Session 4c Paper 2

COMPETITION BETWEEN BUSES AND MINIBUSES - IMPACT ON FUEL CONSUMPTION

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ABSTRACT

The energy efficiency model has been developed to study the impact of competition between public transport modes in urban transport. The model is highly versatile, may be used for any number of travel modes and road types. The paper presents the development of the model and its application to the assessment of two competing modes - buses and minibuses. The case study evaluated the efficiency of passenger transport operations in the current situation and the impact of four future scenarios in the year 2000.

A spontaneous growth of the minibus industry is one of the worse scenarios. It will have two negative effects: inefficient use of fuel, especially during critical peak periods, and reduction in the diesel fuel use leading to an imbalance in the petrol-diesel consumption split.

The best scenario is based on the simultaneous growth of both bus and minibus industries and the reduction of car travel. The results of the analysis indicate that the best scenario, in spite of the 4 per cent annual growth in travel demand, will produce a higher fuel efficiency than the current traffic situation. This scenario can be achieved by both constructive management of the bus and minibus industries, and traffic management measures discouraging car travel, especially during the peak periods.

The results indicate that the current fuel consumption index of 2.24 l/100 passenger-kilometres will decrease to 1.74 l/100 passenger-kilometres if the best scenario is achieved. If the situation is not managed properly, the index will increase to 4.20 l/100 passenger-kilometres.

The model was found to be a suitable predictive tool for the assessment of the fuel efficiency impact of modal shifts in passenger transport, and for the evaluation of the petrol - diesel fuel consumption balance.

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1. INTRODUCTION

Paratransit

Transport demands of the low-income population groups in urban areas of developing countries have a common trait - dependence on mainly informal, low-cost passenger transport which is not subsidised by government. Vehicles with exotic names such as "jeepney", "bemo", "silor", "sharut", "matatu", "gbaka", "bolue", "fula fula", "molekaja" or "zola budd" can be found in many countries across the globe - from the Philippines to South America and from Turkey to South Africa.

Although not subsidised, these paratransit services are economically viable. In many countries they successfully compete with the government subsidised bus companies. The data in Table 1 illustrate the importance of paratransit operations. The table shows the share of paratransit trips as a proportion of all public transport trips in some cities in Australasia (Tiwari, 1994, Rimmer, 1991, Baxter and Davis, 1992).

Table 1. Share of paratransit trips in some cities

City	Paratransit trips (%)	City	Paratransit trips (%)
Bangkok	50	Jakarta	35
Chiang Mai	87	Manila	36
Delhi	19	Palmerston North	100
Hong Kong	15	Singapore	34
Jaipur	70	Wanganui	100

Two New Zealand towns shown in the table, Palmerston North and Wanganui, are much smaller than the other cities. They have been included as an illustration of the role that paratransit can also play in a car dominated society. In a deregulated passenger transport environment, paratransit services proved more cost effective and replaced the heavily subsidised conventional bus services in both towns.

Paratransit in South Africa

South Africa is one of the countries experiencing a phenomenal growth of paratransit services. This growth can be illustrated by a rapid increase in the number of minibuses - vehicles used for paratransit operations. In 1979 there was a total of 60,000 registered minibuses. In 1984 this number increased to 110,000 (a 13 per cent growth rate) and reached 174,000 in 1989 (a subsequent growth rate of over 9 per cent). During the same period an annual growth rate for cars was a comparatively low 4 per cent, while there was virtually no increase in the number of buses (DOT, 1991).

The minibus market share of public transport has grown in parallel - its growth rate between 1982 and 1990 was estimated at 18 per cent (Van Zyl and Loubser, 1991). At the same time the numbers of rail and bus passengers have been steadily dropping. Typically, between the years 1980 and 1988 the bus transport index dropped from 100 to 72, while the train transport index dropped from 100 to 81 (McCaul, 1990).

Such a rapid growth of minibus industry has strongly affected various matters of national importance, such as travel safety, urban congestion, the allocation of public transport subsidies, and the balance between the national consumption of petrol and diesel fuel. In the circumstances, several government departments decided to initiate studies examining some of the relevant issues.

Objectives of the study

One of these studies is reported here. The issue of concern was the split between the amount of nationally produced petrol and diesel fuels. This ratio is fixed at around 70 units of petrol to 30 units of diesel produced by the refineries. It is of national interest to maintain a similar ratio between petrol and diesel fuel consumption.

The rapid growth of the minibus transport industry has threatened to affect adversely the fuel consumption balance, as buses are diesel-driven while minibuses use petrol. The purpose of the study was to develop and test the fuel efficiency model for the assessment of the future impact of the minibuses in urban passenger transport. The proportion of diesel fuel consumed currently and possible future changes were to be identified. The target year for the analysis was set as the year 2000.

2. THE MODEL

The model was developed on the assumptions that the total number of passenger trips in a transport corridor can be determined from the traffic volumes, traffic composition, and vehicle occupancy. These three variables can be found by means of traffic surveys.

Conversely, if the known variables are the total of passenger trips, traffic composition and vehicle occupancy, traffic volumes can be derived. Traffic speed can then be modelled from the speed-volume curves and finally fuel consumption as a function of traffic speed. The structure of the model is shown in Figure 1.

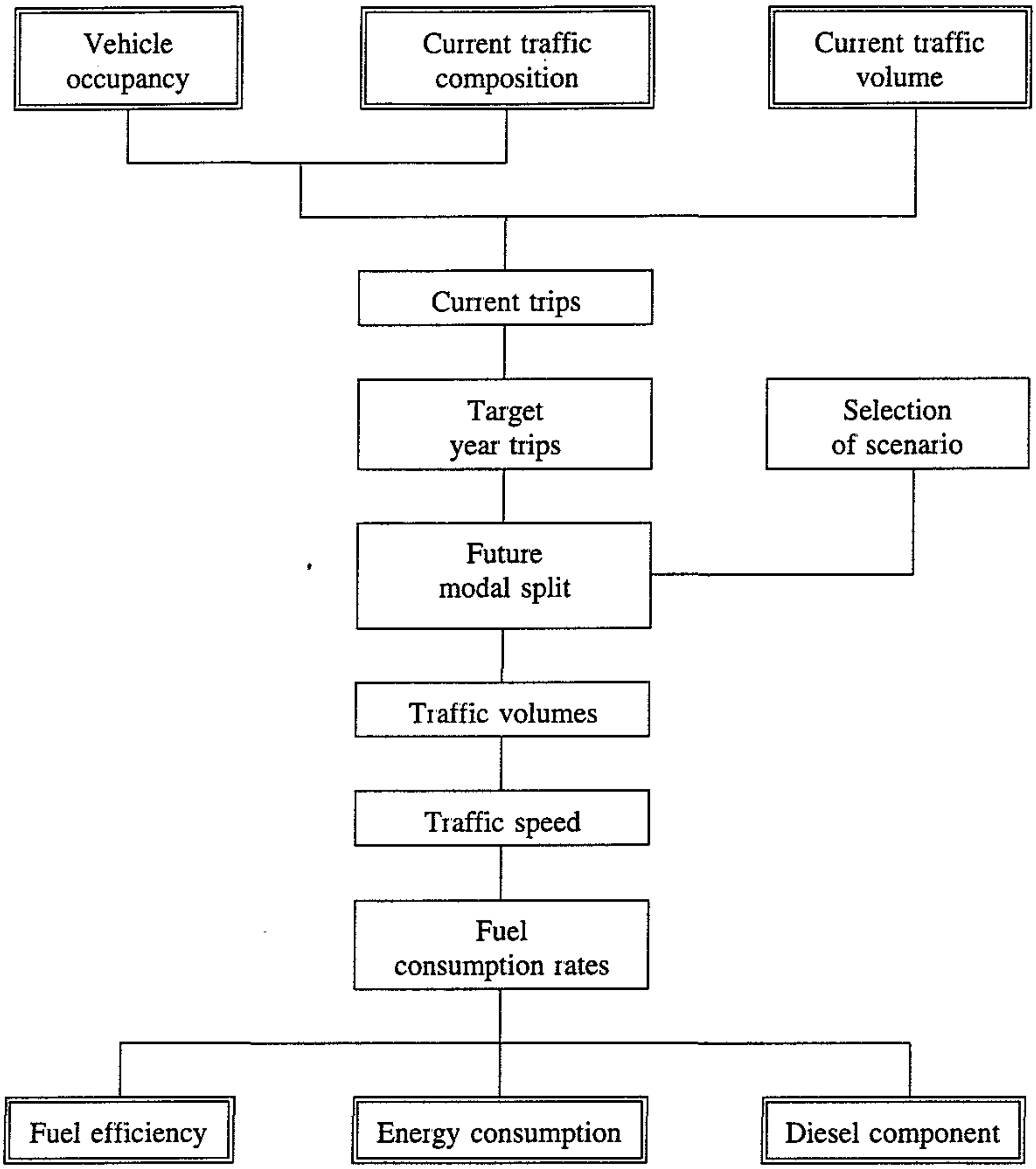

Figure 1 **Fuel efficiency model**

The model was applied to study the efficiency of travel on the major commuter routes in Pretoria. The predominant mode is passenger car. Buses and minibuses are strongly represented in the traffic stream.

The model was used to assess both the existing situation and the future situation in the year 2000.

3. FUTURE SCENARIOS

Current situation

The minibus service has numerous advantages. The service is flexible. It offers high frequency with some personal attention, such as picking passengers up between the scheduled stops. It operates on the routes where, and during the periods when it is most needed. It can be described as demand driven. In the national context it has two major advantages - it creates jobs and does not require subsidies. It has been estimated that the industry created 300,000 jobs directly and indirectly (McCaul, 1990). The ratio of jobs created per vehicle could be as high as 6 to 1.

A number of serious disadvantages also exists. In the deregulated market entry barriers are low and law enforcement extremely difficult. Profit margins are low as a result of fierce competition between the drivers, operators and associations. New entrants on the routes are resisted, often met with violence.

In order to reduce the operating costs, the vehicles are usually maintained by their drivers, whose expertise in this field may be inadequate. In addition, drivers have to work long hours under difficult conditions, which adversely affects their driving performance. During one year in Johannesburg alone minibus drivers commit close to 40,000 traffic violations. Throughout the country up to 33 per cent of all minibuses are involved in accidents annually. This approximately translates into 100 minibus accidents each day, resulting in 30 injuries and 2 fatalities.

Realistic predictions of traffic composition in the future target year were critical to the successful outcome of this study. The background was provided by an analysis of the prevailing trends of commuter traffic and modal shift and the passenger perceptions. The analysed factors were: the numbers of commuters, market share held by buses and minibuses, car commuting and the attitudes of commuters towards minibus and bus travel. Future scenarios could be formulated on the basis of these factors.

The historical trends observed between 1986 and 1991 are summarised in Table 2.

The data in the table support belief that a dynamic growth of the demand for minibus services in urban areas exists, and in time, minibuses will virtually replace buses. However, a market resistance to minibus transport has been appearing. Two major concerns were expressed by commuters: the problem of accidents involving minibuses and increasing irritation with the drivers' road behaviour and their rough treatment of passengers. Questionnaire surveys conducted among passengers indicated a high level of dissatisfaction with minibus travel safety (55 per cent versus bus - 25 per cent) and driver behaviour (45 per cent versus bus - 20 per cent).

These two issues, if not properly addressed, may adversely influence the expansion of the minibus transport.

Table 2. Historical trends

Factor	Annual change (%)	
	Growth	Decline
Country population	2.0	
Urban commuters	4.0	
Car population	2.6	
Minibus population	9.4	
Bus population	1.2	
Car commuters	5.0	
Bus commuters		4.0

The scenarios

Four future scenarios have been developed. Their main features are described below.

Scenario 1 - The age of the minibus

The current trend. A dynamic growth of the minibus industry is sustained and the proportion of minibuses in traffic increases by 6 per cent annually. The proportion of buses simultaneously declines by 6 per cent. As a result there are few buses left in the traffic stream by the target year. The proportion of cars is slightly reduced.

Scenario 2 - Maintaining the Status Quo

The modal balance has been achieved. Each of the modes holds its current share in the traffic composition. Their relative proportions remain constant, although the absolute volumes increase to satisfy the growing demand.

Scenario 3 - The age of the bus

The resistance to minibuses acquires heavy momentum because of the deteriorating safety and increasing travel cost. Buses are heavily subsidised. Polarisation of income differences (the wealthy can afford cars, the poor cannot afford minibus fares) leaves little room for a mode in-between. The proportion of both cars and buses increases, buses by as much as 10 per cent per annum, while that of minibuses declines by 6 per cent.

Scenario 4 - The demise of the car

As the standard of living declines (or, perhaps traffic management techniques discourage the use of cars on commuter routes) cars disappear from the roads and transportation needs are largely satisfied by buses and minibuses. The proportions of both these modes grow rapidly, buses by 10 per cent and minibuses by 6 per cent annually.

4. THE INPUT

Traffic volume and composition

Classified vehicle counts on the studied routes supplied data to determine representative traffic volumes and composition. The study of the minibus equivalent of passenger car units (pcu) was conducted by means of a multiple regression analysis of queue dissipation. Using headways of the vehicle classes for comparison, the minibus pcu was interpolated from the UK values of passenger car units (Webster and Cobbe, 1966).

The results are shown in Table 3.

Table 3. Composition of traffic stream

Mode	pcu equivalent	Proportion (%)	
		Peak	Inter-peak
Car	1.00	85.3	76.7
Bus	2.25	1.6	0.8
Minibus	1.20	12.6	17.8
Truck	2.25	0.5	6.2
Volume (veh/h)		1,550	800

Vehicle occupancy rates

The survey of over 3,000 cars and minibuses, and the data supplied by bus operators, yielded the vehicle occupancy rates. Peak period vehicle occupancy rates were 1.6, 10 and 60 passengers per vehicle for car, minibus and bus respectively. The rates for the inter-peak period were 1.6, 7 and 30 passengers per vehicle.

Traffic speed

The speed of the traffic stream used for the calculation of fuel consumption rates was derived from the speed-volume curves developed for the studied routes (Tomecki, 1989).

Fuel consumption rates

Minibus fuel consumption was measured using vehicles equipped with fuel flow meters. The minibuses were driven empty, half loaded and fully loaded. Each test was performed eight times on the studied routes. The results were used to verify the generalised urban fuel consumption curves.

As a result fuel consumption for all the passenger modes was calculated from the generalised fuel consumption curves based on traffic speed (Pienaar, 1985).

5. ANALYSIS

Basic assumptions

Four assumptions were made in order to simplify the analysis. The assumptions were:

- the annual growth rate of the number of passengers will be 4 per cent
- the proportion of heavy vehicles in the traffic stream will remain constant
- vehicle occupancy rates will remain constant
- fuel consumption rates of the relevant modes will remain constant.

The process

The following process was adopted to analyse the current situation:

- The estimate of the current number of trips. The estimate was based on the observed traffic volumes and vehicle occupancy rates.

  $$T = \Sigma q_i p_i$$

- Traffic speed was estimated from the speed-volume curves calibrated for the studied routes. One of the curves is shown here:

  $$u = 73.58 - 0.002209\, q - 0.00001089\, q^2$$

- Fuel consumption was estimated as a function of traffic speed (Pienaar, 1985). A typical set of functions is shown:

car	$f = 118 - 1.6897\, u + 0.01479\, u^2$
minibus	$f = 95 + 1.048\, u + 0.00204\, u^2$
bus	$f = 487 - 5.690\, u + 0.05856\, u^2$

The notation in the above formulae is:

T	number of trips
q_i	traffic volume: mode i (veh/h)
q	traffic volume (veh/h)
p_i	occupancy rate of mode i (passenger/vehicle)
u	speed of traffic stream (km/h)
f	fuel consumption rate (m*l*/km)

The first step in the analysis of the future situation were the estimates of the number of trips for each of the four scenarios. These estimates were based on the current number of trips and the growth rate of 4 per cent per annum. The trips were split between the modes according to the traffic composition for each scenario.

Traffic volumes were derived from the total number of vehicles of each mode for each scenario. Fuel consumption was calculated using the formulae shown above for traffic speed and fuel consumption rate.

The output

The efficiency of each scenario was assessed on the basis of the traffic stream composition, vehicle occupancy and vehicle fuel consumption. Three indicators were developed:

- fuel efficiency index ϕ expressed in litres of fuel used to convey 100 passengers (including car drivers) over a distance of one kilometre

$$\phi = \Sigma a_i f_i / \Sigma a_i p_i$$

- energy efficiency index τ representing the energy required to convey passengers

$$\tau = \Sigma a_i f_i k_i / 100 \Sigma a_i p_i$$

- diesel component representing the proportion of diesel fuel used

$$\delta = \Sigma a_{id} f_{id} / \Sigma a_i f_i$$

where	ϕ	fuel efficiency of traffic stream (*l*/100 passenger-km)
	τ	energy efficiency of traffic stream (MJ/passenger-km)
	a_i	proportion of mode i in traffic stream
	a_{id}	proportion of diesel driven modes i in traffic stream
	f_i	fuel consumption rate of mode i (*l*/100 km)
	f_{id}	fuel consumption rate of diesel driven modes i (*l*/100 km)
	p_i	occupancy of mode i (passenger/vehicle)
	k_i	diesel/petrol conversion factor (MJ/*l*)

for petrol vehicles $k = 36.0$ MJ/*l*
for diesel vehicles $k = 38.4$ MJ/*l*

6. THE RESULTS

Traffic composition

A graphic representation of the minibus and bus proportion in the traffic stream for the four scenarios is shown in Figure 2. The proportion of minibuses increases for Scenarios 1 and 4, but decreases for Scenario 3. On the other hand, the proportion of buses increases for Scenarios 3 and 4, but decreases for Scenario 1. Scenario 2 does not consider any changes in the market share of the two modes.

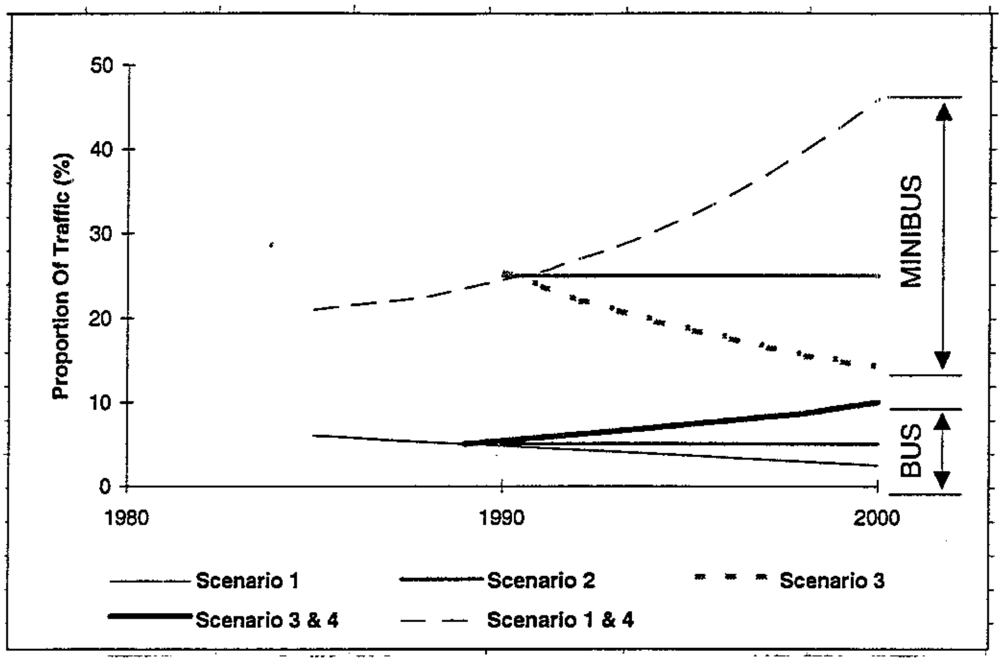

Figure 2 Future modal share

Diesel consumption component

In the current situation diesel consumption accounts for 8.3 per cent of the total fuel consumption of the traffic stream. The least favourable scenario is the minibus domination, where the diesel consumption is expected to drop to 5.4 per cent. The most favourable scenario, where the bus dominates, would result in an increase of diesel consumption to 17 per cent.

Fuel and energy efficiency

The existing situation and the impact of modal shift corresponding to the four scenarios in the year 2000 is shown in Table 4. The values of fuel efficiency and energy efficiency indicators have been calculated using the formulae presented earlier.

Table 4. Efficiency indicators

Scenario	Peak		Inter-peak	
	Fuel (l/100 pass-km)	Energy (MJ/pass-km)	Fuel (l/100 pass-km)	Energy (MJ/pass-km)
Current traffic	2.24	0.81	2.87	1.04
1 Minibus	4.20	1.51	2.48	0.89
2 No Change	6.86	2.48	3.09	1.11
3 Bus	2.50	0.91	3.18	1.15
4 Car demise	1.74	0.63	2.23	0.85

The figures in the table indicate possible outcomes of the competition between buses and minibuses. A noticeable difference may be observed between the peak period and inter-peak traffic. During peak periods buses are more efficient than minibuses, while during the inter-peaks minibuses are more efficient. In fact, during the inter-peak periods buses are as inefficient as cars. In both periods however the highest efficiency is achievable by the scenario which strongly discourages the use of passenger car in favour of the other two modes.

If the current modal split remains unaltered, the resulting peak period travel will be highly inefficient not only in terms of fuel consumption but also in terms of traffic congestion, as the high fuel consumption demonstrates traffic congestion.

The domination of public transport by minibuses shows high inefficiency during peak periods. This is a result of their low passenger capacity. On the other hand buses are inefficient during inter-peaks due to their low occupancy rate at these periods. Scenario 4 based on the growth of both minibus and bus services provides the best solution. The proportion of buses and minibuses increases, while the proportion of cars will be substantially reduced from the current 80 per cent level.

An efficient solution can be achieved by the encouragement, stimulation and effective management of the growth of both the minibus and bus industries. These measures would have to be combined with actions discouraging car travel in peak periods. It is possible to achieve more favourable traffic operating conditions in the target year than those experienced at present.

7. CONCLUSIONS

The energy efficiency model has been developed to study the impact of competition between public transport modes in urban transport. The model is highly versatile, may be used for any number of travel modes and road types. The required input is the vehicle occupancy rate, traffic volume and composition, and speed-volume curves for the analysed situation.

The paper presents the development of the model and its application to the assessment of two competing modes - buses and minibuses. The case study was done in Pretoria, South Africa. It evaluated the efficiency of passenger transport operations in the current situation and the impact of four future scenarios in the year 2000.

A spontaneous growth of the minibus industry will have two negative effects: inefficient use of fuel, especially during critical peak periods, and reduction in the diesel fuel use leading to an imbalance in the petrol-diesel consumption split. The fuel consumption index for such a scenario will be 4.20 l/100 passenger-kilometres during peak periods, the energy efficiency index 1.51 MJ/passenger-kilometre, and diesel consumption of approximately 5 per cent of the total fuel used. The current indicators are much lower at 2.24 l/100 passenger-kilometres, 0.81 MJ/passenger-kilometre and 8.3 per cent respectively.

The best scenario assumes a balanced growth of both bus and minibus transport, with a simultaneous reduction in car trips during peak periods. The scenario increasing the consumption of diesel fuel is the one favouring the growth of bus sector. The indicators for the most efficient scenario are 1.74 l/100 passenger-kilometres during peak periods, 0.63 MJ/passenger-kilometre, and 17 per cent.

The best scenario, in spite of the 4 per cent annual growth in travel demand, results in a higher fuel efficiency than the current traffic situation. This scenario can be achieved by both constructive management of the bus and minibus industries, and traffic management measures discouraging car travel, especially during the peak periods.

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