THE IMPROVEMENT OF PUBLIC TRANSPORT OPERATIONAL PERFORMANCE: THE CASE FOR GAUTENG PROVINCE, SOUTH AFRICA

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ABSTRACT

New transport policies in South Africa place emphasis on the promotion of public transport. This paper explores the improvement of public transport operational performance in Gauteng Province through the development of appropriate and sustainable public transport key performance indicators (KPIs) and corresponding levels of service (LOS) that address basic user needs. The appropriateness of established LOS is tested in low-income areas with low car ownership, where there is an obvious need for an improvement in public transport operations. The existing levels of service provision are compared to expected levels, in order to quantify the gap in service provision. The backlog is quantified in monetary terms using a strategic model able to predict demand changes, as well as the impact on resources as a result of improvements to the system. The results indicate that the achievement of target LOS may be unaffordable, while the implementation of the proposed minimum LOS is cost-efficient.

1. BACKGROUND & PROBLEM STATEMENT

Public transport operations in South Africa, and in particular Gauteng Province, are riddled with problems. The service is characterised by poor performance, most evident in late arrivals, over crowdedness and non-availability outside peak hours, among other. Most often, old and unsafe vehicles are being used for public transport operations. This compromises the safety of passengers and results in an unacceptable rate of accidents involving public transport vehicles.

New government policies place emphasis on the promotion of public transport. The emphasis should be on low-cost, high impact solutions, in other words, identifying affordable minimum levels of service (LOS) that address basic user needs. The main objectives of this research were thus to develop appropriate and sustainable public transport key performance indicators (KPIs) and LOS, to test the practicality of formulated KPIs and LOS, and to establish the additional investment levels required to address the backlog within the public transport system in Gauteng.

Figure 1 shows the geographical spread of public transport usage in the province. It is clear that the majority of public transport commuters are concentrated in the previously disadvantaged areas in the province, where average household income is low and commuters are captive to public transport. These areas include Soshanguve, Mabopane, Mamelodi, among other.

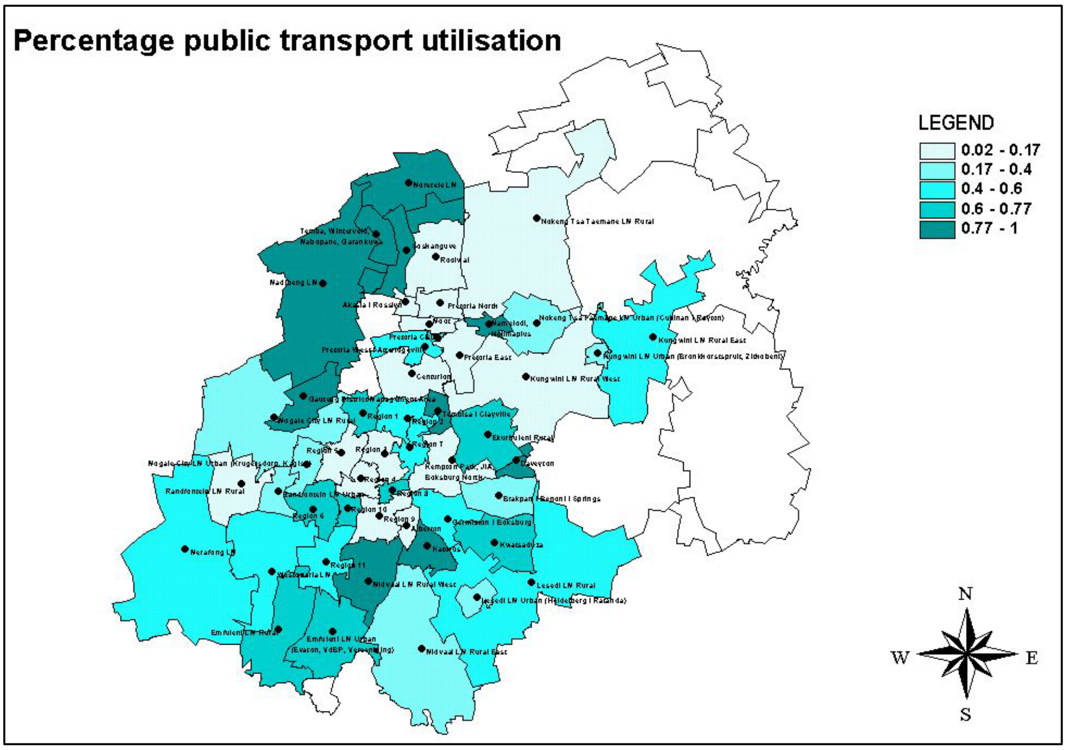

Figure 1. Public Transport Utilisation in the Province.

Source: Data from Gauteng Household Travel Survey (GPDPTRW, 2002)

Public transport is less convenient than private transport, although it can be seen as an opportunity for those with no transport available. These inconveniences, however, need to be minimised in order for the service to be attractive. The identification of these and other problems is often an indication of the wants and needs of passengers. The most pressing transport problems in Gauteng relate to the availability and accessibility of public transport services, service capacity (i.e. crowding) in taxis and trains, frequency of service, cost of public transport, and safety and security issues (GPDPTRW, 2002). These are areas for which public transport LOS ought to be formulated.

2. PROPOSED PUBLIC TRANSPORT KPIS AND LOS WITH THEIR CURRENT STATUS

The identified needs formed the basis for the development of ideal public transport KPIs. These KPIs provide a mechanism to evaluate the performance of the public transport system. Various local studies were scrutinised to obtain appropriate KPIs for application in Gauteng (NDoT, 1998b; GPDPTRW, 2003b; GPMC, 1998). The following KPIs together with corresponding minimum and target LOS were tested for application in Gauteng.

Table 1. Ideal KPIs with Minimum and Target Levels of Service.

No	Parameter	KPI	Levels of Service (1)		
			Bus	Rail	Taxi
1	Availability	Hours of service	18 (24)	18 (24)	18 (24)
2	Accessibility	Walking distance to public transport	1 000m (500)	N/A	750m (400)
3	Service capacity	% Capacity utilisation (Volume to capacity ratio)	1.00	1.00 (0.90)	1.00
4	Frequency	Number of departures per hour in peak period	6 (12)	6	12
5		Number of departures per hour in off-peak period	1 (2)	1 (2)	4
6		Average waiting time in peak period	10 mins (5)	10 mins	5 mins
7	Cost	Percentage of income spent on public transport	10%	10%	10%
8	Safety	Maximum age of vehicles in the fleet	12 yrs	30 yrs	10 yrs
9	Security	Number of security officers per 1000 peak hour passengers	1	1	1

Note 1: Target LOS are indicated in brackets.

Although status quo information was not available for all KPIs, an analysis of the province revealed the findings listed below.

- The availability of public transport currently varies between 14 to 18 hours, although satisfaction ratings are low with regard to the availability of public transport late at night and over weekends (GPDPTRW, 2004c).
- Perceived walking distances for train services are by far the longest and are the only mode for which walking distances exceed the proposed minimum level of service of 1000 metres (GPDPTRW, 2004a). However, walking distance LOS for rail services should not be considered, due to the rigid nature of rail infrastructure and costly infrastructural intervention required. For the other modes, maximum walking distances of 1 000 metres, set by the National White Paper on Transport Policy (1996), appears to be practical.
- Although status quo service capacities are acceptable for bus and taxi services, train services are more problematic in this regard, with overcrowding evident on most urban commuting railway lines, i.e. in excess of 1.00 (GPDPTRW, 2004c).
- In terms of waiting time, 15 minutes appears to be the acceptable maximum for commuters during the peak period, translating into frequencies of at least four departures per hour. All modes have perceived average waiting times less than the proposed minimum of 10 minutes (GPDPTRW, 2004a), implying that equivalent frequencies of six departures per hour can be met. However, current frequencies during the off-peak period fall short of the proposed LOS (GPDPTRW, 2004c).
- Although approximately 60% of public transport commuters spend more than 10% of personal income on public transport, the average spending is estimated at only 1.1% above the proposed level of service (NDoT, 2004b). This implies that the goal of 10% set by the National White Paper (1996) is realistic for application in Gauteng.

- Low satisfaction ratings prevail regarding personal safety at stations and on public transport vehicles (NDoT, 2004b).
- The vehicle age and unroadworthiness are major contributing factors to public transport accidents. Nearly 64% of minibus-taxis and 50% of buses are older than their expected lifespan of 10 and 12 years respectively (NDoT, 2005a).

3. TESTING OF KPIS AND LOS FOR APPLICATION IN GAUTENG

3.1 Development of a Model to Predict Impact of Operational Changes

A strategic model was developed to predict the impact of improved public transport levels of service on passenger demand (service / demand model), the result of which is used in the resource model to calculate the required resources, i.e. estimate cost of implementing proposed operational changes (resource / supply model). The framework of the model is shown in Figure 2.

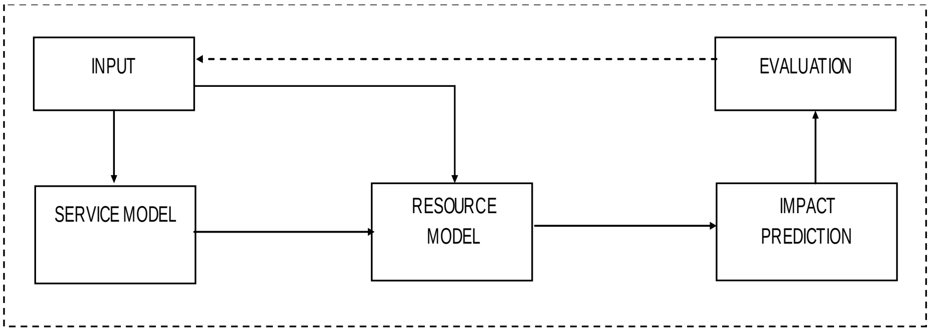

Figure 2. Framework of the Model.

The model structure is depicted in Figure 3. The numbering in the short discussion below corresponds with the numbering in the figure. The following should be noted:

1. Utility functions calculate the utility derived from each mode based on attributes such as walking distances, waiting time, cost of public transport and frequency of vehicles.
2. The probability of selecting each mode is calculated based on utility derived from each mode as well as the utility derived from competing modes in the choice set.
3. The probability of each mode is multiplied by the total number of public transport commuters during the AM peak period to obtain the number of passengers for each mode. The model assumes a fixed demand, i.e. users attracted from modes other than public transport are not taken into account. Moreover, in times of economic prosperity, users leaving the public transport market are not accounted for.
4. Based on the vehicle capacity of each public transport mode, the number of vehicle trips required to serve the particular passenger demand is calculated.
5. The critical peak hour passenger volume is calculated in order to determine the vehicle fleet size. The number of passengers is also used to calculate the annual fee income as well as the number of security officers required per certain number of passengers.
6. If any safety measures are introduced, then aging vehicles in the vehicle fleet will be replaced, adding to the capital expenditure of the operator/authority. In the model, no distinction is made between these two bodies. The capital cost of acquiring new vehicles is discounted over the expected lifespan of the vehicle, at a discount rate of 8% per annum.

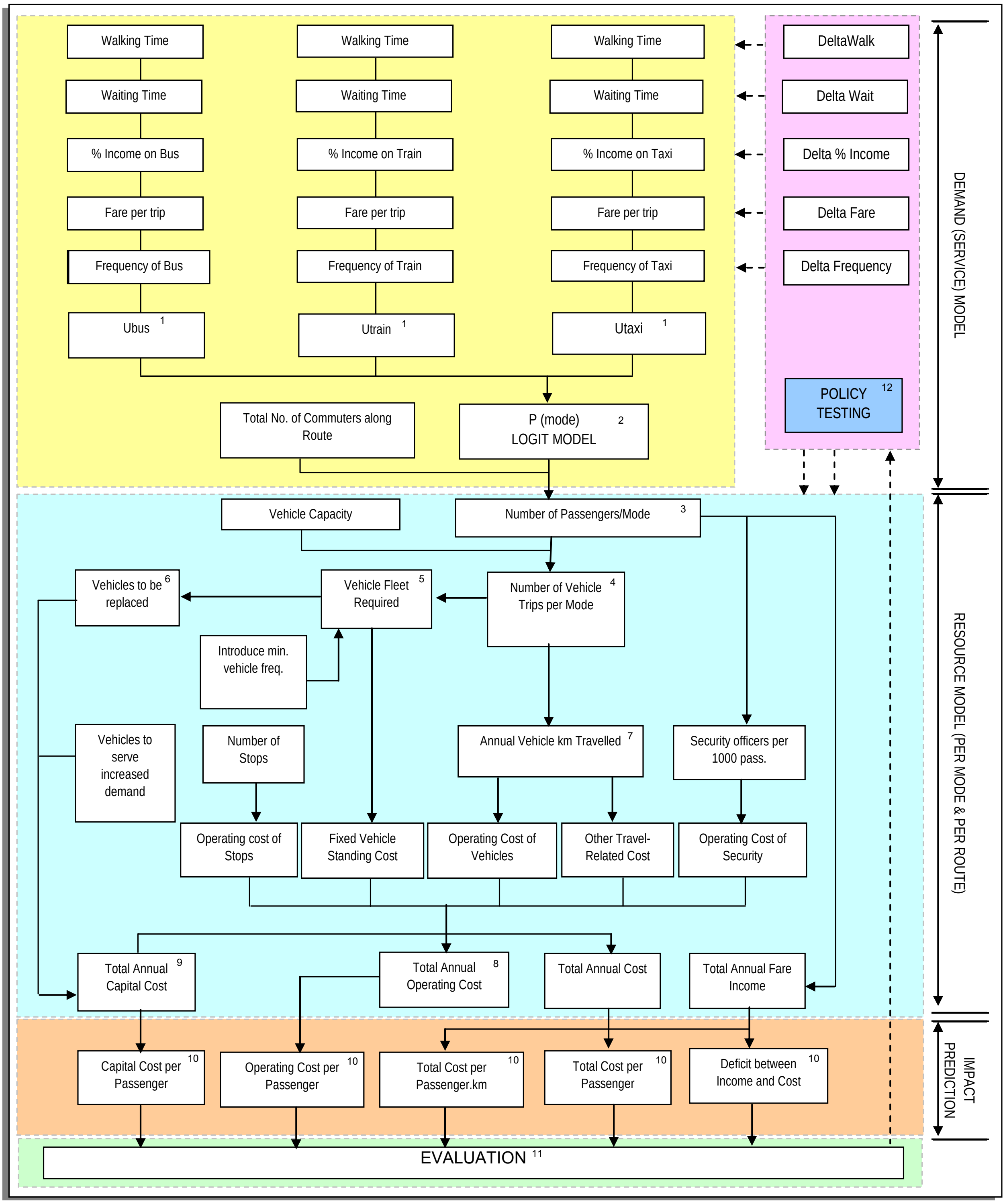

Figure 3. Structure of the Model.

7. The annual vehicle kilometres are calculated based on the number of vehicle trips per annum, which is then used to calculate the running operating cost of each mode as well as other travel-related expenses which account for costs not included in any of the operating cost components (e.g. start up cost of service change, information provision, etc.).
8. Total annual operating cost is calculated by summing operating cost of stops/stations, fixed vehicle standing cost, running cost of vehicles, other travel-related expenses as explained earlier, and the cost of providing security at stations/in vehicles, and the additional cost of improving on walking distances.

9. Total annual capital costs are calculated by adding the cost of replacing aging vehicles in the fleet and the cost of additional vehicles required due to an increase in the number of peak hour passenger trips. No other capital costing factors are taken into account, as it is assumed that they are already in place (such as ways, termini and existing vehicles). This was confirmed by site visits to the pilot areas.
10. The impact of LOS changes is reported by certain important indicators. These are the calculation of annual number of passengers and number of passenger kilometres to determine annual capital, operating and total cost per passenger and per passenger kilometres. The deficit between annual fare income and total annual cost is also reported.
11. The proposed service change/s are evaluated by scrutinising the indicators for efficiency and effectiveness, and if necessary,
12. Policies can be adjusted to produce more cost efficient/cost effective outcomes.

3.2 Methodological Approach

In developing the demand model, discrete choice modelling techniques were applied. Discrete choice analysis is the modelling of choice from a set of mutually exclusive and collectively exhaustive alternatives. The analysis uses the principle of utility maximisation, which models a decision maker to select the alternative with the highest utility among those available at the time the choice is made (Hensher, 2003). The utility of a mode is modelled by constructing utility functions containing parameters for observable independent variables and unknown variables, such that:

$$U_{mode} = ASC + \vartheta_1(WD) + \vartheta_2(WT) + \vartheta_3{*}(IS) + \vartheta_4{*}(CU) + \vartheta_5{*}(F) + \vartheta_6{*}(HS) + \vartheta_7{*}(AGE) + \vartheta_8{*}(SEC) \quad (1)$$

Where:

U_{mode}	-	Utility of a particular mode
ASC	-	Alternative specific constant
ϑ_1	-	Walking distance (WD) coefficient
ϑ_2	-	Waiting time (WT) coefficient
ϑ_3	-	% income spent on public transport (IS) coefficient
ϑ_4	-	% capacity utilisation (CU) coefficient
ϑ_5	-	Frequency of service (F) coefficient
ϑ_6	-	Hours of service (HS) coefficient
ϑ_7	-	Average age of public transport vehicles (AGE) coefficient
ϑ_8	-	Number of security officers per a given number of passengers (SEC) coefficient

The probability of selecting each mode is then calculated by means of the multinomial logit model (MNL) as follows:

$$P_{iq} = \frac{\exp(\beta\,\vartheta_{iq})}{\sum_{Aj\;E\;A(q)}\exp(\beta\,\vartheta_{iq})} \quad (2)$$

3.3 Estimation and Calibration Results

The final demand model took the form as shown in Table 2.

Table 2. Final Demand Model Calibration Results.

MODEL		%Income Spent	Fares	Walk	Frequency	ASCs		
			(R/trip	(min)	(dep/hr)	Bus	Train	Taxi
PT modes	Coefficient	-0.062	-3.328	-0.169	0.257	0.000	-2.370	4.693
Rho-sq = 0.59	T-statistic	-6.4	-25.3	-14.7	2.86	Fixed	-11.3	11.0
	Value of time (R)			R 3.04				

Initially, the model considered four modes: bus, train, minibus-taxi and car (the latter to place public transport in context), but it was found that the inclusion of the car mode disturbs the calibration of the model. Considering the market segment under discussion, it is questionable whether car is a viable transport option. Moreover, travel time is not included as a variable (as it was not identified in the needs analysis), but would have contributed significantly to differences in utility between car and public transport.

One utility function was developed with different alternative specific constants (ASCs) for each of the public transport modes. Only the variables walking time, frequency (and waiting time), fare/trip and percentage income spent on public transport could be incorporated into the utility function. The potential dominance of the ASCs at the outset of the calibration process suggested that the ASCs seek to replicate the modal split values, and thus reducing the explanatory power of the model. However, in the final model, the contribution of the ASCs is estimated at only 22%, which is not reason for concern. In light of all these shortcomings, it should be mentioned that the model is still capable of predicting the actual modal split with good accuracy.

The data used in the analysis was drawn from a Revealed Preference (RP) dataset and is a classic case where only attribute values for the selected mode were collected, and not for all modes in the choice set. Certain assumptions, therefore, had to be made in order to populate the resulting missing values of the alternative modes in the dataset. The reported average attribute value for each mode in the dataset was used for the missing values. However, these values are representative of the attractiveness of the alternative modes, i.e. they promote a better set of attribute levels than what would be the case if information on non-chosen alternatives was indeed available. Consequently, the resulting dataset implied that the attribute values of the alternatives are more attractive than the actual mode selected in the choice set. To overcome the problem, the values of the alternatives are adjusted by introducing a maximum value for a specific attribute in cases where the alternatives are more attractive than the mode selected. The results improved significantly.

No strong correlation was found between waiting time and frequency, although the variables are theoretically highly related. A possible reason for this may be that the two variables do not share the same dataset. Frequencies were extracted from Current Public Transport Records (CPTR) and existing timetables, while waiting time data was extracted from the Gauteng Household Travel Survey (GHTS) database. In addition, it should be noted that perceived waiting time may be different to actual waiting time. Another possibility for the lack of evidence in terms of the relationship between the two variables can be found in the so-called 10-minute theory. In reality, commuters hardly wait for more than 10 minutes in instances where low frequencies are provided. This is because these commuters are familiar with timetable schedules and, therefore, arrive at the stop/station shortly before departure. When higher frequencies are provided, arrivals at stops/stations tend to be random, resulting in a more normal distribution of waiting times. The perceived waiting times might, as a result, not be an accurate depiction of the service currently provided. Based on this and other supporting evidence, and from a forecasting perspective, it is more appropriate to include frequency rather than waiting time.

A lack of quality data hampered the inclusion of other variables identified in the needs analysis, such as off-peak frequency, safety and security and hours of service. In terms of the data requirements, availability and quality, it should be noted that separate databases (CPTR / GHTS) were employed in the analysis. These databases were difficult to integrate as they do not use the same coding. In addition, only RP data is available (see discussion on "missing values" earlier in this section). RP data typically suffers from a lack of variation (in discrete choice modeling, variation is required in order to explain variation), with no information available on the alternatives not chosen. Moreover, limited information is collected by public transport operators, while safety and security information is limited to non-existent.

4. SENSITIVITY ANALYSIS

Sensitivity tests were used to establish the impact of variables on mode choice in the demand model. It was shown that:

- a change in fares had the most impact on mode choice, and therefore ridership, in the range R3.50 to R5.50, with elasticities in excess of one;
- peak period frequency was most responsive in the range five to 15 departures per hour, with moderate elasticities; and
- walking time had the most impact in the range zero to 20 minutes, with elasticities ranging between -0.10 and -0.21.

These findings provide a useful indication of where the focus for policy changes should be placed, for the market segment in question. Special caution should be exercised when designing policies involving public transport fares for the low-income market.

Sensitivity tests of the resource model revealed the facts listed below.

- A change in fares resulted in the highest impact on public transport income and cost with elasticities in excess of one.
- Frequency changes had a moderate impact, with elasticities between 0.44 and 0.98.
- An increase in hours of service had a minimal impact on all services, and the measure can, therefore, be implemented at a rather low cost.
- The model was found to be extremely responsive to a reduction in train crowding, with a 10% reduction resulting in a 12% increase in cost.

5. UNCERTAINTY AND SHORTCOMINGS ASSOCIATED WITH MODEL

The results of any quantitative analysis depend on the quality and credibility of the data source. Moreover, any forecasting procedure is subjected to assumptions and determination of key uncertainties to reduce uncertainty and shortcomings associated with the outcome. Monte-Carlo simulation techniques were employed to quantify uncertainty associated with the model. This allows the specification of probability distributions for uncertain input variables, and defies the need to reduce output variables to single values, but rather to confidence intervals within which output variables are likely to fall. Overall, the most sensitive input variables in the resource model were found to be travel distance, variable operating cost, percentage off-peak passengers, other travel-related cost and fare cost. Figure 2 shows the influence of input variables on the output for minibus-taxi services. The percentage change per influence factor indicates the sensitivity (% change) of the output variable as a result of changes to the input variable (influence factor).

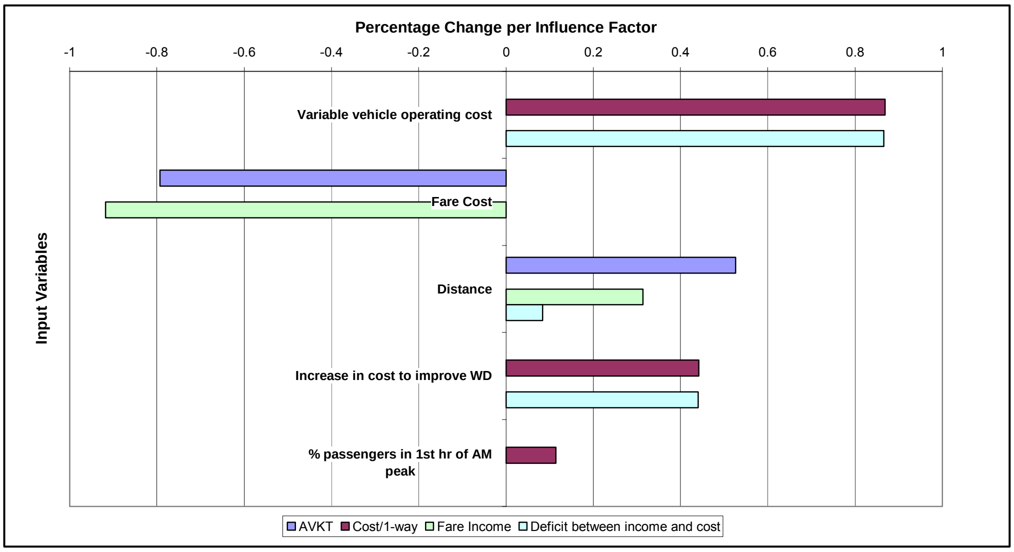

Figure 2. Influence of Input Variables on Output for Minibus-Taxi Services.

Figure 2 accentuates the strong influence of variables such as vehicle operating cost in the model, together with the fare cost of the service. The main shortcomings of the demand model relate to the fact that the current model results are limited to captive, disadvantaged communities travelling for the purpose of work (commuter trips), and the inability of the model to predict demand changes due to improvements of attributes not included in the model, which could subsequently result in the underestimation of possible shifts in demand. The significant influence of fare cost is also not reflected in the results, since the proposed minimum expenditure on public transport was within the target for the pilot area.

There is also a marginal uncertainty associated with the base resource model, due to the aggregation of travel distances, the application of generic cost-related input variables, assumptions made in terms of densification patterns of demand, and the application of generic peaking profiles during AM & off-peak periods. However, these should not affect the theoretical integrity of the model, as only relative changes are of importance.

6. ANALYSIS AND RESULTS

The main output indicators include *cost/one-way trip,* which is calculated by dividing total annual cost by the number of passenger trips per annum, as well as *subsidy* levels required, calculated as the total annual cost minus the total annual fare income. The predicted impact of changes to levels of service is given in **Table 3**.

Table 3. Predicted Impact of Changes to Public Transport Levels of Service.

MODE	Policy Tested	Impact on Cost / One-way	Impact on Subsidy Levels	Impact on Modal Split (1)
BUS	**Base Model Values**	**R 5.17**	**R 14.7 m**	**27.02%**
	Minimum Levels of Service	+ 80%	+ 230%	+ 1.3%
	Target Levels of Service	+ 260%	+ 940%	+ 27.3%
TRAIN	**Base Model Values**	**R 1.25**	**- R 11.6 m**	**29.54%**
	Minimum Levels of Service	+ 430%	+ 680%	+ 6.37%
	Target Levels of Service	+ 930%	+ 1150%	+ 6.37%
MINIBUS-TAXI	**Base Model values**	**R 6.17**	**R25.2 m**	**43.44%**
	Minimum Levels of Service	+ 20%	+ 110%	-
	Target Levels of Service	+ 180%	+ 950%	+ 4.53%

(1): Modal split changes are expressed as a percentage change relative to the base modal split values.

The implementation of the proposed minimum LOS will require increased subsidies in the order of approximately three times the current levels for bus services, eight times for train services and double the current subsidy levels for taxi services. The implementation of target LOS will require increases in subsidies in the order of between 10 and 12 times the current subsidies.

The impact on modal split (demand) is minimal, although the improvement of bus operations to the proposed target LOS is expected to have the most significant impact. The increase in demand for the implementation of target bus LOS is estimated at +27.3%, relative to the base case modal split, which will result in 7.4% additional passengers.

The most cost-effective measure across all modes is the introduction of a minimum level of security, equal to one security guard per 1 000 peak hour passengers. The introduction of acceptable levels of frequency during the AM peak period has proved to be most expensive in the case of bus and train services, while the improvement of walking distances are most expensive in the case of minibus-taxi services.

7. CONCLUSIONS

Based on the findings of the research, the following conclusions can be made:

- The approach of integrating demand / resource (supply) modeling techniques is suitable for analysing public transport operational performance.
- Minimum levels of service for bus and minibus-taxi services are achievable in light of their impact on cost and subsidy levels.
- The improvement of public transport levels of service to the set target may be unaffordable, due to tremendous increases in cost and subsidy levels. However, the improvement of public transport operations may be viable if the alternative is to build more roads for cars, encouraging congestion that would ultimately impact negatively on the economy and the environment.

- The cost implications of improved levels of service can be offset against an increase in fares. The model can, therefore, be used to obtain the maximum possible increase in fares, before the loss in ridership becomes significant.
- In applying discrete choice modelling techniques, more accurate data on alternatives in the choice set ought to be found, either by tailored stated preference surveys, or by synthesis of the data on a discrete level.
- The sensitivity associated with the input variables of the model can be reduced by obtaining area-specific data for operations in the geographical areas in which the model is to be deployed.
- The results are relevant to the low-income market segment with high public transport utilisation. Additional research should also be done for the low-income market with low public transport utilisation, as there is an obvious need for the improvement of the service.
- The list of KPIs and corresponding minimum and target LOS presented in this research should be debated among the relevant stakeholders.

8. REFERENCES

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