The Impact of Passenger Overloading on Mode Choice of Public Transport

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Abstract: Passenger overloading in public transport is one of the most serious drawbacks stated by the travelling public in Sri Lanka. Lack of sufficient seating capacity on a given route, the resultant increase in waiting time, and the level of discomfort experienced by the passengers compel them to seek alternative modes of travel. Where there are no supply constraints in the passenger market, typical parameters of choice are centred around travel time and fare. This paper demonstrates the fact that, where there are constraints in the supply, the degree of overloading becomes the most important parameter that determines the choice of mode of transport. This behavioural feature of choice of mode is found not only in Sri Lanka, but also in other developing countries with similar constraints in supply parameters.

This paper is an attempt to determine, in mathematical terms, the impact of passenger overloading on the mode of choice in bus and rail travel. It is based on a case study carried out in a busy public transport corridor in the Colombo Metropolitan Region. The paper describes the calibration and validation of a logit model. The analysis of model structure and calibrated parameters reveals an optimum point beyond which any increase in passenger overloading results in overall passenger reduction, unless alternative modes of travel too are similarly overcrowded.

Keywords: Overloading of Public Transport, Choice Modelling, Transport in Colombo

1. Introduction

Public transport service providers maximize their daily income by changing the characteristics of their supply by increasing travel times and by overloading. This is a common occurrence when there are no timetables and overloading is not enforced. This paper examines at the impact of overloading on the overall mode choice of transport.

1.1 The Study Area

The area to the south of the City of Colombo stretching up to Aluthgama a distance of 60 kms is one of the most economically active areas in Sri Lanka. It contains the core central business district in the city, as well as the residential areas and continues further to the outer fringe of the commuter catchment for Colombo. This area is 248 hectares in extent and has a population of 1.66 million [1]. The area comprises two administrative districts - Colombo and Kalutara. These districts are further divided into six local administrative areas called Divisional Secretariat Divisions or “travel zones” within the transport corridor. The six transport zones are identified as Colombo, Dehiwala, Ratmalana, Moratuwa, Panadura, Kalutara and Beruwala, all of which are highly urbanized.

The Colombo - Galle, road is a trunk road (Class-A road) which runs through the transport corridor. Many feeder roads (Class-B roads) are connected to this trunk road at several points. Each feeder road carries a large number of passengers from the adjacent traffic zones to this trunk road. A double line rail track also runs parallel to this trunk road along the coast. The distance between the trunk road and rail track is approximately 250 metres, but in urban centres they are located much closer to each other.

Each travel zone is so defined that it has a central bus stand that connects several intra-zonal bus routes. These routes are laid out so that they operate through the industrial zones located in these areas, to facilitate better accessibility to places of work, from residential areas.
Many business establishments, government institutions, universities, residential areas and an airport, are located within this transport corridor. This means a considerable amount of economic activity takes place within this transport corridor as compared to other parts of the Colombo Metropolitan Region.

1.2 Trends in Public Transport
The annual growth rate of population between the years 1981 and 2001 was estimated at 1.3 per cent for the Colombo district and 1.2 per cent for the Kalutara district [1]. Thus, the rapid growth of population in the Colombo and Kalutara districts calls for an efficient and high quality public transport system capable of carrying a high volume of passengers through congested urban and semi-urban centres. Presently, there are 250,000 passengers travelling in this corridor daily [2]. Moreover, due to economic reasons, the urban population is far more dependent on public transport than those in the semi-urban areas [3]. The lack of effective planning and control of land use in this area has resulted in sprawling development, expanding rapidly in all urbanized zones. As a result less space is available for transport infrastructure development. Therefore, in the construction of new roads and highways, lands of high value have to be acquired, resulting in the delay of many road development projects in this area. In fact, the rising demand for all forms of transport including for bus and rail transport has far exceeded the existing transport infrastructure capacity in the corridor.

2. Objectives
The aim of this paper is (a) to present a bus and rail choice model that would be sensitive to the overcrowding measured in terms of the loading factor, and (b) to find out the impact of such passenger demand for overloading on inter-zonal bus travel.

3. Methodology
To achieve these objectives, the steps followed were: (a) calibration and validation of a bus and rail choice model to capture passengers’ travel behaviour on mode choice and (b) application of the choice model to find out a feasible passenger loading level for the bus routes in the transport corridor.

4. Choice Model Calibration and Validation
The modelling was based on individual behaviour pertaining to mode choice based on the utility maximization theory [4]. In this context, a functional form for the model was developed with a set of independent variables that were considered to affect the utility function pertaining to the dependent variable being the choice parameter of mode choice [3]. Thereafter, the model was calibrated using the data collected for the transport corridor under study.

4.1 Data Formulation
The bus passenger demand for the transport corridor was estimated using 30 zonal pairs (6x5) Origin-Destination (O-D) matrix developed from partial travel data that was collected such as, passenger boarding counts, loading and alighting counts[2]. This data was collected at strategically selected locations in the transport corridor, where it was found that there were 15 bus routes connecting the six transport zones. Each zone comprised several bus halting places which were located along the corridor. These were located at approximately equal distances providing access to/from residential, business and institutional premises. Therefore, the corridor demonstrates a regular pattern of passenger boarding and alighting. The corridor carried a total of 3950 bus trips a day in both directions.

The occupancy rate of bus passengers was somewhat difficult to calculate due to the large number of standing passengers and the difference in size of buses. In this context, an estimation procedure was used to estimate the passenger occupancy in buses [2]. According to this method, the estimations are made in such a way that the bus size and the level of loading are observed as against the passengers’ occupancy table, which was pre-calibrated for the various sizes of buses. The bus sizes were categorized seat-wise: i.e.; less than 20 seats, 20-29 seats, 30-39 seats, and buses with over 40 seats. On the study corridor it was observed that over 90 per cent of the buses had a seating capacity of more than 40.

The railway passenger demand was estimated using a rail O-D matrix prepared from sales of third class ordinary rail tickets compiled by the Sri Lanka Railways. The railway season ticket data were excluded from the estimations as it was assumed that rail season ticket travellers’
are captive to railways since the majority of them pay a highly subsidized price as part of a concession granted to government employees.

The formulation of the different independent variables was carried out using a number of secondary data such as bus and rail headways, on board travel times, and accessible distance to rail and bus travelling was collected from a number of different sources [3].

4.2 Model Calibration

The utility maximization principle was considered in formulating the theoretical basis for the model. Entropy assumptions in the energy theory together with the micro economic theory were also considered. It was observed that these theories have similar properties when the behaviour of the attributes follows extreme conditions [4]. The approach using micro-economic theory describes, the passenger about the choice of an attributes, all travel constraints that are transformed into direct or indirect travel expenses which are defined as utility over passengers’ preferences are facilitated by the model. As a consequence, the choice model is expressed as a probabilistic unit as in equation (1) and (2). Moreover, the passenger has preference to travel on both bus and rail, but in always, one preference of a mode is more than the other. Therefore, bus passengers’ probability of choosing bus is expressed as the ratio of bus utility to the total passengers’ utility at the time of choosing the mode.

\[
P_b^k = \frac{e^{U_b}}{e^{U_b} + e^{U_r}} \quad (1)
\]

\[
P_t^k = \left(1 - P_b^k\right) \quad (2)
\]

where, \(P_b^k\) is the probability of choosing the bus to travel from origin “a” to destination “d” by the \(k^{th}\) traveller, and \(P_t^k\) is the probability of choosing the rail to travel from the same origin “a” to the same destination “d” by the \(k^{th}\) traveller.

The passenger preferences fitted into this model which describe the utility differences are expressed in terms of (a) travel time, (b) walking time to the travel mode and (c) the loss of passenger comfort due to the loading levels and waiting time of the modes.

In developing a probability of choosing these alternatives, passengers’ mode preference must be transformed into measurable terms or a choice set [3]. There are two passenger groups in the inter-zonal travel market having the choice set of bus (\(U_b\)) and rail (\(U_r\)). These are expressed by a linear combination of variables as in equation (3) and (4).

Moreover, these equations describe, the manner in which a passengers’ rail travel utility with respect to bus travel, such as: (a) the difference between rail passengers’ accessibility time as in equation (6) and bus passengers’ accessibility time as in equation (5); (b) the difference between bus on board travel time as in equation (7) and rail on board travel time as in equation (8), and (c) the difference between rail waiting time as in equation (12) and bus waiting time as in equation (14).

The logit models of (3) and (4), the coefficients of the variables are the same but, they have been calibrated with different magnitudes to express the utility set of bus passengers as well as the rail passengers. For example, a bus passenger group has a utility set of travelling on buses and a rail passenger group has a utility set of travelling on rail. In a travel market, where there is a mix of these utility sets, the mode choice is expressed as one mode was having more probability of passenger choice than the other [3]. This concept has been made into a “Hybrid” logit model to better describe mode choice on bus and rail in equation (1) and (2).

In the model calibration process, the sensitivity to the dependent variables from three types of exogenous variables was investigated and used 25 data sets of inter-zonal travels. Multinomial Linear Regression Modelling was used to calibrate the choice models, using the SPSS™ statistical software.

The dependent variables of passengers’ choice sets are developed using a binary relationship [3] is formulated according to the fraction of railway paid ticket passengers’ demand to total passengers travel for the utility of rail passengers’, and the bus passengers’ travel demand to total passengers’ travel for the utility of bus passengers.
\[ U_b = 0.195 + 5.860 \left[ (AT^{t}_{od}) - (AT^{b}_{od}) \right] + 2.420 \left[ (TT^{b}_{od}) - (TT^{t}_{od}) \right] + 0.67 \]
\[ + 16.822 \left\{ \left( \frac{1 - LF^k_b}{LF^k_b + LF^k_i - 2} \right) \right\} \left( WT^{t}_{od} - (WT^{b}_{od}) \right) \]
\[ U_t = 0.0183 + 4.936 \left[ (AT^{t}_{od}) - (AT^{b}_{od}) \right] + 1.120 \left[ (TT^{b}_{od}) - (TT^{t}_{od}) \right] + 0.67 \]
\[ + 15.61 \left\{ \left( \frac{1 - LF^k_b}{LF^k_b + LF^k_i - 2} \right) \right\} \left( WT^{t}_{od} - (WT^{b}_{od}) \right) \]

The exogenous independent variables fitted in to these models are formulated as follows,

\( (AT)^b_{od} = \) reliable accessible time of bus perceived by the \( k^{th} \) traveller.

\( (AT^{t}_{od}) = \left\{ \left( \frac{d^{b}_o}{w_o} \right)^k + \left( \frac{d^{b}_j}{w_j} \right)^k \right\} \)

where, \( d^{b}_o \) is the access distance (walking) to bus in origin zone “o” in kms., \( d^{b}_j \) is the access distance to bus in destination zone “d” in kms.; \( w_o \) is the passenger walking speed at origin zone “o” in km/hr and \( w_j \) is the passenger walking speed to bus at destination zone “d” in km/hr. It was assumed that the average walking speed is 4 km/hr when pedestrian density is high and 5 km/hr when pedestrian density is low in the zone [5].

Similarly, \( (AT)^t_{od} \) is the access time for the rail perceived by the \( k^{th} \) traveller,

\( (AT^{t}_{od}) = \left\{ \left( \frac{d^{t}_o}{w_o} \right)^k + \left( \frac{d^{t}_j}{w_j} \right)^k \right\} \)

where, \( d^{t}_o \) is the access distance (walking) to railway station in origin zone “o” in kms., \( d^{t}_j \) is the access distance to railway station in destination zone “d” in km. The accessibility times are estimated based on the distance travelled to the bus or rail station, and the average speed of the traveller in kilometres per hour. With regard to bus and rail travel network, most buses ply on routes close to passenger residences; but, in the case of the rail, passengers travel to the nearest town centre to board the rail. Rail travellers’ journey consists partly of average walking time from the home at origin zone to the rail station, and the average walking time to the travel destination, from the rail station at the destination zone. Therefore, the access distances were found to be higher for rail passengers when compared to bus passengers.

\( (TT)^b_{od} = \) Observed reliable travel time of bus observed by \( k^{th} \) traveller.

\[ \sum_{R=1}^{n} \bar{U}^R_{ij} = \frac{\sum_{R=1}^{n} U^R_{ij}}{n} + \bar{W}^m_{ij} \]

\( \bar{U}^R_{ij} \) is the in-vehicle travel time on route \( R \) to travel from \( i^{th} \) zone and \( j^{th} \) zone as observed by the \( k^{th} \) traveller. \( n \) is the number of bus routes available between \( i^{th} \) zone and \( j^{th} \) zone. \( \bar{W}^m_{ij} \) is an additional weightage, in case there is a mode transfer between zones.

\( (TT)^t_{od} = \) Observed reliable travel time of rail observed by \( k^{th} \) traveller.

\[ = \left( \frac{\bar{U}^{MAX}_{actual} + \bar{U}^{MIN}_{actual}}{2} \right) + \bar{W}^m_{ij} \]

\( \bar{U}^{MAX}_{actual} \) is the actual in-vehicle travel time on the slow train between the zones, and \( \bar{U}^{MIN}_{actual} \) is the actual in-vehicle travel time on the express train between the same zones. This calculation assumed that an equal number of passengers travelled between \( i^{th} \) zone and \( j^{th} \) zone, on slow trains as well as on express trains.

It was found that the passenger utility of the travel time saving variable formed negative magnitudes in some inter-zonal travels, and in each run of the calibration, unexpected singularities in the Hessian matrix [3] were encountered. Thereafter, the Cox Transformation Theory [3] was used to correct those using a Cox transformation value of 0.67 hours.

The rail passengers’ loading factor as a variable of rail discomfort travel developed a significant
casual relationship to the dependent variable. Therefore, loss of travel comfort due to loading and waiting time in rail travel between origin “o” and destination “d” was studied.

\[
(LC)'_{od} = \text{Loss of comfort in rail travel between origin “o” and destination “d”},
\]

\[
(LC)'_{od} = \left\{- \frac{\partial U_{od}'}{\partial x}(W T_{od}^k)\right\}
\]

(9)

where, \(\frac{\partial U_{od}'}{\partial x}\) is the changing utility level of rail passenger due to changing the rail loading factor, when the passenger travels from origin “o” zone to destination “d” zone. The negative value indicates that the initial travel comfort of passenger diminishes when the level of loading increases with the travelling distance.

In the estimation of rail utility, it is assumed that the weightage of rail travel standees at the time of observation is defined by the ratio of the rail standees to the total standees in the travel route. In a competitive inter-zonal travel route, at a given fare and difference of waiting time to travel by each mode, the passenger choice on travel mode depends on the load factor (or supply of seating spaces) of each mode at a given fare and difference of waiting time to travel by each mode, the passenger choice on travel mode, the weightage of rail travel standees at the time of observation is defined by the ratio of the rail travel standees at the time of observation to the average supply of seating spaces of each mode at a given time period. It is assumed, buses bring \(S_1\) number of seats to the travel route and the rail brings another \(S_2\) number of seats, and the number of standees generated as \((L F_i -1)\) and \((L F_i -1)\) respectively. The total standees generated at that market is the sum of individual standees developed as a result of dispatching the number of supply seats \(S_1\) and \(S_2\) of each mode as \((L F_i + L F_i -2)\). Therefore, the utility of rail standees is given as,

\[
UL_{od}^i = \left\{\frac{(L F_b^k -1)}{(L F_b^k + L F_t^k -2)}\right\}; \quad L F_b^k, L F_t^k
\]

(10)

Where, \(L F_b^k\) is the loading factor of the bus travel and \(L F_t^k\) is the loading factor of the rail travel. It is expressed as a ratio of the passengers travelling in the mode between origin zone and destination zone, to the average supply of seating spaces of the same mode during an hourly period.

The load factor is a capacity variable of the mode [6]. In a rail travel route, the capacity variable changes with the distance travelled. This is due to the changing of the loading factor with the distance travelled. There is a co-relationship between loading factor and the distance travelled, \(x\). The variable, therefore, is formulated by partial derivation of the equation (10) with respect to \(x\), and the resultant formula obtained is as follows:

\[
\frac{\partial UL_{od}'}{\partial x} = \left\{\frac{(L F_b^k -1)}{(L F_b^k + L F_t^k -2)}\right\}
\]

(11)

where \((L F_b^k \leq 2)\) and \((L F_t^k \leq 2)\) are the boundary conditions of the model.

\(\text{(WT)}_{od}^b\) of the equation (9), is the perceived reliable waiting time in hours for the rail and is calculated using the observed average daily headway by \(k\) th traveller taking into consideration unexpected delays encountered during travelling.

\[
(WT)'_{od} = H_r^k * w_{od}^b* Dist + TT_{od}^i * w_{od}^m (12)
\]

and,

\[
H_r^k = \left\{\frac{H_{ob}^k}{H_{sh}^k} - H_{sh}^k \leq H_{sh}^k\right\}
\]

(13)

The coefficient of \(\delta\) varies, 0.5\(\delta(0.75)\) depending on the situation. \(H_{sh}^k\) is the observed headway for rail by \(k\) th traveller and \(H_{sh}^k\) is the scheduled headway to travel between origin “o” zone and destination “d” zone.

\[
w^i_{od}^ Dist = \frac{\text{Dist}_i}{\sum \text{Dist}_T} \quad (13)
\]

\(w^i_{od}^ Dist\) is the weighting factor for the waiting time, that relates to the headway \(H^i_{od}\) and is expressed as a ratio of the distance travelled by rail to total travel distance between origin zone and destination zone. \(w_{od}^m\) is the weighting factor selected based on the mode choice at transfer point by the \(k\) th traveller. The weightage varies between 0 and 1, i.e. 0 for no selection of the mode, and 1 for the selection of a high comfortable mode, such as an air-conditioned bus.

\[
(WT)'_{od}^b = \text{perceived reliable waiting time in hours of bus is calculated using the observed average daily headway by } k\text{th traveller.}
\]

\[
(WT)'_{od}^b = H_r^k * w_{od}^b * Dist + TT_{od}^i * w_{od}^m (14)
\]

\[
H_r^k = \frac{BD_{od}}{N_b^k} \quad (15)
\]
$H_{ab}^k$ is an estimated headway of bus based on the observation by $k^{th}$ traveller.

$BD_{ad}$ is the traffic day period for buses in hours, for a travel route between origin "o" zone and destination "d" zone. $N_b^k$ is the number of buses that operate during the same period.

$$w_{ad}^{b, Dist} = \frac{Dist_b}{\sum Dist_T}$$  \hspace{1cm} (16)

$w_{ad}^{b, Dist}$ is the weighting factor for the waiting time related to headway ($H_{ab}^k$) and is expressed as a ratio of the distance travelled by bus, to total travel distance between origin zone and destination zone. $TT_{ad}^{b,k}$ is the transfer time related to change, from bus to rail in hours, during the journey.

When comparing the passengers’ choice sets in models (3) and (4), the scalar values of bus passenger utilities are composed in the multinomial logit model (3), which describes 5.86 of accessibility for travelling, 2.42 of on-board travel time and 16.822 of loss of travel comfort, whereas, the model (4) of rail passenger utility, describes less magnitudes for all scalar values. This indicates that bus passenger utility of travelling in a bus is more sensitive than rail passenger utility of travelling in a rail. Because, rail passenger accessibility time is higher than the bus accessibility time, and inter-zonal bus onboard time is less than the rail onboard travel time due to unperceived high waiting times of rail travel.

4.3 Statistical Tests

The equations (3) and (4) show that, the loading factor is good fit to the passengers’ choice of travel mode. This was checked using two different statistical tests. In the first instance, the Hosmer and Limeshow test which is a goodness of fit test of the Null hypothesis that checks whether the model adequately fits the data was used. This test is appropriate when the chi-square value is small and the p-value is greater than 0.05. The model fits data well. In this model, the chi-square value is 51.484 and the p-value is 0.837.

The second method is the value of Pseudo R-square test that describes the measure of the fit of the model. In the choice models calibrated, the Mc.Fadden value is between 0.2 and 0.4 [7]. This shows an acceptable model fit confirming the extra variables in the current model, or conversely the lack of fit induced by omitting those variables. This is estimated by the likelihood function and it is found to be 0.25. Both the tests indicated the good fit of models (3) and (4).

The Cox and Snell value which is 86.9 per cent indicates the R-Square value of the model and the Nagelkerke value which is 87.0 per cent, gives the adjusted R-square value of the model, as given in the regression analysis theory [3].

4.4 Model Validation

The model was validated with a randomly chosen data sample from the sample of data collected from the corridor which were not used for model calibration [3].

<table>
<thead>
<tr>
<th>Inter Zonal Travels</th>
<th>Bus Share (%)</th>
<th>Rail Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colombo, Moratuwa</td>
<td>88.69</td>
<td>84.60</td>
</tr>
<tr>
<td>Moratuwa, Colombo</td>
<td>81.24</td>
<td>84.56</td>
</tr>
<tr>
<td>Panadura, Dehiwala</td>
<td>94.55</td>
<td>82.08</td>
</tr>
<tr>
<td>Beruwala, Panadura</td>
<td>88.37</td>
<td>79.24</td>
</tr>
<tr>
<td>Beruwala, Kaluatar</td>
<td>81.85</td>
<td>77.89</td>
</tr>
</tbody>
</table>

Obs. = Observed Share   Esti. = Estimated Share

The validation results in most cases showed that rail share varies below 20 per cent of the total travels. Bus share on the other hand, has a significantly high value, due to reliability and better accessibility for inter-zonal bus travel.

The validated bus travel has shown 10 – 13 per cent difference between the observed and the estimated values. However, in a few inter-zonal travels, there is a significant tendency of estimated share. This was due to the small data sample used for the model calibration.

5. Impact of Loading Level on Bus and Rail Choice

The choice model was applied to investigate the effect of overloading on passengers’ choice of bus travel for one of the busy bus routes in the same corridor.
The model has significant behaviour in two stages. First it is assumed that all bus passengers are seated during travel, and they feel comfortable travelling between zones. At this stage, the model choice depends on utility of saving accessibility time by boarding in a mode, and in vehicle travel time between zones. The passenger utility of degree of loading is insignificant when the modal waiting times are unchanged. As a matter of fact, the bus share steadily increases.

In the second stage, assuming that the bus loading factor increases more than the seated passengers, while rail loading factor remains unchanged, then the variable of loss of passenger comfort starts its function and thereafter, model (3) and (4) significantly behave together with the loading level and the gaps between modal waiting times. This significant model behaviour is very specific up to the loading factor of two. This is tested using a set of perceived data of bus loading levels and illustrates a profile of percentage bus share variation against the various bus loading levels as shown in the figure 1. The bus share increases steadily starting with the loading factor at 0.5 and reaches the maximum at 1.6, and tends to decrease thereafter. It indicates that up to the bus loading factor 1.6, passengers are attracted to bus loading and thereafter, they move to travelling by rail. In this scenario, the variation indicates that after the maximum of equation (11), the scalar and vector of the loss of travel comfort variable changes in the opposite direction and thereafter, the bus share declines. As a result, any overloading beyond this point changes passengers’ choice on bus, and they tend to travel on rail, although rail is not a comfortable travel mode.

Assuming that, the maximum loading level on each route is convenient for bus passengers, the study was extended to find out a feasible loading factor, which benefits both passengers as well as the operators. It was indicated that the feasible bus load factor varies for longer travels, for example, Colombo to Panadura, and Beruwala to Panadura at around 1.58. For shorter travels, for example, Dehiwala to Colombo and Kalutara to Panadura, the loading factor was more than 1.62.

In inter-zonal travels of shorter distance, the traveller experiences a lower travel discomfort than in longer inter-zonal travels. Therefore, an average feasible loading factor in each bus route in the travel corridor is estimated to be 1.62. This value can be reached when 25 standing passengers are allowed to travel in a bus. Moreover, when the passengers load is above 60 per cent of the number of seated passengers, one can conclude that the travel convenience reaches an optimum for bus passengers travelling in this transportation corridor; i.e. if the alternative mode is not similarly overloaded too. Otherwise, the seating supply should be increased to reach the set bus loading level for convenient travelling.

6. Conclusions

The important mode choice variable of load factor is successfully included in bus and rail choice model and therefore, it has a great ability to represent the traveller characteristics of inter-zonal travel. This is verified from the validated model parameters. Moreover, it describes the less important travel variables such as in-vehicle travel time, and the accessible times to the mode that are associated with the passengers’ choice.
set. The impact of bus overloading is significant when the overloading exceeds 60 per cent of the seated passengers in a bus, after which the passengers' choice changes to travel on rail. The figure 01, has illustrated passengers' behaviour on mode choice.

References


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