CODATU2015
ENERGY, CLIMATE AND AIR QUALITY CHALLENGES:
THE ROLE OF URBAN TRANSPORT POLICIES IN DEVELOPING COUNTRIES
2 - 5 FEBRUARY 2015, ISTANBUL - TURKEY ITU MAÇKA CAMPUS

Appropriate operating environments for Feeder-Trunk-Distributer or Direct road based public transport services in cities of developing countries.

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For presentation and publication at the
CODATU XVI
Istanbul
Turkey

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ABSTRACT

Bus Rapid Transit projects are being actively promoted internationally. They require the replacement of many direct services by Feeder-Trunk-Distributor services. Often city officials champion these projects on the basis of their success in other countries, without due regard to the existing trip making conditions in their own city.

The objective of the paper is to provide guidance on where Feeder-Trunk-Distributor road based public transport services should replace existing Direct services

Methodology:

A model was developed to estimate the cost, travel time, energy consumption and CO2 emissions of Direct and Feeder-Trunk-Distributer road based public transport services for a wide variety of operating environments described in terms of peak hour public transport trip production density at the origin, peak hour public transport trip attraction density at the destination, route length, percentage of trips generated from the origin distributed to the destination, and the number of routes distributing public transport trips at the destination

Data:

Data on the performance of road based public transport modes have been collected over many years from many cities in South Africa as well as on the range in the parameters used to describe urban environment in which public transport operates.

Expected conclusions:

A statement of which combinations of operating conditions make Feeder-Trunk-Distributer service more advantageous, Direct service more advantageous, and where neither type of service is advantageous in respect of cost, average passenger travel time, energy consumed and CO2 emitted per passenger.

KEY WORDS
direct, feeder-trunk-distributer, public transport, cost, travel time, energy, emissions

INTRODUCTION

Bus Rapid Transit (BRT) has become increasingly fashionable in recent years and is being vigorously promoted in developed as well as developing countries. The immediate image of a BRT is one or more dedicated lanes in each direction, with very well designed stations and a promise that it will at least cover operating costs.

There are many examples where this has been accomplished but the operating conditions that have allowed this to be achieved is seldom factored into the thinking of elected and appointed officials that return from their pilgrimages to examples of BRT, such as Bogota; and previously Curitiba.

This paper describes an analysis to determine the conditions where Feeder-Trunk-Distributor (FTD) services would outperform Direct Services in respect of cost, passenger travel time and energy consumption of the public transport service. The study is limited to road based services, because in the main, rail services need feeder and distributor services to aggregate sufficient passengers. The model, developed for the study takes account of peak hour public transport volume, route length, percentage of trips generated from the origin distributed to the destination, peak hour public transport trip generation density from the origin and to the destination, and the number of routes distributing public transport trips at the destination.

LITERATURE REVIEW

The popularity of BRT

Bus rapid transit is often the published image of FTD public transport services. The image is one of efficiency and modernity with its well designed stations, dedicated roadways and modern vehicles that will achieve greater capacity, speed and operational efficiencies that promise better services without operating subsidy from government (Viva 2007).

Menckhoff (2005) cites the economic experience of BRT services in South American cities as "*BRTs described in this paper (with the exception of Quito's Trole and Ecovía) cover operating costs including vehicle acquisition and depreciation from passenger revenues – different from almost all urban rail systems in Latin America and elsewhere*". This expectation, without mention of the possibility that operating costs might, in some cases, not be fully covered by fare revenue is often repeated by consultants in other countries where trip making and vehicle operating conditions could be quite different; such as the following that refers to Johannesburg and eThekwini (Durban) in South Africa:

> *The use of high-quality dedicated infrastructure and a planning process to optimize operations have allowed cities to significantly reduce subsidies. The Operational Plan for Phase I of Johannesburg's Rea Vaya project projects a 34% net profit for the system. By contrast, eThekwini is projecting to increase subsidies from R 280 million per year to R 1.1 billion per year, a four-fold increase* ($40 million to $ 157 million). (Viva, 2007)

Elected and appointed officials visit successful BRT systems and return with enthusiasm to embark on BRT projects rather than to apply the lessons learnt by identifying the most appropriate public transport solutions for their own cities. What constitutes “success” needs to be defined for each circumstance. The goals for a public transport solution and the importance of each could be vastly different than those of the visited cities. The realism of expectations of no operating subsidy can then be reviewed in light of the system performance required to meet these goals. As an example, high crowding levels would produce higher revenues, but are unlikely to attract riders out of automobiles. Similarly, providing a frequent off-peak services will incur costs but is essential to attract choice riders. One final example is the assumed level of fares – if the new system must charge far more than the previous alternatives in order to break even, it may actually fail in the goal of improving mobility.

There is evidence that some BRT systems purported self-sufficiency comes at the expense of poor performance in some respects. In 2012, there were riots in Bogota centered on the *Transmilenio* BRT. Specifically, riders complained of high fares, chronic overcrowding even in the off-peak and delays caused by this crowding (Sequera and Bajak, 2012). Support for the feeder network with free transfers necessitates a higher fare than the previous system and fare increases have been frequent and above the average inflation rate (Gilbert, 2008).

Feeder-Trunk-Distributor and Direct services

Operations

The often high capital cost of BRT routes and the political implications of providing road space for public transport instead of private motor vehicles can only be justified by high passenger volumes. In many parts of most cities, residential density translated into public transport passenger density is insufficient to produce the volumes required to begin to achieve the economies of scale achievable by BRT from passengers that can walk to BRT stations. This is resolved by developing feeder systems to and distributor systems from BRT terminals and transfer stations (Figure 1).

Feeder-Trunk-Distributor (FTD) versus Direct Services (DS)

The choice between using a FTD or a DS has a long history of discussion. The intention of this paper isn’t to repeat this discussion as the appropriate decision seems to be very case specific. It depends upon the corridor’s physical characteristics, the ridership profile, the demographics of the current and potential ridership, the performance and purchase price of the available vehicles, the local operator and maintenance labour costs, the ability to maintain reliable service schedules, availability of shelters, and various other factors. Furthermore, whether investment capital is available for the upgrade will also affect the potential relative performance of each option.

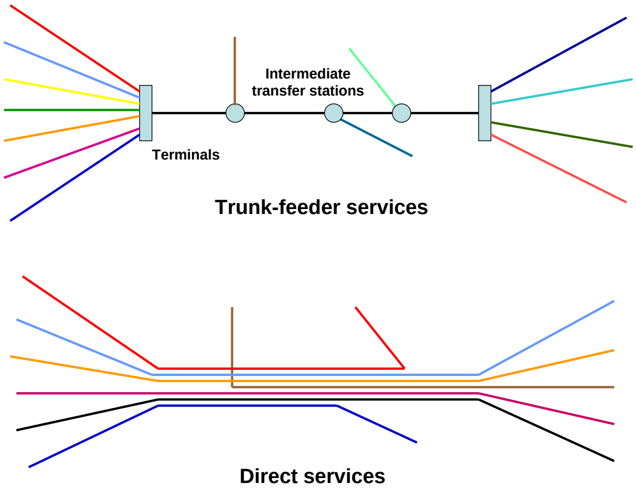

FIGURE 1: Feeder-Trunk-Distributor and Direct Services (Sequera and Bajak, 2012)

The Institute for Development and Transport Policy (IDTP, 2007) lists travel time, operational efficiencies, infrastructure, vehicle types, capacity, and system image and customer friendliness as a basis to compare FTD and DS. These exclude two major aspects; namely cost of delivering the service and the energy consumption / gas emission.

Potential Advantages of Feeder Trunk-Distributor

The obvious advantage of FTD is the division of the trip into three components; namely feeder, trunk and distributor. Each of these components will carry different volumes of passengers; for which different public transport modes might be more appropriate.

Services are expected to be more efficient with vehicles being able to operate on ways that permit less external interference in the flow of public transport vehicles. As such an HOV lane will provide some improvement over conditions with mixed traffic; and a BRT will be even better.

Referenced, hourly capacities of public transport modes vary considerably. For example, the City of Ottawa (2007) indicates hourly passenger capacities per direction of 8000, 10000, 14000 and 14000 for buses, street car and light rail transit (LRT) and BRT respectively; while IDTP (2007) shows the capacity of BRT as 45 000 passengers/hour/direction. Evidence is quoted that "*TransMilenio's double-width busway on Avenida Caracas even accommodates 35,000 pphpd with a mixture of all-stop and express bus services*" (Menckhoff, 2005). On very busy corridors in congested areas where land is at a premium (e.g. the CBDs of cities) being able to achieve such high capacities might be the most important factor. However, caution is advised in interpreting such numbers as multilane capacities often confuse way capacity with station capacity. The former is important for running multiple routes over express sections or for running on motorway but irrelevant for services stopping along a particular route. A two-lane BRT roadway might also be limited by the time allocated to public transport on the traffic signal timings.

It can be expected that vehicle speeds will be higher on dedicated lanes. For example, the *Insurgentes* corridor in Mexico City with median busway was expected to achieve "*a commercial speed of 21 km/hour, compared to 14 km/hour achieved by the bus services currently serving the corridor*" (Menckhoff, 2005).

Other advantages

A second advantage is that FTD services have the potential to provide more frequent off-peak services than DS. While demand may be sufficient during peak periods to provide direct links, FTD allows connections throughout the day. This theoretical advantage requires space and facilities for connecting terminals and introduction of timed-transfer discipline.

The authority and city would also benefit from the higher capacity of the trunk route, which could reduce the land take required to carry people to and from high density areas; such as CBDs.

The transport authority could benefit from FTD from the reduction in the cost of delivering the service through the economies of scale from bigger vehicles and higher speeds. However, if there is an integrated fare structure this improvement must be large enough to compensate for the additional costs of the feeder services.

Potential disadvantages

There are two major disadvantages of FTD. The first is the penalty incurred in changing modes at the terminals. The penalty lies in the time taken to alight from a vehicle, walk to the next stop and wait for the next vehicle and board. The penalty is more than just time. It includes the inconvenience of interchanging between vehicles. The travel time penalty needs to be made up as much as possible by the improved travel speeds on the trunk route. If the aforementioned economies of scale are not sufficient, it may also translate into higher fares to cover the extra vehicles and kilometers incurred.

The second disadvantage lies in the fact that from a passenger's point of view, the feeder vehicles have to travel to the terminal at the feeder end of the trip and after travelling on the trunk section, then travel from the terminal at the distributor end of the trip; with these components amounting to a greater distance than the direct route. From an operator's point of view, the lower cost resulting from the improved efficiencies and economies of scale of the trunk component may not be sufficient to cover the extra cost of the combined system from the total distance traveled and time consumed per day by the fleet.

Towards an analysis model

For the purposes of the present paper it suffices to note that there is both theoretical and empirical evidence to suggest that trunk/branch networks can outperform direct networks under some circumstances. Bruun (2007) describes the theoretical pros and cons between three possibilities: direct service to and from a CBD terminal, the merging of direct services onto a trunk as they near the CBD terminal, and the introduction of a higher capacity mode along the trunk section with the requirement of all passengers from the branches to transfer. He concludes that the best choice depends upon the particular site and objectives of the planning authority. For example, if the primary objective is only serving commuting trips to/from the CBD during peak hours, direct service will usually cost the least. On the other hand, for all day service between multiple origins and destinations, the third possibility is likely to be the best.

Some empirical evidence is also available on the before/after results for LRT systems built in the United States. Thompson and Matoff (2003) compared before/after ridership based on conversion to a timed-transfer system between local buses and LRT from a largely direct to CBD bus system and found substantial ridership increases without large operating cost increases for the corridor. They also found that older peer combined rail and bus systems that did not convert to trunk/feeder experienced relatively stagnant ridership. Clearly, labor costs are much higher in the U.S. and traffic conditions much different, so it doesn’t follow that the results would be similar, but there is enough evidence to suggest that trunk/branch could be promising for developing countries.

The model presented in this paper is capable of including the impacts from changes to most of the relevant variables usually discussed in the literature. Specifically, factors that affect the relevant advantages of FTD versus DS include:

a) Public transport trip production and attraction rates and the proportion of trips distributed to the destination;
b) Route catchment area which depends on the stop spacing and acceptable walking distance;
c) Feeder, trunk and distributor modes and their operating characteristics.
d) The number of routes feeding to the origin terminal;
e) The distance between origin and destination;
f) Distributor catchment area which depends on the stop spacing and acceptable walking distance;
g) The number of routes distributing from the destination terminal.

The issue of reliability is not included as this would require the introduction of stochastic variations in travel times; an enhancement that could be added in the future.

METHODOLOGY

The Conceptual Spatial Model

The spatial arrangement has been simplified to an origin area served by one or more routes; a trunk service; and a destination area served by one or more routes as shown in Figure 2. Trips are produced in the origin area which is composed of one or more catchments of routes that feed the origin terminal. At the origin terminal, trips produced by the origin area are distributed to destination areas through one or more trunk routes. At the destination terminal, trips arriving from one or more trunk routes are distributed through one or more routes that feed the destination area.

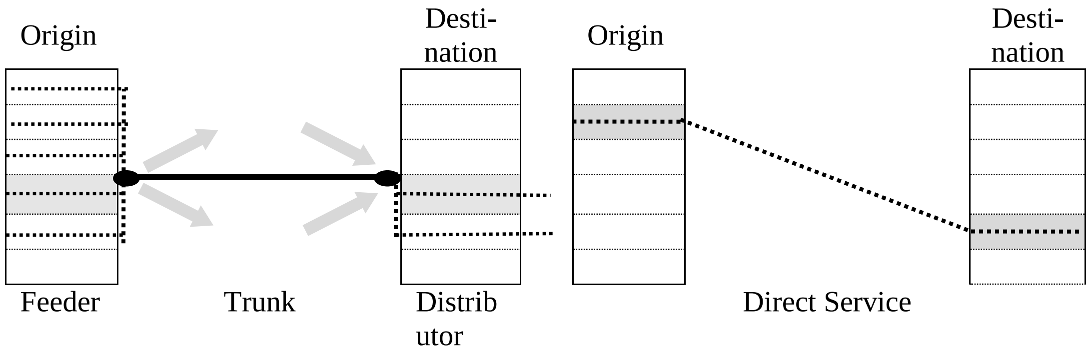

FIGURE 2: Spatial schematic of analysis

The Computational Model

Overall structure of the computational model

The computational model estimates the public transport passengers travelling on the feeder, the trunk, the distributor and the direct route and the lengths of these routes for all the combinations of the variables listed in Table 1. These values are fed to a public transport model to calculate the cost, travel time and energy used to travel each segment of the FTD trip and the DS trip for six public transport modes (Table 2). These outputs are then used to determine the minimum cost, travel time and energy per trip for the FTD and DS alternatives; which are the data used in the analysis.

Input variables to the model

Table 1 shows the values of the input variables used to determine the number of trips and route lengths used to compare FTD and Direct services:

TABLE 1 Trip making conditions used in the analysis

VT	LL	PO	DO	DD	RD
1000	11	15	5	20	1
5000	20	20	10	40	5
10000	30	25	25	85	10
20000	40	(-)	(-)	(-)	(-)

(-) Only three levels of each variable used in analysis

Where:

VT	is the peak hour volume on the trunk route between the Origin and the Destination (PT pax/hr);
LL	is the distance between the end of the Origin and the end of the Destination (km);
PO	is the percentage of trips generated by the Origin that are distributed to the Destination (%);
DO	is the peak hour PT trip production density from the Origin (PT pax/hr/ha) (1ha =2,47acres);
DD	is the peak hour PT trip attraction density to the Destination (PT pax/hr/ha);
RD	is the number of routes distributing PT trips at the destination.
SO, SD	are the stop spacings on the feeder and the distributor services respectively (assumed to be 1000m (3300 ft) and 500m (1650ft) respectively).
Os, Ds	are the number of stops on the feeder route (assumed to be 10) and the distributor route (assumed to be 5).

In this analysis it is assumed that all the passengers produced by the origin are distributed to the destination will travel between the terminals of the trunk route. The model does not account for passenger alighting or boarding on the route; although the public transport model assumes time lost due to vehicles stopping at stations assumed at 1km intervals. In cases where there is very high demand along the trunk, it would shorten wait times at terminals through higher frequency or reduce trunk operating costs through larger vehicles.

Input to the public transport model

The values given in Table 1 produced 1296 cases of trip making conditions. Each case produced values for feeder, trunk, distributor and direct services. These values were input to a previously developed public transport model (Del Mistro and Baloyi, 2000; Del Mistro and Aucamp, 2000, Kingma, Hugo and Del Mistro, 2002) used to calculate the cost, travel time and energy consumed per passenger.

The transport model

Assumptions were made in the model with respect to the distribution of trips throughout the day, minimum service frequency, vehicle speeds over different types of road, etc. The following six modes were considered:

a) 16-Seater minibus in mixed traffic or HOV lane operation.
b) 25-Seater midibus in mixed traffic or HOV lane operation.

c) 66-Seater bus in mixed traffic or HOV lane operation.
d) 80-Seater articulated bus in mixed traffic or HOV lane operation.
e) 66-Seater bus with a BRT way (lateral separation but at-grade intersections),
f) 80-Seater articulated bus with a BRT way (lateral separation but at-grade intersections),

Table 2 shows the values for the most important operating parameters used by the public transport model. Cost data has been updated to 2013 and the operating parameters are typical of South African public transport operations. All the factors are necessary to determine the cost, travel time and energy consumption to service a route. The model was also run for both current and high labor costs to address the argument that is often leveled that low salaries in developing countries makes smaller capacity vehicles more competitive than in developed countries.

TABLE 2 Public Transport Model: Important Operating and Cost Parameters

MODE	16-Seater Minibus	25-Seater Midi	55-Seater Bus	Articulated Bus	55-Seater BRT	Artic bus BRT	HOVmini	HOVbus
Travel speed Destination in peak (km/h)	25	25	25	25	40	40	30	25
Travel speed Arterial in peak (km/h)	45	40	40	40	60	60	50	45
Travel speed Origin in peak (km/h)	35	30	30	30	45	45	40	35
Maximum volume/Capacity ratio	0.85	0.85	0.85	0.85	0.85	0.85		
Vehicle capacity (standing allowed)	16	35	85	120	85	120		
Vehicle capacity (standing is not allowed)	16	25	66	80	66	80		
Cost per vehicle(USDm)	0.032	0.064	0.180	0.240	0.220	0.260		
Capacity per lane(Veh/h)	400	300	250	200	300	250		
Cost of way(USDm/lane-km)	0.500	0.500	0.500	0.500	2.07	2.07		
Cost of Terminals (USDm/peak hour vehicle)	0.002	0.005	0.011	0.022	0.011	0.022		
Cost of stops (USDm/stop)	0.01	0.01	0.01	0.01	0.39	0.39		
Cost of depot (USDm/coach)	0.010	0.030	0.045	0.050	0.045	0.050		
Energy consumption(Mjoules/coach-km)	11.97	12.1	19.36	32.43	19.36	32.43		
Fuel Consumption(l/100veh-km)	19	25	40	67	40	67		
Cost of fuel(USD/l)	1.30	1.30	1.20	1.20	1.20	1.20		
Other Cost/veh-km(USD/coach-km)	0.86	0.265	0.398	0.465	0.442	0.487		
Cost/coach/year(USDm)	0.04	0.028	0.042	0.049	0.047	0.052		
Cost/lane-km/year(USDm)	0.01	0.01	0.01	0.01	0.01	0.01		
Cost/terminal/year (%of capital cost)	5	5	5	5	5	5		
Cost/station or stop/year (USDm)	0	0	0.009	0.009	0.18	0.18		
High Labour Costs								
Other Cost/veh-km(USD/coach-km)	2.9	0.758	1.136	1.33	1.26	1.39		
Cost/coach/year(USDm)	0.2	0.123	0.185	0.216	0.206	0.226		

Outputs of analysis

The public transport model produced the following information for each case of trip making conditions:

a) The total and operating cost per passenger using the feeder, trunk, distributor or direct services. The cost includes capital and operating costs.

b) The travel time for the passenger. It was assumed that on average passengers will travel half of the route length within the feeder and distributor catchment areas; and the full distance between the route catchment and the terminal the catchment is feeding to or distributing from. It was also assumed that the average waiting time is equal to half the service frequency unless the peak hour vehicle frequency was more than 20 minutes. In which case an average wait time of 10 minutes was assumed.

c) The average energy consumed by the vehicles transporting each passenger using each service is derived from the fuel consumption.

Analysis of the outputs

The output data was used to determine the minimum total and operating costs, minimum travel time and minimum energy consumption for each component of the FTD trip; which were added to calculate the minimum value for a FTD service and for the Direct Service. The values for the FTD were divided by the values for the DS (FTD/DS cost, FTD/DS time and FTD/DS energy) as an easy way to compare the performance of the two alternatives.

1296 Cases were developed and analyzed by determining trip making conditions which are advantageous to either FTD or DS.

DISCUSSION OF FINDINGS

Initial outputs

Table 3 provides a summary of the basic outputs of the study indicating the average, lowest and highest values of the minimum FTD and DS trips for high labor rate, low labor.

TABLE 3: Range in output values of cases used in the study

		Feeder- Trunk Distributer service				Direct Service			
	Laborur cost	Total Cost/pass trip MIN(USD)	Operating Cost/pass trip MIN(USD)	Ave Time/trip MIN(m)	Energy/trip MIN (mj)	Total Cost/pass trip MIN(USD)	Operating Cost/pass trip MIN(USD)	Ave Time/trip MIN(m)	Energy/trip MIN (mj)
Min	Low	1.12	0.91	25.14	3.62	1.14	0.959	13.10	8.20
	High	2.54	2.33			1.841	1.24		
Max	Low	4.41	3.60	73.37	35.69	3.510	3.05	51.15	35.56
	High	13.10	11.50			7.606	7.10		
Ave-rage	Low	2.38	1.87	47.58	16.74	2.070	1.79	30.37	18.66
	High	5.65	4.838			4.785	4.25		

Frequency with which Feeder Trunk Distributer Services are better than the Direct Services.

Table 4 shows the distribution of the FTD/DS ratios wrt Total Cost, Operating Cost, Travel time and Energy Consumption for the 1296 cases derived by the combinations of the parameters shown in table1.

Table 4: Distribution of FTD/DS cost, time and energy ratios

	Cost/pass trip MIN(R)		Op.Cost/pass trip MIN(R)		Ave Time/trip MIN(m)	Energy/trip MIN (mj)
	Low labour	High labour	Low labour	High labour		
Min	0.89	0.85	0.80	0.83	1.26	0.36
Max	1.61	2.57	1.63	2.67	2.55	1.48
DISTRIBUTION OF CASES						
<0.5	0	0	0	0	0	2
<067	0	0	0	0	0	17
<1	109	211	420	377	0	1225
<1.25	985	823	847	673	0	43
<1.5	192	155	20	153	573	9
<2	10	96	9	76	417	0
>2	0	11	0	17	306	0
Total	1296	1296	1296	1296	1296	1296

Table 4 shows that:

a) The total cost was less for cases of FTD service that cases for Direct service in 8 and 12 per cent of cases for Low or High labour costs respectively.

b) The operating costs of FTD services were less than those for Direct Services in more than a third of the cases tested.

c) Passenger travel time when using FTD services was always longer than using Direct services.
d) FTD services were found to use less energy than Direct Services in over 97% of cases.

It must be noted that these proportions where FTD is more appropriate only reflect the cases selected in the study not the situation in practice. The next section identifies which conditions are more appropriate for FTD.

Operating conditions where FTD services are more appropriate than Direct Services

The output of the analysis was examined to find the operating condition where the FTD service is more appropriate was over represented as being more appropriate than the Direct service for total cost, operating costs, travel time and energy consumption (as surrogate for gas emissions), Table 5 summarises the findings this analysis.

FTD service appropriate in terms of Total Cost

Table 5 shows that 458 cases (of the 1296 cases) achieved a ratio of the total cost of FTD and Direct services is less than 1; i.e. the FTD is less costly than the Direct service. The table shows that this is most prevalent when:
a) The percentage trips going from the origin to the destination is high at over 15%
b) The destination trip attraction density is higher than 100 trips/ha in the peak hour.
c) The service serves a destination that can be serviced with one distributer route.
d) The trip production density at the residential area is higher than 40 trips/ha in the peak hour.

FTD service appropriate in terms of Operator Cost

While the decision on selecting a transport solution should be based on the total cost (in the broadest sense), most transport authorities base their decision on the operating cost alone, omitting the capital costs and operating costs borne by the transport authority. Table 5 shows the parameters values that are prevalent where the operating costs of the FTD service has a lower operating than the Direct service. 458 Cases found the FTD to be less costly than the Direct service. Table 6 shows that FTD is preferable to a Direct service where:
a) The route length is shorter than 30 km.
b) The destination catchment area can be serviced with one public transport route.
c) Approximately 5 per cent of trips originating at the residential area are travelling to

TABLE 5: Operating conditions appropriate for FTD services

Pk hr trunk pass in peak direction	O-D Distance (km)	% origin trips to destination	Origin trip density (Tr/ha/hr)	Destination trip density (Tr/ha/hr)	# Catchments at destination
Operating parameters					
1000	11	5	20	20	1
5000	20	10	40	100	5
10000	30	25	85	200	10
20000	40				
Total cost (Low Labour Cost)			*458*	*Cases*	*<1.0*
168	163	144	100	112	192
133	120	56	186	142	152
88	83	258	172	204	114
69	92				
Operating cost (Low Labour Cost)			*458*	*Cases*	*<1.0*
165	134	185	177	142	202
157	260	146	132	155	157
99	21	127	149	161	99
37	43				
Travel time			327	Cases	<1.4
90	0	114	114	109	114
87	0	105	105	109	111
81	15	108	108	109	102
69	312				
Energy			314	Cases	<0.8
127	184	134	135	102	148
131	94	94	86	105	98
42	18	86	93	107	68
14	18				

FTD service appropriate in terms of Travel Time

The study found that FTD service never produced a shorter travel time than the Direct Service. Table 5 shows that 327 cases produced travel times for FTD services that were less than 1,4 time longer than Direct services; all the other cases produced relatively longer travel times for FTD. To achieve the lowest ratio requires route distances longer than 30km.

FTD service appropriate in terms of Energy Consumption

Table 5 also shows the effect of Service on energy consumption. It found that except for 53 cases the FTD service was always more energy efficient.

Effect of high labour costs on the appropriateness of FTD service

Table 6 shows the results of the analysis which assumed labour costs were 5 times higher than currently apply in South Africa.

In terms of Total cost of service, FTD service was found to be more appropriate:
a) On routes short routes less than20km.
b) On routes to destinations with trip density of 200 passenger/ha.

In terms of Operator cost of service, FTD service was found to be more appropriate:
a) On routes shorter than 30km.

While the operating conditions are obviously more appropriate FTD in terms of total cost are not the same for low and high labour costs, they are in agreement on short trip length and high trip density at the destination. In terms of operating cost, FTD services are more appropriate on routes shorter than 30 km for both low and high labour costs.

Table 6: Effect of high labour costs on FHT service being appropriate

Pk hr trunk pass in pk dir (phppd)	O-D Distance (km)	% origin trips to destination	O Trip density (Tr/ha/hr)	D Trip density (Tr/ha/hr)	# catchments at destination
1000	11	5	20	20	1
5000	20	10	40	100	5
10000	30	25	85	200	10
20000	40				
Total cost (High Labour Cost)			225	cases	<1.0
69	137	90	65	0	98
69	71	65	81	103	78
72	8	70	79	122	49
15	9				
Operating costs (High Labour Cost)			346	cases	<1.0
140	86	154	149	105	157
122	221	108	91	117	117
75	13	84	106	123	72
9	26				

Further analysis

Further work on the study can include:

a) A study of the effect of reliability on the two PT alternatives.
b) A review the values of the parameters used in the study to identify whether more accurate values of boundary conditions could be determined.
c) The development of a multi-criteria evaluation method to combine the outcomes of the three criteria; namely cost, time and energy; which could be used to choose the "best" mode for each component of the route; as opposed to the current comparison of least cost, least time or least energy consumption.

CONCLUSIONS

This paper described an analysis of the effect of peak hour public transport volume, route length, percentage of trips generated from the origin distributed to the destination, peak hour public transport trip production density from the origin, peak hour public transport trip attraction density to the destination and the number of routes distributing public transport trips at the destination on the cost, average passenger travel time and energy consumed per passenger using a Feeder-Trunk-Distributor service compared to those incurred when using a Direct Service in over a thousand cases.

The study found that the following conditions can favor the implementation of Feeder Trunk Distributor when replacing Direct Services:

a) High trip density at origins and destinations..
b) Single destination catchments.
c) Services shorter than 30 km in terms of total and operator costs and energy consumption and services of 40 km in terms of travel time.
d) Peak hour passenger volumes in the peak direction of less than 10 000. This might seem to be counter intuitive.)

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Further research work is required to include the effect of the improved reliability provided by dedicated facilities, route length, on the definition of boundary conditions of percentage of trips from origin to the destination and public transport trip densities, and the application of multi-criteria assessment.

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