A BEHAVIOURAL PLANNING TOOL FOR MODELLING PUBLIC TRANSPORT SYSTEMS

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ABSTRACT

In this article, we present an integrated methodological framework for modelling travel decisions on public transport networks. The modelled decisions correspond to the selection of stops, modes, services and routes in multi-modal public transport systems. The objective of this study is to enhance and expand the traditional framework of modelling these travel decisions by analysing in detail the behaviour, perceptions and preferences of the travellers. The result of the application of the proposed methodology consists in the assignment of a trip matrix to a public transport network and hence in the flows for the different services. The methodology is applied to the public transport network of Santiago, Chile. The results present a high goodness-of-fit with relation to the observed flows in the network, capturing on a macroscopic level the travel patterns in the network.

Keywords: Public Transport, Transport Planning, Behavioural Modelling, Simulation Tools

1. INTRODUCCIÓN

Understanding how public transport users make their travel decisions and being able to predict their behaviour is essential in transportation planning. The route choice variables normally included in traditional route choice models limit to some basic service levels attributes of the alternative routes, such as travel time and fare (Ortúzar and Willumsen, 2011). However, other variables, related to both the level of service and the travellers' perceptions, influence the user's route choice process but are generally ignore in traditional modelling. The choice of stop is traditionally incorporated implicitly in the route choice, or simplistically modelled as a minimum-time decision.

Particularly in public transport networks with uncertainty on the waiting times (i.e. frequency based systems without timetables), travellers can reduce their expected total travel time by following different route choice strategies. In literature, it is usual to assume that all travellers can consider high-complexity strategies (which might require developed analytical capacities). Similarly, in literature is usually assumed that all travellers have perfect information regarding the levels-of-service of all available alternatives. As expected, these assumptions might not be true for a considerable proportion of the travellers.

The objective of this study is to enhance and expand the traditional framework of modelling these travel decisions by analysing in detail the behaviour, perceptions and preferences of the travellers. Based on the results of the study, two planning tools are developed: (i) a tactical planning tool for authorities, planners and operators, and (ii) a trip planning tool for travellers.

The reminder of the study is organized as follows. In Section 2 we present the methodological framework for analysing and modelling travel demand in public transport systems; in Section 3 we present the application of the proposed methodology to the public transport system of Santiago, Chile; and finally, in Section 4 we present the main conclusions of the study.

2. METHODOLOGICAL FRAMEWORK

This study presents an integrated methodological framework for modelling travel decisions on public transport networks. The modelled decisions correspond to the selection of stops, modes, services and routes in public transport systems. The result of the application of the proposed methodology consists in the assignment of a trip matrix to a public transport network and hence in the flows for the different services.

The general structure of the methodology is as follows, given a trip matrix of origin-destination pairs. For each origin zone, a set of attractive stops to start the trip (regardless of the public transport modes they serve) is generated. For each of these stops, a set of attractive routes to the destination zone is generated. For each stop-route alternative (i.e. a complete travel alternative within the public transport network), the choice probabilities are calculated with a stochastic model based on their attributes (Dial, 1971). Based on the choice probabilities, the trips are assigned to the network.

To model the decisions made by the travellers, we follow a sequential approach. First, we model their choice strategies through their socio-economic characteristics. Then we model the successive choice of stop and route, from the origin zone to the destination zone. Finally, based on the choice criteria, we can assign the trip matrix to the public transport network.

2.1 Modelling Travel Strategies

The proposed methodological framework considers route choice strategies, which deal with the travellers' consideration of a set of common lines when choosing how to travel: the travellers may not choose a single service, but may board the first service from a set of lines (Chriqui and Robillard, 1975; Spiess and Florian, 1989). A novelty of the proposed framework is the consideration of vehicle capacity constraints that result on additional waiting times due to denied boardings. These additional waiting times imply a reduction on offered frequency, having to distinguish between nominal frequency (i.e. dispatch/supply frequency) and effective frequency (i.e. perceived/demand frequency) due to vehicles passing at capacity through bus stops (De Cea and Fernández, 1993).

2.2 Modelling Stop Choice

In the first choice step, we model the choices of public transport stops (i.e., the access from the origin zone to the public transport system). The set of attractive stops for a given origin zone does not depend on the destination. This means that the potential alternative stops are the same for any trip originated in a zone (the accessibility of the network is independent to the travel patterns). Their level of attractiveness (and their consequent probability of being chosen), on the other hand, will depend on the particular destination.

The definition of the set of attractive stops for a given origin zone is comprised of three criteria: (i) all the stops within the zone are attractive, (ii) all the additional stops within a certain distance from the zone's centroid are attractive (such distance can vary depending on the particular public transport mode, e.g. people might be willing to walk more to a metro station than to a bus stop), and (iii) all the additional stops within a certain distance from the zone's borders are attractive. This procedure is summarized in Figure 1. Depending on the size of the zones and the sizes of the "attractive distance" (either from the centroid or the borders), many stops might be attractive for trips that begin in different zones. Both attractive distances must be calibrated.

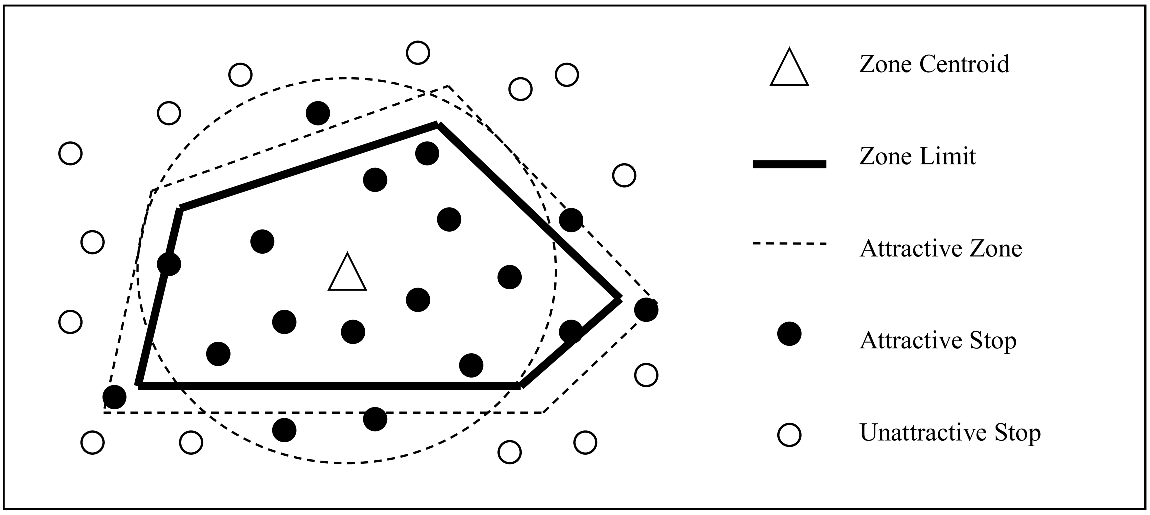

Figure 1 - Definition of Attractive Stops

Among the attributes related to the particular stops, that will determine their probability of being chosen, the proposed methodology considers; (i) walking time to the stop, (ii) waiting time at the stop (dependent on frequency, queuing and crowding), (iii) types of services (dependent on the presence of buses, metro, trams, etc.), (iv) number of services, (v) transfers, (vi) reliability of the services, (vii) safety, and (viii) socio-economic characteristics from the travellers (such as gender or age).

The remaining element that composes the attractiveness of the stop is an aggregate measure of the level of service from the stop to the destination, which depends on the characteristics of the alternative route from the stop to the destination. This aggregate measure is defined as a Log-Sum type (Train, 2009), and is calculated from the route choice modelling.

2.3 Modelling Route Choice

In the next step, we model the choices of public transport routes from the selected stop to the destination zone. On integrated systems, these routes could be composed of different modes and services. For this purpose, a set of attractive routes is constructed based on their generalized level-of-service, which is composed by attributes such as fare, different time components, reliability, transferring experience, vehicle crowding, and network topology (Raveau et al., 2011).

For every combination of origin stop and destination zone, a reasonable number of alternative routes are generated based on “similar performance”. The reasonable number of routes to be generated depends on the particular trip combination. Two route sections have “similar performance” if they satisfy these three criteria: (i) they physically overlap over a certain percentage of their length, (ii) they have comparable generalized costs (which does not excessively exceed the minimum cost alternative), and (iii) they have comparable specific attributes (i.e., frequency, travel time, fare, crowding).

To generate the alternative routes, the link penalty algorithm (De la Barra et al. 1993) is applied. The criterion to generate the routes is a generalized cost function that is calibrated through model estimation from the available survey data. Once the generalized cost function is estimated with the parameters necessary to account for all the elements characterizing the routes and hence the choice of stop, it is passed to the choice set generation technique. The set of attractive routes is also constructed taking into account the overlapping of the alternatives, in order to avoid high correlation and similarity between the obtained routes. It should be noted that the generalized cost function is consistent in the choice set generation and the assignment.

2.4 Travel Assignment

Given the generalized cost function and the generated alternative routes, it is possible to calculate the generalized cost of the routes and the attractiveness of stops. These measures allow calculating the probability of choosing a stop within the set of attractive stops, and the probability of choosing a route conditional on the choice of the stop. The probability of choosing a specific route is consequently the product of the two probabilities.

The model for the selection of the stop may be formulated as a Logit model (McFadden, 1974) considering the attractiveness of each stop as a utility. As some of the relevant attributes such as vehicle crowding and other variables related to comfort depend on the travel decisions of the individuals, the methodological framework results in a fixed-point problem. The application method is iterative until the equilibrium is found. It can be proved that the iterative process converges to a unique equilibrium.

3. APPLICATION TO A REAL NETWORK

The methodology is applied to the public transport network of Santiago, Chile (6 million inhabitants). In Santiago, over 4 million trips are made daily on the public transport modes. The public transport system (Transantiago) consists of 191 feeder (local) bus lines, 118 trunk bus lines, and 5 metro lines. To calibrate the modelling approach, a travel survey was conducted in one of Santiago's main public transport hub. The data gathered with the survey (demand information) was complemented with information regarding the levels-of-service (supply information) provided by the public transport authorities.

The network is modelled with 616 one-way bus lines and 10 one-way metro lines. These lines generate a network with 852,548 line segments (which can be grouped to generate 663,696 route segments when common lines are considered). There are 11,113 bus stops and 108 metro stations (which are modelled through 216 directional stops). The demand is composed by 663,599 trips in the morning peak period (6:30 AM to 8:30 AM) (Munizaga and Palma, 2012) and divided into 779 zones. The zoning was obtained from the Origin-Destination Survey of Santiago.

3.1 Modelling Travellers' Behaviour

The proposed behavioural model is based on Raveau et al. (2011) and considers a hierarchical structure where the travellers first choose an initial mode (between bus and metro) and then their routes to the destination. The model parameters' for the morning peak period are presented in Table 1.

Table 1 - Mode/Route Choice Model Parameters

Variable	Parameter	t-value
In-Vehicle Time	-0.0431	-6.84
Waiting Time	-0.104	-7.37
Access Walk Time	-0.222	-9.03
Egress Walk Time	-0.0783	-6.23
Transfer Walk Time	-0.0644	-4.68
Bus to Bus Transfer	-1.03	-7.69
Bus to Metro Transfer	-0.573	-5.05
Metro to Bus Transfer	-0.788	-4.00
Metro to Metro Transfer	-0.254	-3.88
Vehicle Occupancy	-1.04	-3.96
Angular Cost	-0.0804	-2.87
Access to Metro Station	1.70	9.27
Access to Off-Board Payment Bus Stop	0.324	2.30
Bus Nest Scale Parameter	3.49	5.77 (with respect to 1.0)
Metro Nest Scale Parameter	3.55	4.31 (with respect to 1.0)
Log-Likelihood	-1,424.9	
ρ^2	0.602	

To define the set of attractive stops for each zone, the maximum walking distance was calibrated based on the information of the survey. The attractive distances from the centroid are 600 metres for bus stops and 1,000 metres for metro stations; when these distances are considered for the selected zoning, the additional criterion of distance from the borders (described in Section 2.2) is not needed. Additionally, transfer links were generated between stops within 400 metres.

3.2 Tactical Planning Tool

The first outcome from the application of the proposed methodology is a tactical planning tool, aimed for public transport authorities, planners and operators. This tactical planning tool provides better models in terms of behavioural interpretation and fit, when forecasts are made. Properly understanding the decision-making process of the travellers is fundamental to obtain reliable predictions and evaluating tactical changes to the network (such as modifications to the existing lines, the construction of new lines and changes in the operation).

The resulting flows of the application from the methodology are presented in Figure 2, where the thickness of the lines represents its flow volume. The results present a high goodness-of-fit with relation to the observed flows in the network (particularly for the most important services, such as the metro lines and main bus corridors), capturing on a macroscopic level the travel patterns in the network.

Figure 2 - Assignment Flows for Santiago

To illustrate the goodness-of-fit of the assignment, Figure 3 presents the load profiles of metro Line 1 (the most loaded line in the public transport network). The correlation between observed and modelled loads is 98% in the eastbound and 99% in the west bound. Satisfactory results are also obtained in the other metro lines. Given that the metro network is the structural backbone of the system, a proper forecasting of its usage is basic for any tactical planning tool.

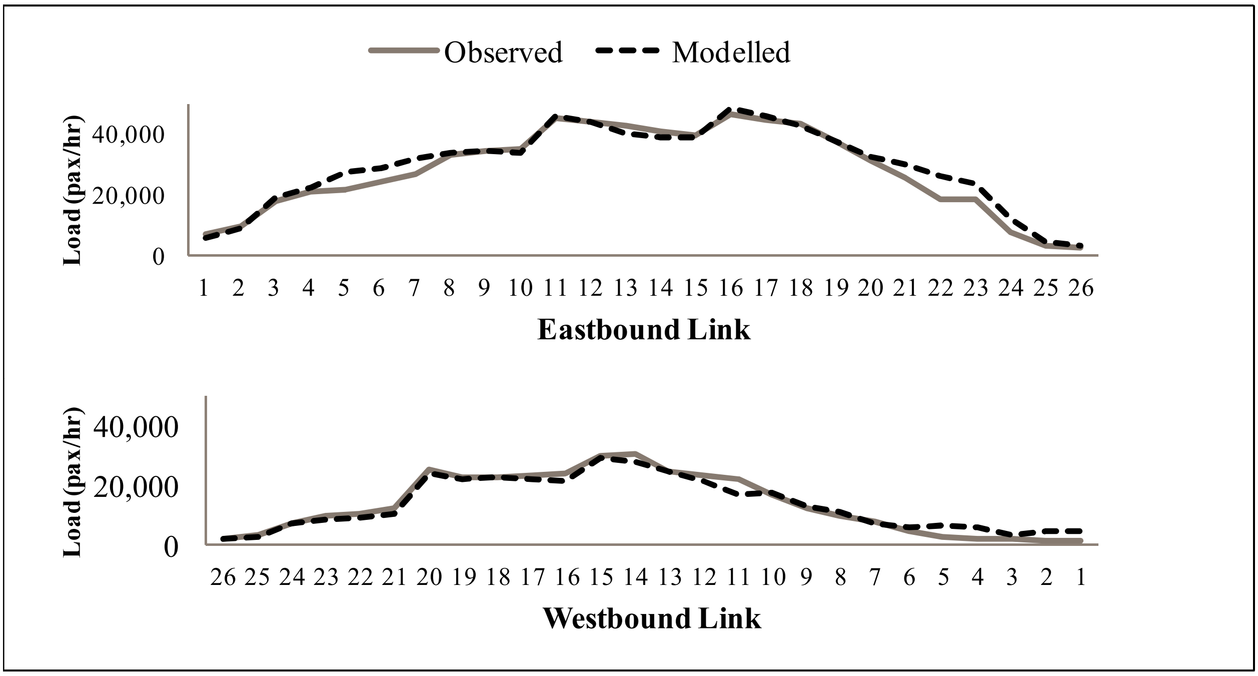

Figure 3 - Load Profiles on Metro Line 1

To analyse the goodness-of-fit of the results on the bus lines, Figure 4 presents the load profiles of ten lines (five trunk lines and five express buses with limited stops) serving approximately 7.5 Kilometres of segregated bus corridor Santa Rosa, in the south of Santiago. The observed and modelled load profiles are compared. The aggregate flows of the ten lines are shown on panel (a), while the specific flows of each line are shown on panels (b) through (f).

Figure 4 shows that the model successfully recovers the aggregated flows in the corridor (with a correlation of 98% between observed and modelled data). This way, on a macroscopic level, the tactical planning tool is capable of reproducing the decisions of the travellers. The flow predictions for each of the individual lines have a slightly lower fit to the observed data (which is expectable), with correlations between the observed and modelled data varying between 76% (line 206) and 99% (line 209). The tactical planning tool also reproduces the general travel patterns. Interestingly, there is a tendency to underestimate the flows on the trunk lines, and overestimate the flows on the express lines.

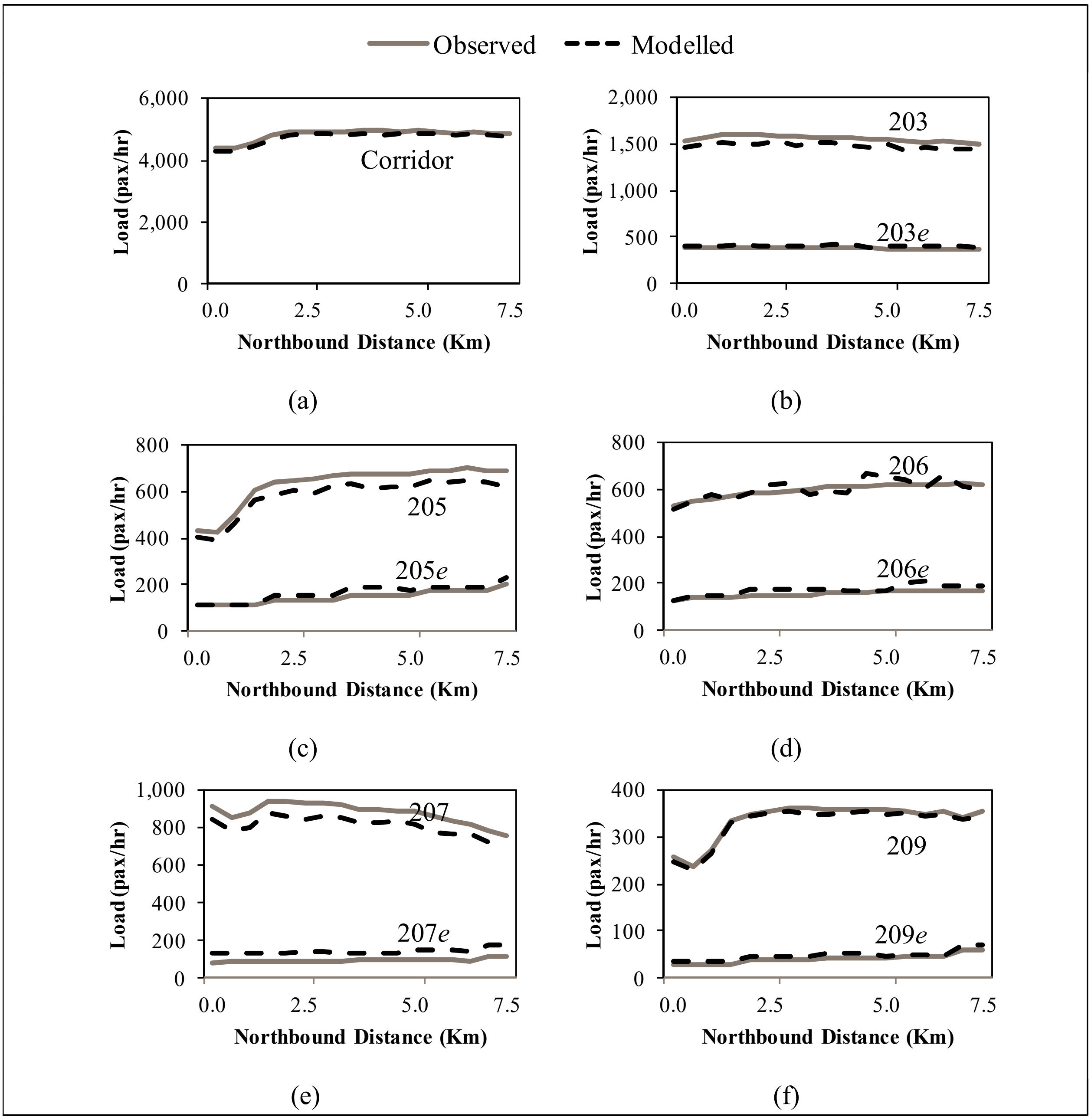

Figure 4 - Load Profiles on Santa Rosa Corridor

To assess the tactical planning tool's forecasting capability in terms of stop choice, we analyse the decisions observed and predicted in Plaza de Maipú, one of Santiago's main public transport hubs. In Plaza de Maipú there are two trunk lines stops, two express lines stops, and a metro station. Table 2 shows the observed and modelled choice percentages for each of the five stop alternatives. It can be seen that the general choice patterns are well predicted, with a mean absolute error of 4.2%. The metro is overestimated, while the express lines are underestimated.

Table 2 - Stop Choice Probabilities on Plaza de Maipú

Stop	Observed Probability	Modelled Probability
Metro Station	36.0 %	40.6 %
Trunk Lines Stop #1	12.4 %	10.7 %
Trunk Lines Stop #2	13.3 %	19.2 %
Express Line Stop #1	20.4 %	14.1 %
Express Line Stop #2	17.8 %	15.4 %
Plaza de Maipú	100.0 %	100.0 %

Finally, in terms of execution times, the tactical planning tool reached a convergence of 2% in five hours, after computing ten assignment iterations. The convergence is measured in terms of weighted flow difference in successive iterations. For a big network as the Santiago public transport system, the convergence tends to be flat and slowly decreasing. In this case, 20% convergence is reached in two iterations and 5% convergence is reached in five iterations. Additional iterations (over the ten iterations considered) have little impact on the convergence.

4. . CONCLUSIONS

Understanding public transport users' preferences and decision-making process is an essential step in transportation planning, in order to correctly predict their travel decisions and the resulting flows on the public transport network. The objective of the proposed modelling framework is to enhance the traditional behavioural considerations. The results present a satisfactory goodness-of-fit in terms of macroscopic predicted flows, when compared with the actual decisions of the travellers.

The proposed methodology for modelling travel decisions on public transport networks is applied to develop a tactical planning tool, oriented for authorities, planners and operators. This way, the potential advantages of the proposed methodology can be extended to make actual improvements and contributions on a given public transport system, instead of simply being a theoretical contribution.

It is important to take into account that the application of the proposed methodology to the tactical planning tool is designed to be in constant improvements. The modelling approach is susceptible to be adjusted, either in terms of specification (e.g. changing the models' formulation) or composition (e.g. changing the intervening variables or their parameters). The models are yet to be calibrated for a non-peak period, and there is a necessity to compare the proposed methodology's performance with other planning tools available.

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