A Probabilistic Revenue Estimation Model For Providing A Mass Rapid Transit System

K.M.Anantharamaiah
Professor, Indian Institute of Management Bangalore

Vijay Raman
Director, Chakra Infrastructure Consultants Private Limited, Bangalore

ABSTRACT: Developing countries seek public private partnerships to establish mass rapid transit systems in metropolitan cities. These founder owing to differing risk perceptions of participants and the associated increase in capital costs owing to risk premiums. The authors argue that risk analyses should be conducted with probabilistic demand estimates rather than conventional single variant sensitivity analysis. The availability of inexpensive, powerful desktop computers has made this a feasible proposition. The methodology developed by the authors in this paper is an additional module to a four-module planning model presented in earlier CODATU conferences. The probabilistic methodology is validated with data for Bangalore pertaining to 1994. This methodology could facilitate improved sharing of risks between stakeholders.

RESUMÉ: Les pays en voie de développement cherchent l'association avec les secteurs gouvernementaux et prives pour l'installation d'un système de transport rapide dans les métropoles. A cause des perceptions différentes des participants sur le coût des assurances, le projet n'aboutit pas. Les auteurs pensent que les analyses devraient être basées sur les demandes probabilistiques plutôt que de regarder les analyses conventionnelles. La disponibilité d'ordinateurs "desktop " puissants et peu coûteux ont rendu cette proposition faisable. La méthodologie développe par les auteurs dans ce papier est un module supplémentaire aux quatre-modules du concept originel présente auparavant aux conférences du CODATU. La méthodologie probabilistique est validée avec les données de Bangalore de 1994. Cette méthodologie pourrait améliorer le partage des risques entre les partenaires.

1 IMPORTANCE OF URBAN MASS TRANSIT IN DEVELOPING COUNTRIES

Urbanisation has been increasing all over the world. Whereas it has more or less stabilised in developed countries, it is increasing in the developing countries. The recent census of India in 2001 indicated that urbanisation increased from 25.7 per cent to 27.8 per cent in the decade 1991-2001. The number of urban dwellers was 285.4 million in 2001 (implying an increase of 67.7 million in the urban population in that decade). Nearly 10.5 per cent of India's population lives in 35 urban agglomerations each with a population of more than a million persons (Census of India 2001). These urban agglomerations have 107.89 million people and most of the country's vehicle population. Per capita income levels are also relatively high. Thus, these agglomerations have a high intensity of traffic demand. However, owing to the historic development of these urban habitats, road space within their boundaries is restricted and has not grown commensurately. Further, the supply of roads to meet traffic demand has been characterised by roads with inferior geometrics and poor road surface quality. This has resulted in congestion, accidents, fuel wastage and environmental deterioration. Traffic planners have understood the supply-demand mismatch and have advocated development of mass rapid transit systems (MRTS) rather than attempting to increase road space to cater for the increasing number of private vehicles. This is meaningful from a consideration of both the economic and environmental aspects as the benefits far outweigh the costs.

2 ROLE OF THE STATE AND THE PRIVATE SECTOR

Traditionally, urban transport in developing countries has been the responsibility of the state. The state and local bodies have provided the road network, traffic management schemes and the public transport system. Urban services, including transport infrastructure and services, have been treated as public goods and user charges have not, generally, covered costs. This has lead to deterioration of infrastructure and services and the inability on the part of state entities to provide adequate financial and managerial resources to refurbish and enhance urban services. In most cities of the developing world urban transit is bus based. In the context of the financial and managerial problems mentioned various alternative arrangements have been attempted by states to encourage private sector participation in urban transit, while retaining responsibility for road infrastructure. These include: -

- Handing over public bus transport to private agencies
- Management contracts to private agencies to run existing bus transit organisations
- Hiring private sector buses to work under public sector managerial control (thereby avoiding capital outlays by state entities for new buses)

However it has been realised that owing to restricted road space expansion of bus systems has limits and it is not easy to establish dedicated (not grade separated) bus corridors in the existing road networks with hub and spoke arrangements to cater for traffic. Establishing additional infrastructure for a MRTS (be it a bus way, light rail transit system (LRT) or heavy rail system) is the next higher level of transport supply provision in large urban agglomerations. This raises the quantum of financial and managerial resources well beyond what local bodies and state entities are able to provide. Hence most initiatives to establish a MRTS have considered public private partnerships, particularly bringing in commercially oriented management techniques wherein customer needs are specifically addressed to retain market shares.

3 FINANCIAL AND ECONOMIC ANALYSIS IN PUBLIC PRIVATE PARTNERSHIPS

Private sector participation necessarily involves addressing issues concerning market size and segmentation, demand variation, revenue streams, project costs, and cash flow analysis to earn an acceptable rate of return on the capital employed after covering all expenses. The financial rate of return of the project is a primary criterion. Unless the system is a total monopoly, customer service automatically becomes the most important sub-objective, as with poor service, there could be a lateral shift to private modes. On the other hand, the perspective of the state is acceptable economic returns from a project, as the main objective is the general welfare of the community. Many state owned MRTS projects are economically sound (based on criteria of avoiding pollution, saving time and fuel, avoiding accidents, etc) though they are not financially viable. In this context it should be noted that Fouracre et al. 1990 have also stated that most heavy rail urban transit systems cannot produce economic returns (in addition to being financially unviable) unless, among other factors, the city under consideration has 5 million inhabitants with annual per capita incomes exceeding US $ 1,800 at 1990 price levels).

Thus, attracting the private sector to urban mass rapid transit requires that a project be structured to make the private participation component commercially sound. This can happen if the project itself is totally financially remunerative. Alternatively, if the project is economically sound but financially unviable, then there is a case for the state to provide incentives to the private sector that would make the project financially attractive. These concessions can be in terms of land development rights, grants for system construction and operation, financial assistance in terms of low interest and subordinated debt, fiscal concessions, etc.

3.1 *Transparency in Procedures*

Owing to the nature of urban mass transit, confidence in the policies of the state is an essential prerequisite for public private partnerships. One important confidence building measure is transparency. The state needs to be open about the procedures for involving the private sector. All data on a project proposal should be in the public domain (such as feasibility studies traffic data, cost analysis) and selection of a private sector partner needs to be conducted with clear and unambiguous parameters and criteria. Transparency is also a requirement wherever there are fare implications and if public funds are involved in the partnership structure as subsidies (be they capital or recurrent ones).

3.2 *Revenue Streams*

A selected partner will need to conduct due diligence and detailed investigations, including risk analysis, to ensure that the revenue streams of the project are bankable for raising loans for the initiative. A large body of literature is available regarding risk analysis techniques. Data on interest rates, wholesale price indices, etc are available at country levels. Using these, the total fixed cost of the facility can be realistically estimated by the investor. The operating costs depend on the expected demand and the type of service that is to be provided. The total cost is likely to be a step function of the aggregate demand. The main problem in ascertaining project viability is not so much in the technology of systems or costing elements but in establishing confidence in revenue streams.

This requires detailed analysis of cost and revenue streams. Conventional revenue forecasting methods for the provision of a new MRTS usually considers fare box revenue, which is dependent on the traffic demand forecasts and is the major source of revenue. Other sources such as advertising and property development can also give subsidiary, though welcome, revenue stream enhancements. The uncertainty in traffic demand is generally addressed by sensitivity analyses of individual key variables taken one at a time. However, wherever the project revenue structure is only marginally profitable the private sector partner seeks arrangements that increase confidence in the revenue streams. Risk perceptions lead to higher premiums on debt instruments and insurance and increase capital costs. Since developing countries are only reluctantly moving away from state ownership to private public partnerships this often results in an impasse, stalling worthwhile MRTS projects. We propose an alternative method of scenario building and a probabilistic analysis for travel demand and revenue forecasting to avoid this hiatus.

3.3 *Importance of Demand Analysis*

The revenue stream is based on the expected traffic demand and fare structure. A complication is that the quantum of the MRTS fare (when compared to other transport modes) will influence the traffic demand. There are a number of factors concerning land use structure and transport system characteristics, which determine the demand. If we consider the average fare as a decision variable, the relation between the aggregate revenue and the average fare is likely to be a continuous non-linear function. In earlier papers and studies the authors have discussed various aspects of determining the travel demand as part of a multi-module MRTS planning programme encompassing the facets of traffic forecasts, system parameters and engineering costs, financial analysis and project structuring, environmental analysis and economic viability (Raman and Anantharamaiah 1996a, 1996b, 2000, and Chakra Infrastructure Consultants Private Limited. 1994,1995, 1997a, 1997b).

One can see the primary importance of getting the demand estimate correct. An overestimate of demand will result in higher system cost and unrealised revenue, which may put the project in jeopardy after construction leaving the project promoter in financial distress. An underestimate will show poor revenue streams and may make the project appear unworthy of attention. This is a business opportunity lost to the private sector and a social loss as well, as doing nothing or alternative methods of mitigating traffic problems by the state may be expensive and impose economic burdens on the community.

4 STATIC AND PROBABILISTIC ESTIMATIONS OF RISKS

The conventional method of assessing the revenue stream is to calculate the demand for various fare structures and multiply the fare with the traffic demand to get the revenue curve as a function of fare. The demand itself is estimated not by the time series method but by the established land use traffic model that is a sequence of four sub-models with appropriate feedback loops. The sub-models require inputs from a number of independent variables such as trip rates, speed distribution on the network, average trip lengths, etc., to estimate the spatial distribution of population, future employment distribution, etc. Values of variables are required for both the initial case (for calibrating the model) and future horizon years for estimating trip demand. At the end of the analysis, the output of the model will be the traffic demand estimated as passenger kilometres in the mass rapid transit system. This multiplied by the average fare is the total estimated revenue. This type of single estimate will not give sufficient confidence to the investor as one is not sure whether this is an overestimate or an underestimate. A sensitivity analysis of input variables may not be sufficient. What the investor wants to know is the type or quantum of risk that is being taken with reference to the revenue stream. In particular, in Raman and Anantharamaiah 2000 the authors mentioned that a further enhancement of their four module model would be to introduce a fifth module incorporating probabilistic methods of supplementing confidence levels in the project. Such an estimate, which tells the investor the probability of achieving the traffic demand, could enable the investor to take known risks. For example, the investor may like to know the revenue per day that has a probability of being achieved ninety per cent of the time. That is there is a ninety per cent probability that the revenue will be realised. As mentioned, if we can provide such information the risk premiums on capital costs of MRTS projects can be avoided or reduced, making these initiatives implementable.

The private participant is faced with a number of risks while considering investing in a MRTS project.

These are related to currency, country, interest rate, inflation, technology, and revenue streams. The revenue risk is quite crucial as it relates to demand not realised; and on whether the future system users have capacity to pay and are willing to pay. An analysis of willingness to pay and its importance is well understood now (Raman and Anantharamaiah 1996a). Despite this, many a project has floundered due to demand not materialising and/or not being able to collect tariffs. In such cases the state steps in to provide partial revenue risk coverage. This could be through establishing a level of demand and service provision and sharing the profit or loss when there is a deviation from this figure. Even in such cases the problem remains as to the best method of arriving at the demand norm to trigger such action. We suggest that a probabilistic demand curve can assist the state and investor here as well. For example, a 90 per cent probability (or any other such threshold) of achieving base case traffic could be an agreed level of comfort for both sides of a public private partnership.

5 THEORETICAL FRAMEWORK

The methodology proposed makes use of the high speed, inexpensive, computing capabilities of desktop machines that have recently become widespread. These allow complex calculations with feedback loops of traffic demand, distribution, modal split and traffic assignment incorporating many variables (as mentioned earlier and as detailed in Raman and Anatharamaiah 1996a, 2000) for cities with million plus populations to be undertaken in a few minutes for each scenario.

Important variables of the model, which exhibit uncertainty regarding their future values, need to be identified. These could be, for example, the growth rate in per capita trip values, the reduction in road traffic speed expected in sections of the network without the MRTS, the average trip lengths in terms of travel time, the changes in the modal split as technology and economic conditions improve, etc.

The expression for traffic demand is a function

$$d = f\,(t,a,b,c,d,\ldots) \qquad (1)$$

Where d is the traffic demand, t is the toll/fare that is a policy decision variable and a,b,c,.. are the independent variables that represent travel characteristics, and

$$r = d*t \qquad (2)$$

Where r is the total revenue of the system.

The current methodology is to make an educated prediction of the value of a,b,c,…. Subsequently, t is fixed to maximise the value of ‘r’ (keeping in mind that the relationship between t and d is not linear). We suggest that based on the variable concerned and historic data of the city, one can develop a probability distribution curve for each of the variables, a,b,c ….. These could be normal distributions, uniform distributions or distributions of any other type. A simulation will give the values of these variables based on the probability distributions, which can be used to develop alternative scenarios. If, for example, there are 6 such key variables and every variable is sampled 4 times, then the number of alternative scenarios are 4^6, or 16384 scenarios.

The value of ‘r’ for each scenario is then computed and arranged in ascending order, which would lead to a cumulative probability distribution, assuming that all scenarios had an equally likely chance of occurring. Based on this curve, the state and private sector investor can decide on the traffic demand which provides an adequate level of comfort, say achieve base case traffic forecasts not less than 90 times out of 100. Since each scenario is independent of all others, once the initial sampling is over and a quick executing programme (software) has been developed, a bank of computers can calculate the project probability distribution function fairly easily.

6 SIMULATION FOR BANGALORE

We conducted this analysis for the City of Bangalore, which is the capital of State of Karnataka in Southern India. The Bangalore urban agglomeration is the fifth largest in India, has a population of about 5.7 million (Census 2001) and is a major industrial and technology driven city. It is a major centre of both engineering and knowledge-based industries. The city has about 1.7 million vehicles and is mainly dependent on the bus system for mass transit, which carries about 2.6 million commuter trips per day (estimated at 55 to 60 per cent of all trips that are longer than 1 km). Traffic is entirely road based and suffers from severe bottlenecks and congestion. Presently the city is trying to alleviate traffic problems in the short-term through traffic management schemes including grade separators at intersections and computerising major routes with signalised intersections.

For a long-term solution to the problem, the city is trying to develop a MRTS. Authorities have been considering various proposals in the nature of a ring railway, a “skybus” system, bus ways and an elevated LRT network. Though, out of these, the LRT has reached an advanced stage of planning the problems of risk perception mentioned earlier in the paper have brought this initiative to a standstill. This system was to be implemented through a private consortium on a BOOT basis. We provide some key parameters of the LRT revenue estimation model and how it could be further improved through the probabilistic methodology suggested by us.

During the feasibility study the authors developed the project concept, the, the original model and the required system software. Descriptions of this are available in Raman and Anantharamaiah 1997a, 1997b and 2000. Some important parameters are: -

- Lowry type model for population distribution,
- Trip generation model for different trip purposes using a per capita trip generation factor, which varies from zone to zone,
- Trip distribution model using gravity model and Tanner type deterrent function using a triple constraint model
- Modal split model using trip travel times, willingness to pay and associated diversion curves for modal split; A sub-split model for the LRT using a logit model at selected fare levels
- Willingness to pay was modelled on responses to a survey of 4,000 households conducted in 1994 and structured around the (then) prevailing bus fare of 0.25 Rupee per km for a 4 km bus journey.
- Bus routes were modelled with a time factor of 1.5 to cater for bus stops and a route factor of 1.5 to cater for routes taking inter zonal paths other than the most direct one.
- Traffic assignment model using shortest time paths, inter-modal transfer penalties of 150 seconds and constraints on LRT use with a requirement of the LRT assigned journey meeting a criterion of use of a minimum of two contiguous LRT inter station links.
- Competition between private modes, the bus system and proposed LRT are modelled
- There is provision for options such as park and ride system, alternative fare structures, speed improvements in central areas of the city through traffic management systems, etc.

Using the methodology proposed in this paper we have analysed whether our original estimate at the time of the feasibility study was an underestimate or overestimate. As the objective was to test the methodology, some parameters were selected randomly and their numerical values for the base traffic forecast year of 2011 (the horizon year) varied to build alternative scenarios. These were: -

Table 1. Values of Parameters to Develop Probabilistic Scenarios for the 2011 Traffic Forecast

Parameter	Number of Variations	Values
Minimum number of LRT Links to be used	3	1,2 or 3
Multiplier for road speed in central areas	5	0.8, 0.9, 1.0, 1.1, 1.2
Multiplier for road speed in peripheral areas	3	0.8,0.9,1.0
Multiplier for per capita Work trips	5	0.8,0.9,1.0,1.1, 1.2
Multiplier for per capita Education trips	5	0.8,0.9,1.0,1.1, 1.2
Multiplier for per capita Social trips	5	0.8,0.9,1.0,1.1, 1.2

We did not vary the fare parameter and modelled all variations for an LRT fare structure of 2.2 times the bus fare. Thus, a total number of 5625 scenarios were analysed. A fast algorithm was developed and the entire analysis was carried out on a desktop computer system. The results of the analysis are presented below. To illustrate the methodology, we have normalised the values of the system outputs by computing the outputs as a ratio of the basic output from the model (for the year 2011). Table 2 provides the probability distributions.

Table 2. Normalised Probability Distributions for the Bangalore LRT 2011 Traffic Forecast

Per cent	Revenue	LRT Traffic
5	1.21	1.07
10	1.17	1.06
15	1.14	1.06
20	1.12	1.05
25	1.09	1.04
30	1.07	1.03
35	1.05	1.03
40	1.03	1.02
45	1.01	1.01
50	0.99	1.00
55	0.97	0.99
60	0.95	0.98
65	0.93	0.97
70	0.92	0.97
75	0.90	0.96
80	0.88	0.95
85	0.85	0.92
90	0.83	0.92
95	0.79	0.91
99	0.69	0.90

The table prepared from the results of this analysis indicates that if the investor wanted a 90 per cent confidence level in the traffic forecast for the year 2011 then he should multiply the base traffic forecast figures by 0.83 for revenue and 0.92 for the percentage of total traffic that would use the LRT. In other words, the original base figures were an overestimate for this level of confidence. When the rate of return from these projects hover in the region of 8 to 10 per cent, such an overestimate of demand can cause problems to investors, lending institutions and the community.

Per contra, the caveats in this demonstrative analysis are: -

- That the parameters chosen for variations of scenarios in this simulation are not comprehensive. One ought to evolve more scenarios than what we have illustrated. One should, for example, vary the crucial factor of the LRT fare (compared to the prevailing bus fare for a 4 km journey)

- We have considered uniform probability distributions for all parameters for simplicity. Further research could show that the pattern of distributions would be more varied.

Our data sets are based on information collected in 1994. This is in the public domain. We do not have access to further information collected by state agencies in the past two years that could be of immense value in validating the public private partnership approach to implementing the Bangalore LRT.

7 CONCLUSIONS

The main theme of this paper is to suggest probabilistic risk analysis as an improvement to the conventional singe variable sensitivity analysis. We have therefore developed such a module as a fifth facet of our MRTS planning model (Raman and Anantharamaiah 2000). A systematic methodology can be used to build a large number of scenarios, all of them having the same probability of being realised. A sampling method across the individual probability distribution of the variables can be used to build the scenarios. The methodology has been demonstrated (albeit not comprehensively) in the case of the Bangalore LRT using 1994 data.

Using the methodology suggested here, confidence in the projected revenue streams of a MRTS project can be enhanced. This can lead to reducing risk perceptions and, consequently lowering the quantum of risk associated premiums in project capital costs. This approach could provide the basis of rational risk sharing arrangements between the state and the private sector in a public private partnership to develop such projects.

REFERENCES:

Census of India 2001, *Provisional Figures*, New Delhi Office of the Registrar General, India,

Chakra Infrastructure Consultants Private Limited 1994. *Feasibility Study of the Bangalore Mass Rapid Transit System*. Bangalore: IL&FS and Government of Karnataka.

Chakra Infrastructure Consultants Private Limited 1995. *Request For Proposals*. Bangalore: Bangalore Mass Rapid Transit Ltd.

Chakra Infrastructure Consultants Private Limited 1997a. *Bangalore LRT Traffic Forecasts for UBT Limited*, Bangalore: ICF Kaiser Ltd.

Chakra Infrastructure Consultants Private Limited 1997b. *Pune LRT Feasibility Study. Bangalore*, Nandi Infrastructure Corridor Enterprises Ltd.

Fouracre, P.R. Allport, R.J. & Thomson, J.M. 1990 *The Performance and Impact of Rail Mass Transit in Developing Countries* TRRL Research Report 278.

Raman, Vijay & Anantharamaiah, K.M. 1996a. *A Price Related Transport Demand Model for a Developing Metropolis: Case Study of Bangalore* Proc CODATU VII, New Delhi, 12-16 February 1996 Tome 1: III-97 - III-106.

Raman, Vijay & Anantharamaiah, K.M. 1996b. *Can Willingness to Pay for Better Journey Times Justify a New Urban Mass Transit Mode?* Proc NCOTS IV Conference Bombay 9-11 December 1996: 11–25

Raman, Vijay & Anantharamaiah, K.M. 2000 *A Mass Transit Planning Model for Large Cities with Public Policy Implications* Proc CODATU IX, Urban Transport and Environment, Mexico City 11–14 April 2000, pp 257-262