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World City Mode Choice: Choice of Rail Public Transportation

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The choice of technology to transport passengers in large metropolitan areas is an important issue everywhere. There are many factors involved in this choice. This paper deals with the possibility of the objective use of available information in the analysis of the suitability of a rail public transport system for a city. A database has been made from publications on public city transportation and country level information. Logit models of choice have been calibrated by the maximum likelihood and nonlinear least square methods based on the acquired information. Each city is treated as an "individual", choosing rail or non-rail modes for its trips. Only cities with a population of more than one million have been included in the analysis to ensure the instigation of mode diversification in these cities. Selected models have been validated and then used to suggest the desirability of a rail public transport mode in some sample cities, according to world practice.

INTRODUCTION

The choice of technology for the movement of passengers in large metropolitan areas, particularly in developing countries, poses some difficult questions for transportation authorities in many of these population centers. On the one hand, increasing demand for transportation, deteriorating urban environments and tension caused by traffic and congestion and, on the other hand, deteriorating transportation systems and the lack of resources to upgrade these systems may make one conclude that high investment options are the only solution to ever-rising transportation problems. This makes the issue a financial one for those responsible.

Questions facing authorities may include:

- Does the city need a high-cost transportation system, such as rail transportation?
- What proportion of rail/non-rail mass transportation is appropriate for the city?
- What spectrum of public transportation systems (various types of buses and light and heavy rail transit) is suitable for the city?
- What are the appropriate market shares for the modes in this spectrum?

These are very difficult questions to answer for a multitude of reasons. One is the perceived need for high-cost alternatives (e.g., rail transport systems) stemming from a rapid increase in transportation demand and amplified by a deteriorating environment, including air pollution, largely caused by the use of fossil fuels and out-dated motor vehicles. High-cost transportation alternatives, believed to have a high capacity and which enjoy clean technologies, seem appropriate to solve the above-mentioned problems.

Another reason is the inherent complexity of problems stemming from many other sources, as follows. One is the existence of multiple objectives linked with the interests of diverse groups, which makes the problem controversial and political in nature. Another is that effective mass transportation technologies are very expensive and the resources available to these large cities are very limited. Government subsidies may already account for a substantial portion of the public transport budget, so that local and central governments are no longer potentially and/or politically able to un-

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dergo further major expenses in this regard. Moreover, sources of non-government, or tax or toll-based funds in many third world countries are very limited for different reasons. Existing tax laws may be out-dated or ill-defined (an example is where taxes are collected from producers rather than consumers) and the legislative mechanisms in these countries may be plagued with political and administrative complexities.

For most developing countries, new transportation technologies are imported from industrialized countries. Authorities in developing countries encounter the added difficulty of financing the new systems with foreign currencies, a precious resource to many of them.

Finally, a shortage of information and data, tools for analysis and experts are other complex aspects to the problem of choosing an appropriate technology for effective mass transportation in large metropolitan cities in many developing countries. These difficulties make the decision-makers choose subjectively when an opportunity to invest in a new transportation system appears. As a result, such decisions are apt to involve errors.

There is numerous literature regarding public transportation analysis and planning; [1-3] are examples of texts covering various aspects of public transportation planning and technology, which also present many related references. Banister and Pickup [4] present another bibliography in this area. The conference proceedings published by the Institution of Civil Engineers [5,6] present many research papers on the issue of rail public transportation. Some authors (e.g. [7]) try to sketch the situation where a rail transit system becomes successful. Recently, Parajuli and Wirasinghe [8] presented a decision analytic model for the selection of mass transit technology in a transit corridor with a known right-of-way category and rules of operation. They, basically, attempt to analyze (various aspects of) the problem of public transport technology choice. However, because of the complexities mentioned above (as well as others not mentioned), it is unfortunate that it is not an easy task to find out when a rail public transport system does suit a city.

One way to help the decision-making bodies of large cities in their choice of alternative transportation technologies is to inform them of the decisions of others in similar situations. Many large cities have made these choices in the past century as their systems deteriorated, became obsolete and demand changed spatially and temporally. They now possess a wide range of systems to serve their needs. One can consider a city (including its citizens, interest groups and various governmental and decision-making bodies) to be an "individual" who chooses modes to make trips. The decisions of these individuals can be used to build a model of mode choice, which describes the choice of modes (technologies) as a function of the characteristics of the cities (individuals), attributes of the technologies (modes) and peculiarities of the countries (environment) to which they belong. In effect, such a model is a condensed "expert" system.

The main purpose of this paper is to propose a means to aid the decision maker in adopting rail transit. Furthermore, it can be used by rail transit system providers to demonstrate the potential of cities that can benefit from such systems. To this end, this study employs Jane's Urban Transport Systems [9] as the source of transportation data for the cities and the United Nations Report on Human Development [10] as the source of socio-economic characteristics of the respective countries, to create a database for the choice of technologies (mode of transportation) by the representatives (of the citizens) of large cities in the world. The information collected will form a base for an objective analysis of the choice problem and will be used to calibrate a mode choice model to show whether or not the common practice of world cities would candidate a city with given characteristics for a rail transportation system. Some models will be presented, calibrated, validated and used to suggest the choice of non-rail or rail + non-rail options to serve a city's transportation needs. The data base used in this study may suggest the type of information that is essential for some choice analyses and, hence, may be used as a guide for various organized efforts in data collection in this area.

DATABASE CHARACTERISTICS

General Database

There are some organizations that collect and periodically report data on various aspects of the modes of transportation available in large cities around the world (e.g. [9,11]). The collected information, however, varies among references and includes the overall characteristics of the city (population, area, etc.), various public transportation modes, a basic description of these modes (annual vehicle-kilometers, etc.), fare structure of the modes, working hours, sources of funds and a detailed description of vehicles (number of seats, passenger capacity, etc.).

One difficulty in using these data is that not all of the items are clearly defined, nor are the questions always accurately answered by the transportation authorities of the participating cities. It should also be added that there are considerable data missing from the above compilations. Another difficulty is that data from various sources may not be put together to enhance the quality of data (cross checks, filling in missing information, etc.), or widen the range of information

Table 1. Content of database for an analysis of public transportation technology needs.

Information Category	Main	Bus, Trolley Bus, Other Non-Rail	Tramway, LRT, Metro	Minibus, Taxi
Identity	Row no. Country name City name	Row no.	Row no.	Row no.
City characteristics	City population (mil.) Greater city pop (mil)			
Country characteristics	Real GDP/capita[1] Adjusted GDP/capita[1] GDP index[1] Human dev. index[1] Degree of industrialization[2] Political system[3]			
Public transportation trips (millions/year)	All modes, 1987 All modes, 1988 All modes, 1989	1987 figure 1988 figure 1989 figure	1987 figure 1988 figure 1989 figure	Yearly fig.
Vehicle-kilometers (millions/year)		1987 figure 1988 figure 1989 figure	1987 figure 1988 figure 1989 figure	Yearly fig.
Network characteristics			No. of lines Total route length No. of stops	No. of routes Total route length
Vehicle characteristics				No. of vehicles Vehicle capacity
Service characteristics			Headway, pk. Headway, off pk. lst train time Last train time	
Fare structure			Flat Regional Distance-based	
Operating cost Financial sources	Subsidies Commercial Fare		Subsidies Commercial Fare Others	

1. See [10] for definition; 2. Industrialized equals 1, otherwise 0; 3. Formerly socialist equals 1, otherwise 0.

(across attributes or subjects), because they differ in the definition of terms or belong to different years. Also, some relevant information for objective analyses of such data has not been collected. The aim of the collecting organizations seems to be to give an overall picture of the transportation infrastructure of the large cities of the world for qualitative and comparative analyses of their transportation systems or for a study of the transport technologies themselves.

Employing Jane's Urban Transport Systems [9] as the source of transportation data, only large urban areas with a population of 1 million and over are considered to ensure the diversity of modes within a city and the need for various modes. Table 1 shows the type of information included in the database for each mode.

To reduce the number of missing values for the subject cities, data spanning the years 1987 to 1989 have been considered. The data show very little change in these consecutive years, thus, they can correct themselves and their average values can be a good estimate of the respective yearly figures. For the few cities with missing values in these three years, the available values in the nearest year have been considered. One hundred and seventy four cities were selected for the construction of this data set.

The socio-economic characteristics of the countries of the selected cities, from the United Nations Report on Human Development for 1992 [10], belongs to a year close to our 1987-89 statistics for trips. Other reports in this series were consulted for the cases which lacked information. The data were added to the "main" table, which was augmented by two other items of information: "degree of industrialization" and "political system". The items in the database are shown in Table 2.

Rail/Non-Rail Database

To address what share of the trips made in a large city is given to rail public transport systems by the city authorities, a database of mode choice by a city was created with the following specifications. For modes containing data for all three years from 1987-89, an average figure was computed as a representative value of that information item (e.g., yearly trips made by that mode). Cities with no values for any of the modes were discarded. Also, trips reported for several companies operating in a specific mode (e.g., bus companies) in one city were added together to form the total trips made by that mode. The case (city data) was omitted if ambiguities existed for the data. For minibuses and taxis (minibus-taxi), data were rough estimates of percentage. Where the information could be translated into yearly trips, the case was included in the data-base, otherwise it was omitted.

The trips made by the rail modes were summed together, as were those of non-rail modes. Rail and non-rail trips were then added together to build two super modes: "rail" (rail + non-rail) and "non-rail", for each city (denoted by r and n, respectively). The database thus created includes the information items shown in Table 2. This database contains 126 records for 126 cities with populations of over 1 million.

MODEL FORMULATION

As mentioned before, one may consider each city as an "individual" who is making a choice of its mode of transportation. In this concept, the transportation authorities and the users of the facilities are considered elements of one entity deciding to make some modes available to itself, as well as deciding how often to use which mode. Suppose that the then decision to

Table 2. Database for analysis of rail/non-rail choice.

Information Item in Database	**Definition**	**Equivalent Variable in Models**
Row	Subject ID number	
Popl	City population, millions of population in∼1989	P
Poph	Greater city population, millions, in∼1989	p^g
Pas-rail	Passenger trips made by rail public transport, billions/year in∼1989	T^r
Total-pas	Total passenger trips by rail and non-rail public transport, billions/yr in∼1989	T^t
Pas-popl **Pas-poph**	"Total-pas"/"pop-1"(x100) "Total-pas"/"pop-h" (x100)	tpp tpp^g
Railexist	If pas-rail > 0 (existence of rail mode) = 1, otherwise = 0	y
Rgdp	Real GDP per capita (ppp $1000) in 1992	G
Ad-gdp	Adjusted real GDP per capita ($1000)	AG
Hdi	Human development index	hdi
Pol	Formerly socialist countries = 1, otherwise = 0	pol
Indst	Industrialized countries = 1, otherwise = 0	ind

"∼": A year close to.

have a rail system is the current such decision (this is generally true and, hence, it does not seem to be basically a binding assumption). It will be assumed that the underlying rule of choice follows a logit model as follows [12]:

$$p_r = \frac{e^{u_r}}{e^{u_r} + e^{u_n}} = \frac{1}{1 + e^{-(u_r - u_n)}}, \tag{1}$$

$$p_n = 1 - p_r, \tag{2}$$

where p_r is the probability that the "individual" chooses to have both rail and non-rail modes of transportation, as opposed to p_n, where it chooses only non-rail modes. It is assumed that the modes of transportation existing in the city will be among the current choices. It is also assumed that all cities have had some form of non-rail transportation (e.g., bus) before having a rail transportation system. In this sense, p_r is equivalent to the probability of having a rail system.

It is clear from Equation 1 that p_r and, hence, p_n, are only functions of the relative utilities of the two states, $u_r - u_n$, rather than their absolute values. Moreover, it can also be concluded from Equations 1 and 2 that the ratio of the probabilities of the two states (rail/non-rail), usually referred to as relative odds [12], is:

$$\frac{p_r}{p_n} = e^{u_r - u_n}. \tag{3}$$

So that, again, it is the relative utility functions which govern the ratio. Equations 1 and 3 convey the notion that, to specify the utility functions of the states, it is sufficient to define them as follows (assuming an additive utility function):

$$u_r = \sum_{j=1}^{k-1} \alpha_j f_j(x_j), \tag{4}$$

$$u_n = \alpha_k, \tag{5}$$

where x_js are the choice descriptive variables and α_js ($j = 1, 2, \ldots, k$) are parameters of the utility functions (to be calibrated).

Model Calibration

Maximum Likelihood Estimation Method

By assuming that the decision of public transport technology in one city is independent of those in other cities, the contribution of city i to the logarithm of likelihood function, $L^*(i)$, is defined as:

$$L^*(i) = y_i \ln(p_r(i)) + (1 - y_i)\ln(1 - p_r(i)), \tag{6}$$

where y_i takes the value of 1, if city i has both rail and non-rail public transport systems and 0 otherwise. Then, the logarithm of likelihood function, L^*, would be computed as:

$$L^* = \sum_{i=1}^{N} L^*(i), \tag{7}$$

where N is the number of cases under study (here, 126). Thus, if city i has both rail and non-rail systems, then $y_i = 1$ and $1 - y_i = 0$ and the contributing portion of Equation 6 becomes $\ln(p_r(i))$. Otherwise $y_i = 0$ and Equation 6 contributes $\ln(1 - p_r(i))$, which equals $\ln(p_n(i))$.

Maximizing the objective function, Equation 7, with respect to the α_js and using an appropriate statistical optimization package, such as GAUSS [13], gives the estimated parameters of the utility functions, based on the maximum likelihood criterion. Many models with different utility functions have been calibrated and tested, among which three formulations have been chosen as the "best" models, based on the following criteria: (a) The estimated parameters are significantly different from zero, at least at the 95% confidence level; (b) The parameters have the correct signs (i.e., as expected or interpretable); and (c) The analog of R^2 (coefficient of determination) in least square estimation, ρ^2, as defined below, has the highest value among the calibrated models:

$$\rho^2 = 1 - L^*(\alpha)/L^*(0), \tag{8}$$

where $L^*(\alpha)$ and $L^*(0)$ are the (negative of) log-likelihood function at the estimated values of the parameter vector α and at $\alpha = 0$, respectively. The former carries the power of the calibrated model in representing data and the latter shows that of the no information (equally likely alternatives) case. Thus, ρ^2 shows the percent improvement in the log-likelihood value of the calibrated model, as compared with that for the no-information case (with equal probability for the two alternatives). The selected models mentioned above are given in Table 3 as models ML1 to ML3.

Nonlinear Regression Approach

Some of the superior models calibrated by the maximum likelihood method are recalibrated using the method of nonlinear regression, minimizing the sum of squared errors. The results are shown in Table 3, as models NLS1 to NLS3.

As may be seen in Table 3, rescaling the parameters [14] of models NLS1 and NLS2 with the objective of having identical constant parameters, as in those of models ML1 and ML2, respectively, yields similar parameters to those of ML1 and ML2.

Table 3. Selected models for the choice of rail/non-rail public transportation in large cities.

Model	Parameters of $u_r = \sum_{j=1}^{k-1} \alpha_j x_j$ and Their (t-stat)							$u_n = \alpha_k$	$L^*(\alpha)$[8]	ρ^2 or R^2[9]
	AG[1]	P[2]	tpp[3]	pol[4]	ind[5]	G[6]	hdi[7]	(t-stat)		
ML1	1.010 (2.3)	0.824 (4.0)	0.474 (2.3)	2.645 (1.9)	3.090 (4.0)			9.350 (4.0)	41.235	0.53
ML2	0.502 (2.1)	0.634 (3.8)	0.590 (3.8)		3.333 (4.8)			6.586 (4.4)	44.019	0.50
ML3	0.866 (1.9)	0.797 (3.9)	0.512 (2.8)	3.995 (3.2)		0.190 (3.7)		9.545 (3.8)	45.154	0.48
NLS1[10]	3.808 (3.3) 0.918	3.257 (3.5) 0.785	2.807 (3.1) 0.677	10.530 (3.1) 2.538	12.520 (3.2) 4.018			38.792 (3.4) 9.350		0.67
NLS2[10]	1.653 (3.1) 0.539	1.750 (3.3) 0.571	1.865 (3.0) 0.609		8.330 (3.1) 2.719			20.179 (3.2) 6.586		0.58
NLS3[10]		3.354 (3.0)	0.784 (2.6)	11.247 (3.0)			54.390 (3.2)	55.617 (3.2)		0.56

1. AG: Adjusted real GDP per capita; 2. P = City population; 3. tpp = Per capita public passengers per year;

4. pol = Political system of the country; 5. ind = Industrialized status of the country; 6. G = Real GDP per capita;

7. hdi = Human development index; 8. $L^*(0) = 88.34$;

9. ρ^2 is a goodness-of-fit measure for maximum likelihood method, and R^2 for nonlinear least square method.

10. Figures in the third row are rescaled values of parameters.

Evaluation of Models

Table 3 shows that models ML1 and NLS1 possess better goodness-of-fit values than those of their respective counterparts. Table 4 shows some characteristics of the predictions of models ML1 to ML3 in Table 3. The same information for models NLS1 to NLS3 are given in Table 5. The correlation matrix in Table 4 shows that there is a strong association between the existence (or non-existence) of rail in a city (y) and the probability that the city has a rail (and non-rail) public transportation system (p_r), as predicted by a model. Higher correlations exist between the predictions of these models themselves. This is expected, since y is integer-valued (i.e., it has a value of 0 or 1) while its prediction is real-valued (between 0 and 1). Of the three models in Table 4, prediction results for model ML1 show higher correlation with y (0.7841) and indicate a lower mean for probability, p_r, when there is no rail in the city (0.217). They present a higher value for it when the city, in addition to non-rail urban transportation technology, also has a rail system (0.815). The standard deviations of p_r values for $y = 0$ and 1 in Table 4 also show more stable predictions for model ML1 relative to the other two models (ML2 and ML3).

Table 5 shows characteristics similar to model ML1 for model NLS1, compared to the others. However, model NLS1 shows stronger values for the above-mentioned statistics than model ML1; its p_r predicted correlation with y is 0.8264 (instead of 0.7841 in the case of model ML1), with a mean p_r for cases having non-rail and rail modes equal to 0.126 and 0.887 (instead of 0.217 and 0.815), respectively. On the other hand, model NLS1 shows slightly higher standard deviations for its probability, p_r, for the two cases of $y = 0$ and 1, than does model ML1. This is also true for models ML2 and NLS2, which are the same, but calibrated by different methods. Hence, Tables 4 and 5 show that models calibrated by the nonlinear regression method (NLS) predict closer to the two extreme values of 0 and 1, but with higher dispersion (standard deviation).

Figure 1 shows the probability for the choice of rail (p_r) in the cities under study for rail ($y = 1$) and non-rail ($y = 0$) modes, as predicted by models ML1 to ML3, which are calibrated by a maximum likelihood procedure. The figure indicates predicted

Table 4. Some characteristics of the predictions made by ML1 to ML3.

Information Category	Information Item	p_r			No. of Observ.
		ML1	**ML2**	**ML3**	
Correlation Matrix	y#	0.7841	0.7544	0.7553	126
	p_r, ML1	1.0000	0.9761	0.9499	
	p_r, ML1		1.0000	0.9167	
	p_r, ML1			1.0000	
p_r Statistics for Cases Where $y = 0$	Mean	0.217	0.236	0.243	58
	Std. Dev.	0.263	0.273	0.263	
	Minimum	0.001	0.007	0.008	
	Maximum	0.990	0.955	0.997	
	SEE	1.212	1.157		
p_r Statistics for Cases Where $y = 1$	Mean	0.815	0.799	0.793	68
	Std. Dev.	0.214	0.223	0.218	
	Minimum	0.076	0.102	0.069	
	Maximum	1.000	0.9999	0.931	
	SEE	0.263	0.279		

$y = 1$ (0) if rail does (not) exist in the city.

Table 5. Some characteristics of the predictions made by models NLS1 to NLS3.

Information Category	Information Item	p_r			No. of Observ.
		NLS1	**NLS2**	**NLS3**	
Correlation Matrix	y #	0.8264	0.7723	0.7605	126
	p_r, NLS1	1.0000	0.9496	0.9195	
	p_r, NLS2		1.0000	0.8851	
	p_r, NLS3			1.0000	
p_r Statistics for Cases Where $y = 0$	Mean	0.126	0.155	0.190	58
	Std. Dev.	0.268	0.280	0.317	
	Minimum	0.000	0.000	0.000	
	Maximum	1.000	1.000	1.000	
	SEE	2.127	1.806		
p_r Statistics for Cases Where $y = 1$	Mean	0.887	0.839	0.862	68
	Std. Dev.	0.255	0.285	0.261	
	Minimum	0.000	0.001	0.000	
	Maximum	1.000	0.999	1.000	
	SEE	0.287	0.340		

$y = 1$ if rail exists in the city, otherwise $y = 0$.

versus observed probability values (p_r). As may be seen in this figure, for all three models, the probabilities of choosing rail are clustered in the higher values (i.e., closer to 1) for cases with existing rail transport and vice versa. Model ML1 performs better, in this sense, by predicting closer to 1.0/0.0 for cases where y = 1/0, than do the other two.

Figure 2 is similar to Figure 1, but for models NLS1 to NLS3, which are calibrated using the nonlinear regression method. This figure shows that the models predict values of p_r much closer to 1.0/0.0 for cases where $y = 1/0$, compared to models ML1 to ML3 in Figure 1. (The number of observations is the same in both figures.)

Figures 3 and 4 show the information in Figures 1 and 2, respectively, in a frequency distribution form for the superior models ML1 and NLS1. As is evident from Figures 3 and 4, the frequency distributions are polarized for model NLS1 and more widely distributed for model ML1.

DISCUSSION

The merit of the Nonlinear Least Square (NLS) calibrated models compared to those calibrated by Maximum Likelihood (ML) is the higher correlation between predictions and observations, p_r, where $y = 1$ and p_n, where $y = 0$. (This is no coincidence, since, in the NLS

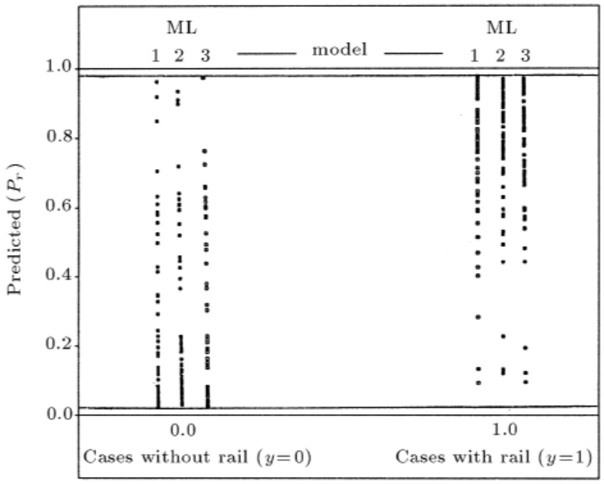

Figure 1. Predictions of models ML1 to ML3, for the choice of rail public transportation, p_r, where rail mode exists ($y = 1$) and where it does not ($y = 0$).

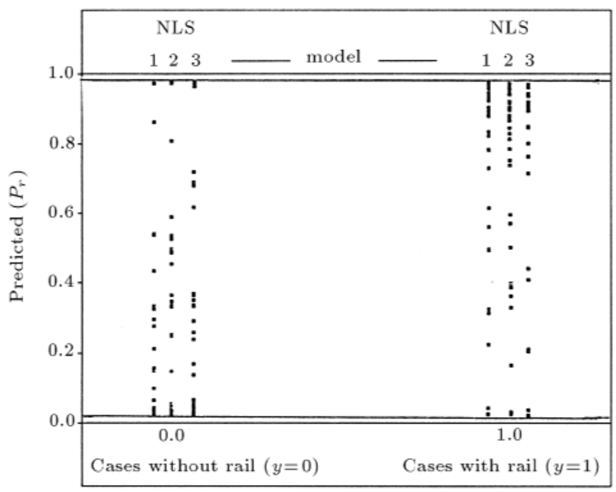

Figure 2. Predictions of models NLS1 to NLS3, for the choice of rail public transportation, p_r, where rail mode exists ($y = 1$) and where it does not ($y = 0$).

method, total "distance" between the corresponding prediction and observation (sum of squared error) is minimized.) However, maximum likelihood models have other merits that deserve attention.

First, it should be noted that the ML method might be more appealing, theoretically, than NLS. This stems from the fact that the ML method is based on maximizing the probability of the joint occurrence of some (assumed independent) events, as opposed to the NLS method, which minimizes the sum of (squared) errors.

Second, it has been pointed out that, although ML estimates of the parameters cause the models to predict p_r a little farther from 1.0/0.0 for $y = 1/0$, the predictions are more consistent and have lower dispersions (standard deviation), when compared to the parameters obtained with the NLS method. In

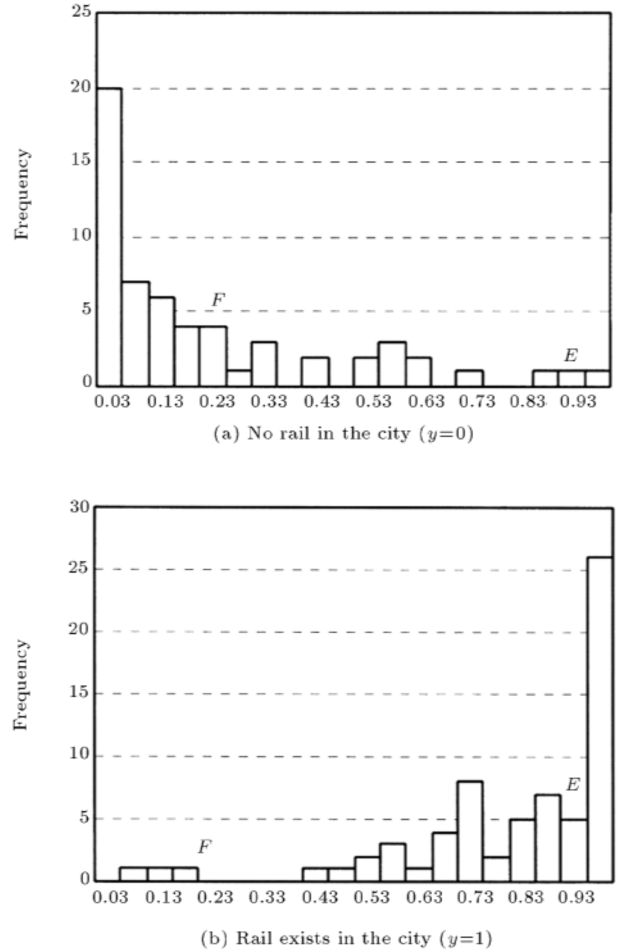

Figure 3. Frequency distribution of the probability to have rail (and non rail), p_r, as predicted by model ML1 for cities with (a) no-rail and (b) rail public transport system.

fact, the standard error (standard deviation divided by mean) of the estimates (SEE) of p_r, for cases where $y = 1$ and $y = 0$, is lower for the ML method than for the NLS method, as shown in Tables 4 and 5.

Third, it can be shown that the direct (point) choice elasticities are as follows [14]:

$$E_i(x_{ik}) = (\partial p_i/p_i)/(\partial x_{ik}/x_{ik})$$

$$= x_{ik}.(\partial v_i/\partial x_{ik}).(1 \quad p_i), \tag{9}$$

where x_{ik} is kth variable in the utility function of the ith choice and $E_i(x_{ik})$ is the direct (point) elasticity of choice of i with respect to x_{ik}. v_i is the deterministic part of the utility function of alternative i, the partial derivative of which, in Equation 9, is equal to α_{ik}, the coefficient of x_{ik}, when v_i is a linear function of x_{ik}s:

$$E_i(x_{ik}) = x_{ik}\alpha_{ik}(1 \quad p_i). \tag{10}$$

Since the parameters of the NLS models in Table 3 are three to four times larger than those of the ML models, Equation 10 shows that ML models with lower

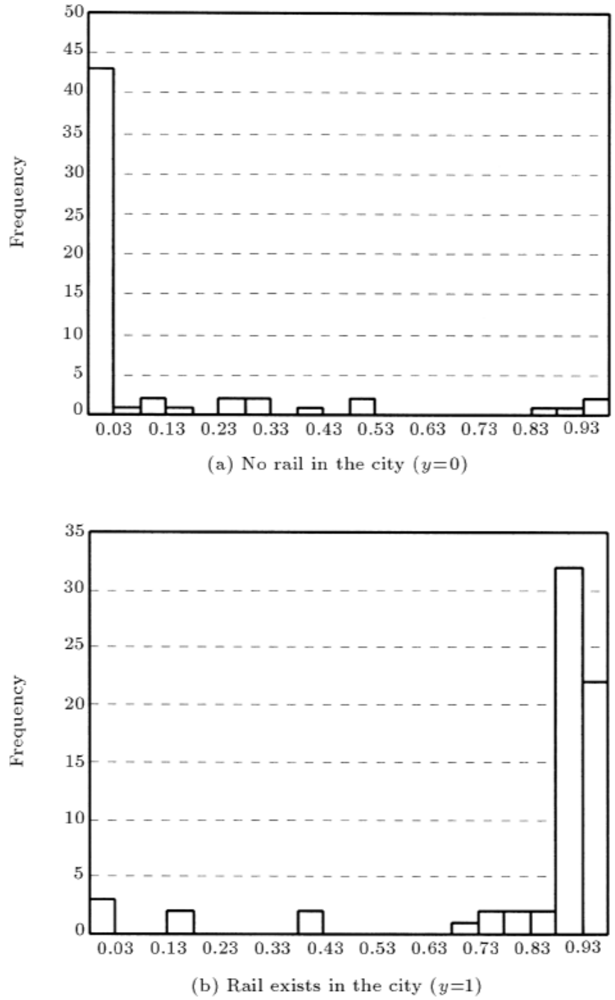

Figure 4. Frequency distribution of the probability to have rail (and non rail), p_r, as predicted by model NLS1 for cities with (a) no-rail and (b) public rail transport system.

α_{ik}'s exhibit lower choice elasticity, with respect to the variables in the utility function, compared to their NLS counterparts.

Finally, Tables 4 and 5 show that the correlation coefficients for predictions between ML models are higher than those between NLS models. This means that, for the models at hand, the ML estimates of the parameters create models that are less affected by changes in variable specifications. That is, ML models show higher stability in their predictions, so, if a variable is missing from the utility function, or vice versa, it will harm these models less.

MODEL PREDICTION

The models presented in this paper can be used to predict whether or not transportation authorities of a given city, with a population of over 1 million, will decide to add rail transportation to the existing non-rail modes, as would an "average" city. Two cities, E and F, in a country with the following characteristics, are considered. The country has an adjusted per capita GDP of \$5,155 per year (AG = 5.155) and a human development index (hdi) of 0.77, which is non-socialist (pol = 0) and is not considered to be industrialized (ind = 0) in 1992. The available set of information pertinent to cities E and F belongs to year 1994, the closest year to year 1992 and includes the following:

1. Population: 6.8 and 2.03 million, respectively;

2. Estimated total public transport trips per year: 1,830 million and 535 million, respectively (T^t = 1.83 and 0.535);

3. Total public transport trips per year per capita: 269.1 and 263.55, respectively (tpp = 2.691 and 2.6355).

Let us, now, consider model ML1 to suggest whether these two cities need public rail transportation, according to "world practice". The utilities of rail (rail + non-rail) and non-rail alternatives are $U_r^E = 12.082$ and $U_n^E = 9.350$ for city E, resulting in $p_r^E = 0.939$ for this city (Table 6). This is rather high, suggesting the need for a rail transport system according to such practices. Similar computations use $U_r^F = 8.127$ and $U_n^F = 9.350$ as the utilities of rail for city F, which result in $p_r^F = 0.227$.

Are these probabilities high enough to warrant the construction of a rail transportation system? To answer this question, Acceptance (A) and Rejection (R) Criteria (C) must be defined:

1. AC = The construction of a rail transport system is warranted, according to "world practice", if $p_r \geq p^u$;

2. RC = The construction of a rail transport system is not warranted, according to "world practice", if $p_r \leq p^l$;

where p^u and p^l are two pre-specified thresholds, with $p^l \leq p^u$. A simple case would be where $p^l = p^u = 0.5$. If the value of p_r for a city i, p_r^i, is less than 0.5 (or greater than or equal to 0.5) one would reject (or accept) the construction of a rail system for that city. A more rigorously defined value of the thresholds may be obtained as follows:

A set of cases in the data-set with rail transport systems, i.e., with $y = 1$;
R set of cases in the data-set with no rail system, i.e., with $y = 0$;
n total number of cases in the data-set;

Table 6. Model suggestion for building a rail transportation system in sample cities E and F.

City	Model	Case Description	U_r	U_n	p_r	p_n	Decision* $p^l = 0.217$ $p^u = 0.815$
F	ML1	Base case	8.127	9.350	0.227	0.773	Indecisive (∼ No)
	ML1	Population increase to 3.52 million	9.354	9.350	0.501	0.499	Indecisive
	ML1	Adj. real GDP increase to \$7000 & ind = 1	13.080	9.350	0.977	0.023	Yes
	ML1	Country become industrial: ind = 1	11.217	9.350	0.866	0.134	Yes
	ML1	City in a socialist country: pol = 1	10.772	9.350	0.806	0.194	Indecisive (∼Yes)
	ML2	Base case	5.428	6.586	0.239	0.761	Indecisive (∼No)
	ML3	Base case	5.458	9.545	0.252	0.748	Indecisive (∼No)
	NLS1	Base case	33.640	38.792	0.006	0.994	No
	NLS2	Base case	16.986	20.179	0.039	0.961	No
	NLS3	Base case	50.754	55.617	0.008	0.992	No
E	ML1	Base case	12.082	9.350	0.939	0.061	Yes
	ML2	Base case	8.485	6.586	0.870	0.130	Yes
	ML3	Base case	12.287	9.545	0.940	0.061	Yes
	NLS1	Base case	49.179	38.792	0.99997	0.00003	Yes
	NLS2	Base case	25.436	20.179	0.9948	0.0052	Yes
	NLS3	Base case	66.796	55.617	0.999986	0.000014	Yes

* Yes = Build; No = Do not build,
∼ Yes = Almost Yes, ∼ No = Almost No,
Indecisive = Further investigations are needed to reach a conclusion.

$$n_A = |A|;$$

$$n_R = |R|;$$

$$p^u = f(p_r^i, i \in A); \tag{11}$$

$$p^l = g(p_r^i, i \in R); \tag{12}$$

where:

$$n_A + n_R = n, \tag{13}$$

and where $f(.)$ and $g(.)$ are two functions of the probabilities of choosing a rail system for some cases in the data-set, A and R, respectively, as predicted by a choice model, such as model ML1. The following average functions for $f(.)$ and $g(.)$ will be used in this paper:

$$p^u = \frac{1}{n_A} \sum_{i \in A} p_r^i, \tag{14}$$

$$p^l = \frac{1}{n_R} \sum_{i \in R} p_r^i. \tag{15}$$

It is clear that, for $p^l \leq p^u$, there may be an area of indecisiveness, where $p^l < p_r^i < p^u$, in which case, one may neither accept nor reject the need for a rail transport system for city i.

For the data set at hand, based on the predictions of model ML1, $p^l = 0.217$ and $p^u = 0.815$ and then based on the values of p_r^E and p_r^F computed above, one may say:

- $p_r^E = 0.939 > 0.815$, where construction of rail transportation is warranted for city E;
- $0.217 < p_r^F = 0.227 < 0.815$, where no conclusion may be reached on construction of a rail system in city F.

In fact, a closer look at the p_r values shows that city E has a p_r value greater than those of 56 out of 58 cities (97%), which do not have a rail public transport system (Figure 3a). Moreover, the value of p_r for city E is greater than that of 40 out of 68 cities (59%), which have some type of rail transit system (Figure 3b). The p_r value for city F is greater than that of 40 cities with no rail (69%), but greater than that of only 3 cities with rail (3%) (see Figures 3a and 3b). That is, city E is doing much better than most others that do not have rail and better than 50% of those that have rail and, hence, probably needs a rail transport system. By contrast, city F is doing better than 50% of cities with no rail, but much worse than those with a rail system. Thus, based on the information at hand, it is difficult to predict whether or not it needs a rail system according to "world practice".

Table 6 presents the suggestions made by various models for the construction of rail transport systems for cities E and F. These are identified as "base cases" in this table. As may be seen in Table 6, models ML1 to ML3 present consistent values for p_r, as do models NLS1 to NLS3, for each city. However, values for p_r, given by models NLS1 to NLS3, are substantially lower than those given by models ML1 to ML3 for city F, whereas the reverse is true for city E. That is, models NLS1 to NLS3 predict in extremes, as mentioned before, easily rejecting a rail option for city F and accepting it for city E. It seems as though the NLS method of calibration has some sort of internal mechanism that demands a decision for a given case.

SENSITIVITY ANALYSIS

It is instructive to find out under what circumstances would an indecisive situation turn into a definitive one. Likewise for other factors, what changes in some attributes of city F turn its indecisive situation into a clear positive signal for the construction of a rail system. Table 6 shows the effect of some of these changes upon the choice of technology in city F.

If city F were experiencing a high rate of population growth because of high in-migration, what level of city population would warrant construction of a rail system? Assuming a more liberal value of $p^u = 0.5$ for an AC, from Equation 1, one should have:

$$p_r = \frac{1}{1 + e^{u_n - u_r}} \geq p^u = 0.5, \tag{16}$$

or:

$$u_n - u_r \leq 0. \tag{17}$$

From model ML1 in Table 3, it can be shown that:

$$P \geq 3.52 \quad \text{million people.} \tag{18}$$

If the estimated population for 20 years from now is approximately at this level, one may suggest a rail transport system for city F now, owing to the fact that it usually takes 5-10 years to build such systems, particularly in developing countries.

If city F is in an industrialized country with an adjusted per capita GDP of around \$7000 (instead of \$5155 value), then, all else being the same, $p_r^F = 0.977$, warranting a rail system. The value of p_r^F, with the original adjusted GDP value in an industrialized country, would become 0.866, suggesting the same conclusion.

Even if city F was in a formerly socialist country, all else being the same, p_r^F takes a value equal to 0.806, barely justifying the existence of a rail system in this city, according to average practice in world cities.

CONCLUSIONS

The purpose of this paper was to propose a concept for a decision-maker facing a decision about the need for a rail public transport system for a city, information regarding the average practice of world cities. The cities of 1 million population and over in the world are envisaged as "individuals" that are selecting modes of travel.

To this end, a data set was created. This data set is neither complete in variables, nor exhaustive in cases. It is an example of how to bring together some of the already collected data by various organizations. A binary logit model is proposed to model the choice of mode (technology) for a city. Several models have been proposed and calibrated by two methods, the method of Maximum Likelihood (ML) and the Nonlinear Least Square method (NLS) and, then, validated according to various statistics.

The selected models have been used to describe the need for a rail mode for two sample cities, as well as to perform a sensitivity analysis for a non-decisive case. Based on the calibrated models, it is found that:

- The NLS model predictions are closer to the two extreme values of probability range [0,1],
- The NLS models predicted with wider dispersion (standard deviation),
- The standard error of estimates of ML models is lower, which implies more consistent predictions by these models,
- ML models with lower utility parameter values exhibit lower choice elasticity with the utility function variables, which reduces the risk of erratic predictions,
- ML models showed higher correlation coefficients for their respective predictions.

It is very important to emphasize that the models presented in this paper are intended to condense world practice in introducing rail transport systems to large cities. They should be viewed as some tools for conveying such information and are, by no means, designed to imply a final "yes" or "no" to the construction of a rail transport system in a city.

The choice of rail transportation is a multi-objective decision. It would be naïve to think otherwise. However, one may place a weight of nearly 100% on a single objective, e.g., "creating the image of a modern city" to decide to build it, or see it in defiance of personal freedom to decide against its construction. Such singularities, or other possibly irrational decisions in this regard, may be captured by the random part of the utility of the decision.

Future research directions may include enhancement of data in dimensions such as geography and the shape of the city.

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