cost structures, operating cost and fuel consumption rates within the five modes of freight transport; and (d) the salient economic features of the freight transport market. The research approach and methodology combine (a) a literature survey; (b) empiric research, (c) an analysis of the cost structures of freight transport operators from different modes of transport; and (d) interviews conducted with specialists in the freight transport industry.

Keywords: Economies of Density; Economies of Distance; Economies of Scale; Economies of Scope; Efficiency; Freight Transport; Fuel Consumption; Modes of Freight Transport; Transport Operating Cost

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1 Introduction

The goal of the research was to compile an overview of the most salient aspects of efficiency achievement that can give guidance in freight transport policy formulation in South Africa. The research approach and methodology combine (a) a literature survey; (b) an analysis of the cost structures of freight transport operators from different modes of transport; (c) previous empiric work conducted by the author; and (d) interviews conducted with specialists in the freight transport industry. In this paper the results of the research are described qualitatively. Section 2 supplies a background and overview of opportunities for the achievement of economies in freight transport. In Section 3 the subgroups of economies achievable in the freight transport industry are discussed. Section 4 deals with aspects of efficiency within the five modes of freight transport, with special reference to the operating cost and fuel consumption rates between South Africa's largest industrial cities and seaports. The conclusions and a summary of the project findings are contained in Section 5.

2 Background and overview

The factors contributing to internal scale economies in freight transport are, firstly, the spreading of fixed cost commitments over extended output capacity; secondly, certain inputs that can be obtained cheaper as output rises; and thirdly, the employment of more productive indivisible inputs and technology that enjoy increasing returns to scale.

Economies of scale exist when an expansion of the output capacity of a firm, fleet or plant causes total production costs to increase less than proportionately to the increasing output capacity. However, economies of scale in transport often also refer to vehicle size rather than firm, fleet or plant size, especially in the case of ships and pipelines. Ships, notably bulk carriers and container vessels, and pipelines often operate as separate business entities. In this sense, the prerequisite for economies of scale, and thus of falling average unit cost, is a cost structure that is characterised by a high ratio of fixed to total cost, so that with increasing output capacity, the fixed cost per unit of output declines faster than the variable cost increases per additional unit of production within the output capacity.

While economies of scale in their strictest form are considerably important in the freight transport industry, there are circumstances under which it is not merely the pure size of the output capacity of a firm, fleet or plant that causes total production costs to increase less than proportionately to the increasing output capacity, but due to a growth in output capacity, opportunities arise to also obtain the benefits of increasing returns to scale. The returns can be shown by their effect on long-run average costs – if output rises by a larger percentage than inputs, there are increasing returns to scale, and thus decreasing long-run average cost per unit of output, in this case contributing to economies of scale. Economies of scale in freight transport are often enhanced by the attainment of one or more of three subgroups of economies, namely those of density, scope and distance. These are discussed in the following paragraphs.

Economies of density exist when the total cost to transport units of freight from their points of departure to their intended destinations decreases by increasing utilisation of existing vehicle fleet and infrastructure capacity within a given market area. Economies of density are enhanced by, first, using high-capacity technology to carry and handle large bulk loads; second, minimising loading and unloading times; third, utilising traffic consolidation (i.e. load, trip, route and freight-handling terminal consolidation); and fourth, maximising the immediate and continuous utilisation of vehicles. (Immediate utilisation refers to the measure to which the carrying capacity of vehicles is utilised, while continuous utilisation refers to the number of revenue-kilometres or revenue-trips covered per time period.)

Economies of scope are achieved when the cost of producing two or more products together, in either a joint or common process, is less than the total cost of producing them separately.

Joint products (also called by-products) are the inevitable and inseparable consequence of a single production process. For example, an outbound journey automatically gives rise to an inbound one. This implies that if a full vehicle load has to be hauled from home depot A to point B, carriage of a back haul from point B to home depot A would reduce the average cost of the two hauls so that it will be lower than the cost of carriage from A to B only, as the vehicle inevitably has to return to its home depot. Failure to solicit available back-haul business is a lost revenue opportunity (i.e. a waste), and therefore implies failure to deal with joint costs profitably.

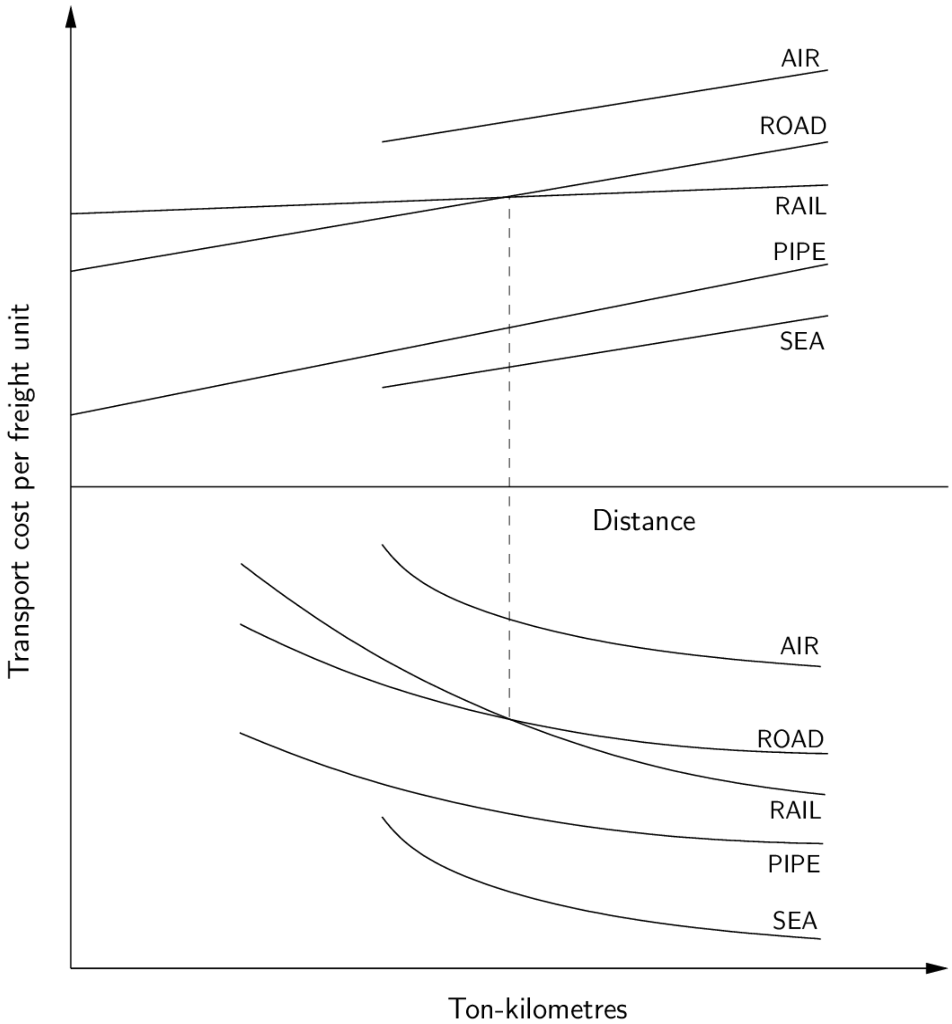
Common production (also called shared production) occurs when different products are deliberately produced together in a common process. In this case, the similarities of the production processes permit the use of the same technology. The cost that arises in this instance is common and therefore shared among the commonly produced products. For example, when fleet capacity exceeds the demands set by seasonally fluctuating contractual agreements, the spare capacity can be filled with spot-market shipments solicited through reduced tariffs.

Economies of distance (also known as long-haul economies) are attained when the total transport cost per ton-kilometre decreases as the trip distance increases. Economies of distance arise when there are trip-specific fixed costs that are not affected by the distance of the journey, and also by cost items that increase less than proportionally to an increase of distance. Examples of the former are terminal costs, such as aircraft landing fees and seaport charges; train marshalling (shunting) costs; trip documentation; and loading, stowing and unloading costs. As one has to pay these costs regardless of the distance, doubling the length of a haul does not result in doubling the costs. An example of the latter is the declining aircraft fuel consumption rate on a flight after take-off when the cruising altitude has been reached.

3 Comparative modal cost levels, cost structures and fuel consumption

The cost to transport a unit of freight by air is the highest of all modes of transport, and by road the second highest on long trips and third highest on short trips, where road is cheaper than rail transport. In view of the fact that rail transport achieves considerably more economies of distance than road transport, road transport becomes progressively more expensive than rail transport for all classes of freight as trip distances increase above approximately 500 km. For trips shorter than roughly 150 km, road transport is virtually always cheaper than rail transport. For all types of goods that can possibly be carried either by road or rail transport between the same trip origins and destinations, the equal cost distance of the two modes lies between approximately 150 and 500 km. Overland pipeline transport is the cheapest mode for those types of commodities that can be transported by pipeline. Either rail or road transport is the cheapest mode of transport for all those commodities that cannot be carried by pipeline. The total unit cost to carry freight by sea on voyages longer than 300 km is the lowest of all modes of transport. (Air freight flights and sea voyages shorter than 300 km seldom occur in South Africa – hence the reason why the 'air' and 'sea' curves in Figure 1 commence from positions to the right of the y-axis.) Over equal distances, the unit cost in ton-kilometres to carry freight on voyages longer than 300 km by sea is substantially lower than any of the three modes of land transport. However, these three modes can be cheaper than inter-port sea carriage when, firstly, the sailing distance between the ports is too short for vessels to gain sufficient economies of distance; secondly, the trip origins and destinations of freight shipments are accessible by road, rail or pipeline, but are significantly remote from the ports, and vice versa when the inter-port distance is substantially long and/or the origins and destinations are close to the ports; and thirdly, where sea transport is subject to exceptional charges, such as heavy canal dues. Despite the fact that tank ships run empty during return trips, pipeline transport can only compete cost-wise with sea transport between the same origin and destination if the pipeline route is considerably shorter than the sea route, or where sea transport is subject to exceptional charges, such as heavy canal dues (Pienaar 2013). An example is the 254-km-long Trans-Israel crude oil pipeline route between Eilat on the Red Sea and Ashkelon on the Mediterranean coast. This route is substantially shorter than the one around Africa, and cheaper than using the Suez Canal (EAPC 2009).

Figure 1. Comparative cost of the five modes of transport to carry freight



3.1 Air transport cost structure

The cost structure of air transport is characterised by fairly balanced proportions of fixed and variable costs (ICAO 1999). With freight-only services, the fixed costs normally exceed the variable costs to some extent. The higher need for investment in freight terminals and related facilities when an airline's business orientation towards freight services increases suggests that significant economies of scale exist in air freight operation (Cowie 2010).

3.2 Road transport cost structure

The fixed costs of operators with non-specialised fleets who carry (full) truck loads and do not own any terminal facilities are very low. The financial barriers to market entry for these operators, especially in cases where their vehicles are hired or leased, even more so for single-vehicle operations, are very low, and this market segment is highly competitive (Cowie 2010). Of all freight transport industry segments, the aforementioned non-specialised truck-load (TL) road haulage is the closest to perfect competition. Against this, specialised carriers and carriers of part-loads, also called less-than-truck-load (LTL), and parcels generally require terminals. This increases their fixed costs, and they face some financial barriers to entry. Their unit costs decrease with increased traffic volume (economies of density) and distance of haulage (long-haul economies). Although specialised and LTL carriers operate in an oligopolistic market, it is one in which competition is reasonably intensive and mostly based on the price charged. Fleet sizes in the road freight market vary between one vehicle (often owner-driver operators) and more than a thousand.

Larger road transport carriers who own suitable terminals can achieve considerable economies of scope by sorting and then consolidating heterogeneous part loads effectively into homogeneous containerised shipments, thereby creating an economy of density, which in turn enhances economies of scale. However, none of these potential advantages preclude competition from smaller operators, which indicates that the achievement of economies of scale in road transport is not strong (Button 2010).

Of all forms of transport, road transport has the smallest proportion of fixed to total costs, making this market sector highly competitive, and thus less prone to monopolistic or oligopolistic behaviour.

As can be deduced from Table 1, for combination vehicles that are permanently engaged in long-distance carriage, fixed costs vary between approximately 35 and 40 per cent of total costs, and for rigid goods vehicles permanently employed in local delivery and collection work, the fixed and variable costs are fairly evenly balanced. Whenever long-distance operations involve frequent travelling on tolled roads and high payments of overtime remuneration and overnight allowances, variable costs may rise to 70 per cent of total costs (RFA 2012).

Table 1. Typical cost structures of different sizes of road freight vehicles based in the Western Cape province in South Africa and used in professional haulage (May 2012 values)

COST ITEM	TYPE OF VEHICLE AND CARRYING CAPACITY					
	Light delivery vehicle: 1 ton	**Rigid truck: 4 tons**	**Rigid truck: 8 tons**	**Rigid truck: 15 tons**	**Combination vehicle: 20 tons**	**Combination vehicle: 32 tons**
Overhead cost per year	**R25 090 (10,1%)**	**R48 150 (10,0%)**	**R60 640 (9,1%)**	**R81 150 (9,0%)**	**R104 700 (6,9%)**	**R119 780 (6,6%)**
Standing costs per year	**R125 452 (50,8%)**	**R240 742 (49,8%)**	**R303 207 (45,6%)**	**R405 772 (44,7%)**	**R523 509 (34,7%)**	**R598 904 (33,2%)**
Depreciation	R28 640	R46 430	R65 980	R102 060	R122 570	R134 900
Interest	R9 110	R15 260	R23 480	R39 120	R39 000	R59 040
Insurance	R15 180	R25 430	R39 130	R65 200	R75 450	R90 110
Licence	R492	R1 302	R4 467	R9 732	R14 439	R19 524
Crew	R72 030	R152 320	R170 150	R189 660	R272 050	R295 330
Annual running costs	**R96 540 (39,1%)**	**R194 450 (40,2%)**	**R300 500 (45,3%)**	**R419 650 (46,3%)**	**R881 690 (58,4%)**	**R1 085 360 (60,2%)**
Fuel	R57 180	R114 370	R166 350	R213 130	R559 910	R655 220
Lubricants	R1 430	R2 860	R4 160	R5 330	R14 000	R16 380
Maintenance	R31 130	R63 640	R98 070	R148 060	R183 700	R233 550
Tyres	R6 800	R13 580	R31 920	R53 130	R124 080	R180 210
Total annual haulage cost	**R247 082 (100%)**	**R483 342 (100%)**	**R664 347 (100%)**	**R906 572 (100%)**	**R1 509 899 (100%)**	**R1 804 044 (100%)**
Annual kilometres	48 000	48 000	48 000	48 000	110 000	110 000
Operating days per year	225	225	225	225	245	245
Fuel cost (diesel)	11,0ℓ/100km @1 083,0c/ℓ	22,0ℓ/100km @1 083,0c/ℓ	32,0ℓ/100km @1 083,0c/ℓ	41,0ℓ/100km @1 083,0c/ℓ	47,0ℓ/100km @1 083,0c/ℓ	55,0ℓ/100km @1 083,0c/ℓ
Lubricants	2,5% of fuel	2,5% of fuel	2,5% of fuel	2,5% of fuel	2,5% of fuel	2,5% of fuel
Maintenance	64,85c/km	132,58c/km	204,31c/km	308,46c/km	167,0c/km	212,32c/km
Tyres	14,17c/km	28,29c/km	66,50c/km	110,69c/km	112,80c/km	163,83c/km

Source: Compiled by the author from various sources

Notes: Diesel price: coastal wholesale price for the period 2 May to 5 June 2012 of low-sulphur diesel plus 5c/ℓ; licence fees for the Western Cape applicable throughout 2012

3.3 Rail transport cost structure

Owing to the large initial cost as an absolute quantum and the high ratio of fixed costs in freight rail transport, the breakeven point between revenue and total cost occurs at a very high level of production. This means that a large volume of freight services must be sold before a profit can be realised. This may imply that a profit can only be realised if there is one incumbent rail operator in the market (i.e. a natural monopoly) (Cowie 2010). Approximately 75 per cent of rail transport costs are fixed over the short term (Havenga and Pienaar 2012).

3.4 Pipeline transport cost structure

Pipelines provide their own right of way. Since the pipe component, the pumps, the tank and plant facilities are highly specialised and durable, fixed cost constitutes a high portion of the total cost – the highest of all modes. Pipeline transport is highly efficient when the utilisation of capacity remains consistently high. Because the fixed costs of pipeline transport are proportionately much higher than the variable costs, and continuous pumping may be done with no need for any return flow and no materials handling taking place, economies of scale prevail in pipeline transport. Because of the high capital costs of a pipeline, the financial barrier to entering the market is high. Approximately 85 to 90 per cent of pipeline transport costs are fixed over the short term (Department of Logistics, US 2008; Pienaar 2009).

Financial stakeholders in pipeline operations tend to consolidate and start with a large initial investment, which tends to yield higher returns, partly because of economies of scale and partly because of inherent performance characteristics (for example, a 30 cm pipe operating at capacity transports three times the quantity carried by a 20 cm one) (Nersa 2007). The gains from scale are substantial. For example, the lowest cost for a throughput of 100 000 barrels of crude oil per day in a 45 cm pipeline would be approximately double the cost per barrel when compared to carrying 400 000 barrels per day in an 80 cm pipeline over the same distance.

3.5 Sea transport cost structure

The cost structure of sea transport is similar to that of air transport. It is characterised by balanced proportions of fixed and variable costs. Sea transport does not need a supplied right of way. The travel 'way' involved, namely the sea, does not require investment, and seaports are not owned or supplied by shipping firms. Expenses in ports can be as high as a third of direct voyage costs; however, these obligations only arise when a port is visited (Stopfort 2009).

3.6 Air transport fuel consumption

The freight aircraft model used most by South African Airways (SAA) domestically is the Boeing 737-200(F) with a carrying capacity of 20 tons (i.e. 20 000 kg). Its fuel consumption between the three busiest domestic airports is given in Table 2.

Table 2. Freight aircraft fuel consumption between the busiest airports in South Africa

Route	Total consumption (ℓ)	Consumption/ton (ℓ)
Johannesburg – Cape Town	6 662	333
Johannesburg – Durban	3 400	170
Durban – Cape Town	6 593	330

Source: Africon 2008

3.7 Road transport fuel consumption

As can be deduced from Table 1, the diesel fuel needed to transport one ton of freight by road through the use of a combination road truck with a carrying capacity of 32 tons between the largest three cities in South Africa is as follows:

Johannesburg – Cape Town : 36,76ℓ
Cape Town – Durban : 42,38ℓ
Durban – Johannesburg : 15,78ℓ

3.8 Rail transport fuel consumption

Most rail freight haulage in South Africa is conducted with electric traction, followed by diesel traction. The estimate for Transnet Freight Rail's (South Africa's national freight rail operator) present diesel consumption is 1,86ℓ/100 ton-kilometre for net freight movement (18,6 mℓ/ton-kilometre). This is an average countrywide diesel consumption rate for all types of freight, excluding the mass of rolling stock. The average utilisation of rail (train) payload capacity in South Africa is approximately 45 per cent. The diesel fuel consumption to carry one ton of freight (including the mass of containers but excluding rolling stock) between the three largest cities in South Africa is shown in Table 3.

Table 3. Diesel fuel consumption to carry one ton of freight by rail transport between the three largest cities in South Africa

Route	Route distance (km)	Diesel consumption (ℓ/ton)
Johannesburg – Cape Town	1 496	27,8
Johannesburg – Durban	727	13,5
Durban – Cape Town	1 951	36,3

Source: Africon 2008

3.9 Sea transport fuel consumption

Average fuel consumption in tons for container vessels between South Africa's three busiest container ports is detailed in Table 4 (Africon 2008):

Table 4. Average fuel consumption in tons for container vessels between South Africa's three busiest sea ports*

Container vessel	CPT – PE (422 nautical miles)***	PE – Durban (391 nautical miles)	CPT – Durban (800 nautical miles)
5 000 TEU**	49,7	46,0	94,2
2 000 TEU	26,4	24,4	50,0
1 000 TEU	18,5	17,2	35,1

*Fuel cost can be taken as approximately 52 per cent of vessel operating cost.

**TEU: 'Twenty foot, Equivalent, Unit' (a 20ft (6 m) standard sea container).

***Average sailing speed of the three sizes of container vessels used in South African coastal shipping: 5 000 TEU vessel – 23 knots; 2 000 TEU vessel – 19 knots; 1 000 – 16 knots. One knot equals one nautical mile per hour. A nautical mile equals 1 842 kilometres at the equator.

Average fuel consumption in kilograms per container between South Africa's three busiest sea ports is shown in Table 5 (Africon 2008).

Table 5. Average fuel consumption in kilograms* per container** between South Africa's three busiest sea ports

Container vessel	CPT – PE	PE – Durban	CPT - Durban
5 000 TEU	9,9	9,2	18,8
2 000 TEU	13,2	12,2	25,0
1 000 TEU	18,5	17,2	35,1

*One kg of marine fuel is equal to approximately 1,12ℓ.

**In South Africa, the average mass of a TEU container including its content is approximately 13,24 tons (13 240 kg).

According to the records of South African coastal container shipping providers the cost of fuel consumption on average amounts to 52 per cent of variable voyage costs.

4 Economies achievable in freight transport

4.1 Air transport

4.1.1 Economies of fleet size

In air transport, there is a technical limit to the economies of scale that one can achieve by increasing the fleet size. Making use of a large fleet without increasing the number of airports visited requires frequent and large operations. This is feasible only if there is a continuously high demand for the large number of aircraft (Wei and Hansen 2003). Although increasing fleet size does not necessarily result in significant economies of scale, a large fleet, but with mixed operations, may result in significant economies of scope. It may be more economical for one carrier to undertake both scheduled and charter flights than for separate carriers to specialise in one of the two types of service. Air and sea transport enjoy similar economies of fleet size – the second highest level after rail transport. However, air and rail transport do not generally compete with each other.

4.1.2 Economies of vehicle size

In seasonal or peak-oriented markets, operating large aircraft with flexible cargo–passenger combinations may result in increased loads and thus increased economies of scope (Holloway 2008). In order not to prolong aircraft turnaround times at airports, large aircraft require effective procedures and equipment to load and unload them quickly. Air and sea transport enjoy similar economies of vehicle size – the second highest level after pipeline transport. However, air and pipeline transport are not in competition with each other.

4.1.3 Economies of infrastructure extension

An obstacle to effective service delivery with air transport is its inability to provide door-to-door service. Airfreight operators are in direct competition with passenger airlines for airport access, as areas of high demand for passenger destinations are often also areas of high demand for freight. The prevalence of airport congestion (both in the air and on land) at major passenger hub airports contributes to the fact that freight-only operations tend to be at night and/or based around regional airports (Cowie 2010). Adapting terminal facilities at regional and other subordinate airports that are close to concentrated areas of freight supply and demand to accommodate airfreight traffic effectively should enhance the accessibility and market coverage of this mode of transport. This could lead to total transit time savings, and reduce the cost of providing airfreight services. However, business logic requires that the value of improved airport accessibility, greater market coverage, transit time savings through less congestion, and reduced cost of airport access and egress, and other benefits, must offset the cost of such airport infrastructure upgrades and extensions.

4.1.4 Economies of distance

On condition that intermediate landing is not necessary and that the crew does not need to be changed, longer route lengths give rise to significant economies of distance. With no intermediate landings, large time savings are achieved, as well as savings with those variable cost items that do not vary according to the length of flights. These are:

- aircraft maintenance necessitated by the number of landings (for example wheel fittings, tyres);
- charges for traffic control and navigation close to airports;
- landing charges;
- terminal services (such as cleaning; power connection; charges for cargo handling, loading and unloading, parking); and
- additional fuel consumption immediately after take-off.

These five points become less significant as flight lengths increase. For example, a Boeing 737-200(F) consumes between 1 200ℓ and 1 300ℓ of fuel to reach its cruising altitude, after which it cruises at 4,24 ℓ/km, hence an economy of distance (Africon 2008).

Air and sea transport enjoy similar economies of distance – after rail transport, the second highest level. Air freight flights shorter than 500 km seldom occur in South Africa; however, in exceptional cases commercial freight consignments are carried on passenger flights as short as 300 km, for example between the airports of Port Elizabeth and East London – hence the reason why the ‘air’ curves in Figure 1 commence from positions to the right of the y-axis.

4.2 Road transport

4.2.1 Economies of fleet size

Increased road vehicle fleet sizes, coupled with productive utilisation of this greater capacity, can result in some economies of scale. Although the achievement of economies of scale emanating from fleet size is moderate, it is in relative terms, the second highest of the various modes after rail transport. Own facilities, such as terminals – particularly for specialised carriers – provide opportunities for economies of scale (Cowie 2010). Potential sources of economies of scale are a workshop owned by the business for vehicle maintenance and repairs; standardisation of vehicles, which reduces the quantity of spare-part inventories; discount on bulk purchases; and so on.

4.2.2 Economies of vehicle size

As the carrying capacity of road vehicles increases, vehicle-specific costs increase less than proportionally. Vehicle-specific costs are running costs, such as fuel and oil consumption, maintenance and tyre wear. Also, engine size and the number of crew members required increase less than proportionally to an increase in vehicle size (RFA 2012). The costs of dispatching and load documentation tend to remain the same regardless of load or shipment size that vehicles of different sizes can carry. These relationships account for the trend towards long-haul road vehicles whose length, width, height and gross vehicle mass are often the maximum that road traffic legislation allows. Although the achievement of economies of vehicle size in road transport is significant, it is in relative terms along with rail transport the lowest, resulting mainly from the limits of vehicle dimensions prescribed through legislation.

4.2.3 Economies of infrastructure extension

In view of the fact that governments typically recover road-user cost responsibility, except licence fees, through levies included in the price of fuel and through toll tariffs, thereby converting a fixed-cost responsibility into variable transport expenditure, road transport businesses do not gain significantly from enlarged road capacity. However, with standing costs being fixed, at least on a monthly basis, extensive travelling (many kilometres per month) and the avoidance of travelling during periods of traffic congestion so as to increase trip speeds, some economies of density, albeit small, in terms of infrastructure use can be attained.

4.2.4 Economies of distance

Generally, owing to the high ratio of vehicle running costs (which accumulate as distances increase) to total costs of individual vehicles, and the relatively small terminal facilities or absence of own facilities, road transport does not enjoy significant economies of distance – in fact it is the second lowest of all modes of transport, with pipeline transport having the least.

4.3 Rail transport

4.3.1 Economies of fleet size

Economies of fleet size in rail transport are attained through operating long trains, the carrying capacity of which is well utilised, and not simply by operating a large vehicle fleet of wagons and locomotives. In this context, rail transport enjoys the highest level of economies of fleet size of all modes of transport.

There are considerable economies in hauling more wagons per train and employing a stronger locomotive whenever train lengthening requires this. However, there comes a point where an additional locomotive will be needed with further train lengthening. Demand permitting, logic dictates that several wagons should be added when an extra locomotive is employed to keep the required train and locomotive traction power efficiently in balance. The economies stemming from operating the longest trains technically possible and employing multiply-linked locomotives are that, firstly, only one locomotive crew remains necessary for multiply-linked locomotives; secondly, traffic scheduling and control of a few long trains are simpler and potentially safer than operating several short trains, which in total carry the same payload volume or mass as a single long train; and thirdly, the utilisation of railway lines increases because the required minimum time headways and following distances between short and long trains differ proportionally less than the difference in train length.

4.3.2 Economies of vehicle size

The width of rail wagons is limited by the gauge of the railway line. Efficiency requires that the same gauge be used throughout the system. The height of wagons is limited by overhead clearances along the way. The length of wagons is limited by their structural robustness to withstand the pressure exerted by payload mass on wagon sections not directly supported by sets of axles and wheels, and by the maximum axle mass loads that railway infrastructure can accommodate. Although the achievement of economies of vehicle size in rail transport is significant, it is in relative terms along with road transport the lowest, resulting mainly from the limits of vehicle dimensions dictated by technical considerations (Button 2010).

4.3.3 Economies of infrastructure extension

With rail transport, the move from a single- to a double-track system may quadruple the capacity of the line by eliminating directional conflict, and a quadruple track should more than double the capacity as it additionally also permits segregation by speed. However, there is no sense in building railway lines of larger capacity than will be required (Button 2010. As is indicated in the next subsection, extension of rail route lengths to link distant origins and destinations has the potential to encapsulate long-haul advantages, therefore, under the banner of infrastructure extension, both economies of density and of distance may accrue. However, such beneficial interaction between increasing returns to scale due to greater traffic density and a gain in efficiency through long-haul advantage is dependent on (a) sufficient demand; and (b) firm size. In rail transport ‘size of the firm’ conventionally incorporates ‘fleet size’ and ‘network size’.

4.3.4 Economies of distance

In view of the fact that rail transport has relatively high terminal costs, it enjoys substantial economies of distance as trip lengths increase – the highest of all modes of transport.

When analysing rail transport, one should distinguish between unit costs (for example the cost per ton-kilometre) decreasing due to economies of density and distance. Through economies of density and distance, a rail transport operation may enjoy a natural monopoly on a particular route. On condition that the utilisation of train-carrying capacity is high, the former economy stems from its cost structure, which is characterised by a relatively high ratio of fixed to total cost so that with increasing the annual distances of all trains collectively, the fixed cost per unit of performance (train-kilometres and eventually ton-kilometres) declines faster than the variable cost increases per additional unit of performance within the output capacity, and the latter economy from the high amount of terminal operating costs (at trip ends) that do not change as trip distances increase.

4.4 Pipeline transport

4.4.1 Economies of vehicle size and infrastructure extension

Pipeline transport has unique characteristics: the carrying unit (i.e. the 'vehicle') is also the infrastructure. On the principle of economies of density, an increase in pipe diameter can result in a lower unit cost. The fundamental relationships involved depend upon the principles of geometry concerning the relation between the surface area of a pipe's wall and its volume. Consider a circular cross-section of a pipe. Because the area of a circle is πr^2, its area increases with the square of the radius. The circumference increases only in proportion to the radius, since the circumference is $2\pi r$. The friction that must be overcome to move a liquid commodity through a pipeline is the friction between the liquid and the wall of the pipe. Increasing the diameter of a pipe will therefore increase the quantity of liquid in the pipe faster than it will increase the area of the wall of the pipe in contact with the liquid. Consequently, there are gains in economies in the propulsion power required to pump the same quantity of commodity by increasing the diameter of the pipe. There are also economies in the cost of the pipe itself. For larger pipes, the quantity of body steel per unit of pipe carrying capacity is less than for smaller pipes. An uninterrupted and prolonged throughput of a large volume of homogeneous product increases economies of density. Should such continuous pumping with a specific product not be sustainable, common production can make petroleum pipelines more cost effective, since a variety of petroleum products can be pumped consecutively, thereby enhancing the achievement of economies of scale through economies of scope.

4.4.2 Economies of distance

Longer pipelines do not give rise to significant economies of distance. In fact this is almost non-existent – the lowest of all modes of transport. The reason for this is that additional pump stations and more pipes in direct proportion are required for longer distances (Gwilliam 1970).

4.5 Sea transport

4.5.1 Economies of fleet size

As is the case with air transport, economies of scale are possible with large individual vessels and not necessarily with large fleet operations. Single-ship operators or those operating a few ships – for example operators of charter ships – are often able to compete with larger scheduled conference liners, which indicates that sea transport enjoys little in terms of economies of fleet size.

4.5.2 Economies of vehicle size

Shipping benefits through economies of scale are associated with operating larger ships (Talley et al., 1986). Larger ships result in lower costs per ton (in the case of bulk shipping) and lower costs per standard container (in the case of container shipping) (Stopfort 2009). However, larger ships may cause problems for other areas of the maritime industry, mostly at the ports. Bigger ships require wider entrance channels, deeper draughts, larger cranes and other loading and unloading equipment, as well as sufficient storage space to hold the volumes of freight before or after loading and unloading them. Air and sea transport enjoy similar economies of vehicle size – the second highest after pipeline transport.

4.5.3 Economies of infrastructure extension

Evidence exists that in port operations a fourfold increase in container port size can reduce the cost of handling container traffic by approximately one-quarter (Heaver 1975). However, seaports are not owned or supplied by shipping firms, so ship owners may not automatically reap the benefits of improved port efficiencies. Port charges are levied by the owning port authority. Whether a portion of the value of efficiency improvements and other cost advantages are passed on to visiting ships will depend on the policy of the governing port authority. Often, the various commercial ports in a country reside under the control of a single port authority, which may set uniform port charges for similar port services throughout, regardless of the different cost structures and changing degrees of competitiveness among ports.

4.5.4 Economies of distance

Generally, for container vessels and the various types of bulk carriers, expenses in ports are in the order of a third of direct voyage costs (this can constitute up to roughly 40 per cent if the ship itself or its cargo requires prolonged and/or special berthing and handling arrangements) (Stopfort 2009). In view of the high terminal expenditure and the fact that the 'way' of travel involved – the sea – does not require investment or any significant expenses apart from navigational support that may sometimes be necessary, ships enjoy substantial economies of distance as voyage lengths increase. Air and sea transport enjoy similar economies of distance – the second highest after rail transport. Sea freight voyages shorter than 500 km seldom occur in South Africa; however, in exceptional cases commercial freight consignments are carried on combination-vessel voyages as short as 300 km – for example between the ports of Port Elizabeth and East London, and between Cape Town and Mossel Bay – hence the reason why the 'sea' curves in Figure 1 commence from positions to the right of the y-axis.

5 Concluding summary

5.1 General

The factors contributing to scale economies in freight transport are, firstly, the spreading of fixed cost commitments over extended output capacity; secondly, certain inputs that can be obtained more cheaply as output rises; and thirdly, the employment of new indivisible inputs that enjoy increasing returns to scale (i.e. more productive technology). In freight transport, the latter two factors are achieved through emerging efficiency gains and productivity activators that are specific to, firstly, increasing fleet size and maximising use of its capacity; secondly, increasing vehicle sizes and maximising use of their capacity; and thirdly, extending the capacity of transport facilities and infrastructure, and intensifying the use thereof. Subsequently, economies of scale in freight transport are often enhanced by the attainment of one or more of three subgroups of economies: economies of density, scope and distance.

Although increasing fleet size in air transport does not necessarily result in significant economies of scale, a large fleet, but with mixed operations, may result in significant economies of scope. It may be more economical for one carrier to undertake both scheduled and charter flights than for separate carriers to specialise in one of the two types of service. Similarly, it might be more economical for one airline operator to offer both passenger and freight services than for separate carriers to specialise in one of the two types of service.

Large road transport carriers who own suitable terminals can achieve considerable economies of scope by sorting and then consolidating heterogeneous part loads effectively into homogeneous containerised shipments, thereby creating an economy of density, which in turn enhances economies of scale. It is therefore clear that while in freight transport economies of scale in their strictest form – that of being dependent on size of the firm (i.e. number of vehicles in the firm's fleet) – are considerably important, they cannot be divorced from the attainment of one or more of three subgroups of economies: economies of density, scope and distance.

In rail transport, under the banner of infrastructure extension, economies of both density and distance may accrue. However, such beneficial interaction between increasing returns to scale due to greater traffic density and a gain in efficiency through long-haul advantage is dependent on (a) sufficient demand; and (b) firm size. In rail transport 'size of the firm' conventionally incorporates both 'fleet size' (where 'fleet size' refers to train length) and 'network size' (where 'network size' refers to route kilometres).

Pipeline transport has unique characteristics: the carrying unit (i.e. the 'vehicle') is also the infrastructure. On the principle of economies of density, an increase in pipe diameter can result in a lower unit cost. An uninterrupted and prolonged throughput of a large volume of homogeneous product increases economies of density. Should such continuous pumping with a specific product not be sustainable, common production can make petroleum pipelines more cost effective, since a variety of petroleum products can be pumped consecutively, thereby enhancing the achievement of economies of scale through economies of scope.

With sea transport, as in the case of air transport, economies of scale are possible with large individual vessels and not necessarily with large fleet operations. Economies of scale in transport often refer to vehicle size rather than firm, fleet or plant size, especially in the case of ships, notably bulk carriers and container vessels, which often operate as separate business entities. Single-ship operators or those operating a few ships – for example operators of charter ships – are often able to compete with larger scheduled conference liners, which indicates that sea transport enjoys little in terms of economies of fleet size.

Table 6 provides a comparative summary of the most salient economic features of the five modes of freight transport**.**

5.2 South African conditions

The cost to transport a unit of freight by air is the highest of all modes of transport, and by road the second highest on long trips and third highest on short trips, where road is cheaper than rail transport. In view of the fact that rail transport achieves considerably more economies of distance than road transport, road transport becomes progressively more expensive than rail transport for all classes of freight as trip distances increase above approximately 500 km. For trips shorter than roughly 150 km, road transport is virtually always cheaper than rail transport. For all types of goods that can possibly be carried either by road or rail transport between the same trip origins and destinations, the equal cost distance of the two modes lies between approximately 150 and 500 km.

Overland pipeline transport is the cheapest mode for those types of commodities that can be transported by pipeline. Either rail or road transport is the cheapest mode of transport for all those commodities that cannot be carried by pipeline. The total unit cost to carry freight by sea on voyages longer than 300 km is the lowest of all modes of transport. Over equal distances the unit cost in ton-kilometres to carry freight by sea is substantially lower than any of the three modes of land transport. However, these three modes can be cheaper than inter-port sea carriage when, firstly, the sailing distance between the ports is too short for vessels to gain sufficient economies of distance; secondly, the trip origins and destinations of freight shipments are accessible by road, rail or pipeline, but are significantly remote from the ports, and vice versa when the inter-port distance is substantially long and/or the origins and destinations are close to the ports; and thirdly, where sea transport is subject to exceptional charges, such as heavy canal dues. Despite the fact that tank ships run empty during return trips, pipeline transport can only compete cost-wise with sea transport between the same origin and destination if the pipeline route is considerably shorter than the sea route, or where sea transport is subject to exceptional charges, such as heavy canal dues. Of all the modes of transport that use liquid fuel for propulsion, rail freight over long hauls is the most cost- and fuel-efficient mode of land transport. From seaport to seaport, coastal shipping is the most cost and fuel efficient. Between Cape Town and Durban, rail transport consumes 36,3ℓ of fuel to transport one ton of freight, and large (5 000 TEU), medium-sized (2 000 TEU) and small (1 000 TEU) container vessels consume approximately 1,6ℓ, 2,1ℓ and 3.0ℓ respectively to transport the same weight . The latter fuel consumption rates with container vessels are taken at 100 per cent utilisation. If sea transport utilisation of payload capacity were to decline to the same level as that of rail transport (i.e. 45 per cent) fuel consumption of sea transport to carry one ton of freight between Cape Town and Durban with large, medium-sized and small container vessels would rise to only 3,53 ℓ/ton, 4.70 ℓ/ton and 6.59ℓ/ton respectively.

Table 6. Comparison of salient economic features of freight transport modes

Economic characteristics	Air	Road	Rail	Pipeline	Sea
Cost level	Highest	Second highest	Moderate	Second lowest	Lowest
Cost structure (fixed- to total-cost ratio)	Balanced (second lowest, similar to sea)	Lowest	Second highest	Highest	Balanced (second lowest, similar to air)
Economies of fleet size	Second lowest (similar to sea)	Second highest	Highest (achievable through long trains)	Lowest, non-existent (referring to number of pipes)	Second lowest (similar to air)
Economies of vehicle size	Second highest (similar to sea)	Lowest, although achievement is still significant (similar to rail)	Lowest, although achievement is still significant (similar to road)	Highest (referring to pipe diameter)	Second highest (similar to air)
Economies of distance	Second highest (similar to sea)	Second lowest	Highest	Lowest (almost non-existent)	Second highest (similar to air)

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