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Modeling Travel Demand in a Metropolitan City
Case Study of Bangalore, India

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Keywords: urban transportation; travel demand forecasting; public bus transport; mass rapid transit systems; urban transportation modeling

Abstract

Increasing urbanization, population growth and rising incomes have led to rapid growth of travel demand in Indian cities. The paper provides a modeling approach for forecasting urban travel demand and assessing public transport options for large metropolitan cities. A travel characteristics model is used to forecast the pattern of travel demand in Bangalore city up to the year 2014. The paper examines the scope of a public bus transport service and a mass rapid transit system for meeting the projected travel demand and thereby curtailing the growth of personal vehicles in the city.

INTRODUCTION

The demand for transportation in urban centres is linked to the residential location choices that people make in relation to places of work, shopping, entertainment, schools and other important activities. As cities grow, they support more people and more dispersed settlement patterns. Increasing demand for transportation is an inevitable outcome of urban growth. A universal trend that has been observed is that as household incomes grow, people prefer personal transportation to public transport. The obvious and compelling reason for this is that personal transport maximizes individual mobility, freedom of choice and versatility that public transport systems cannot match. However, the experience of cities in many developed and developing countries shows that an efficient and economic public transport system can reduce dependence on personal transportation.

Increasing urbanization, population growth and rising incomes are the primary causes of rapid growth of travel demand in Indian cities. During the last decade, motor vehicle ownership in several metropolitan cities (those with over 1 million population) has been growing at nearly 10% per annum (World Bank, 2002). This has led to alarming levels of traffic congestion, air and noise pollution, and road accidents in most of the large cities. Other factors that have contributed to the severity of urban transport problems are shortage of road space, inadequate public transport systems and absence of disincentives for use of personal vehicles (Singh, 2005; Down to Earth, 2003).

Bangalore is the fifth largest metropolitan city in India and the hub of India's computer software and information technology industry. During the period 1991-2002, ownership of personal vehicles in the city has risen sharply and public transport service has been unable to keep pace with the rapidly increasing travel demand. Despite several road improvement projects, traffic congestion in the city continues to worsen. It is widely accepted that the city needs to upgrade its

public transport system by expanding the levels of bus services and providing a mass rapid transit system (Raman and Anantharamiah, 2000). It is also observed that urban planning and land use policies in India encourage urban sprawl, which makes it difficult to provide adequate urban public transport (Pucher *et al,* 2005).

This paper provides a modeling approach for forecasting urban travel demand and assessing the effectiveness of public transport options in controlling the growth of personal vehicles in large metropolitan cities. The paper is based on a case-study of Bangalore, India. A travel characteristics model is used to forecast the pattern of travel demand in the city up to the year 2014. Four alternative scenarios are simulated to analyse the scope of expanded public bus services and a mass rapid transit system for meeting the projected demand in comparison to a "business as usual scenario" characterized by rapid growth of personal vehicles.

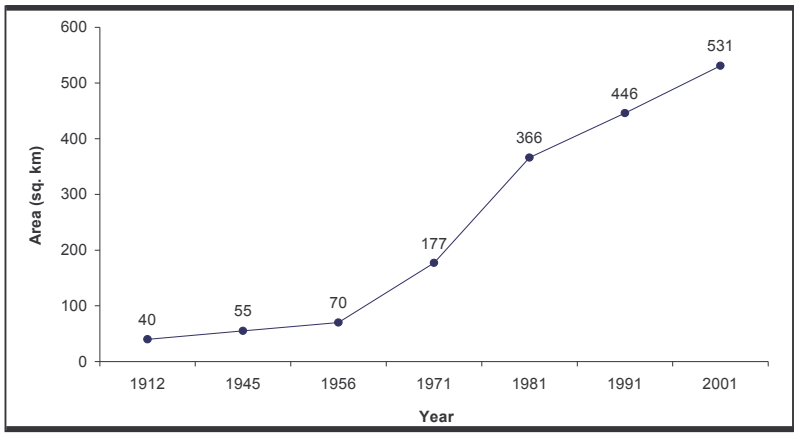
The paper is divided into five major sections. The first section provides introduction of the problem situation. The next section describes the urban transport scenario in Bangalore city. The following section provides detailed description of the model structure, assumptions and validation. This is followed by discussion of model results. The final section summarizes the key conclusions of the paper and their implications.

URBAN TRANSPORT SCENARIO IN BANGALORE

Physical Growth

The physical growth of Bangalore city is characterized by urbanisation of the surrounding rural communities and their incorporation into the city on a continuous basis over the years. The primary impetus for the city's growth has been its rapid industrialization since the 1950s when many public sector undertakings established large-scale units around the city. In the 1970s, these industrial townships were integrated into the Bangalore urban agglomeration (UA).

Fig. 1: Growth of Bangalore UA (1912-2001)



Source: Census of India reports

In the 1990s, Bangalore emerged as a world-class hub of computer software and information technology industries. The employment opportunities created by these industries as well as the city's quality of life are providing further impetus for growth. From a tiny village in the 12th century, Bangalore has gradually evolved into India's fifth largest city. It is still developing as a sprawling mega city in all directions. It is evident that local transportation demand in Bangalore city would continue to increase at a rapid pace.

Growth of population and income

During the last decade (1991-2001) the population of Bangalore (UA) increased from 4.1 million to 5.7 million. This represents an increase of 37.7%. However, about one-third of this increase was due to the fact that new areas were added to the Bangalore (UA). If we adjust for this factor, the net increase in population was approximately 22% which is equal to annual rate of growth of 2.0%.

We have based our analysis of household income on the series of MISH surveys conducted by NCAER from 1985-86 to 1998-99. We have interpolated and extrapolated the NCAER data to arrive at the estimated household income in Bangalore city from 1991 to 2002. The compounded annual rate of growth (CAGR) of household income in Bangalore city from 1991 to 2002 is estimated to be 7.4%.

Table1: Demographic changes in Bangalore UA (1991-2001)

	Unit	1991	2001	CAGR (%)
Area	sq km	446	531	-
Population				
- as in Census 2001	million	4.13	5.69	3.3
- after adjusting for increase in area	million	4.66	5.69	2.0
Density	Persons per sq km	9,260	10,716	-
Average annual household income	Rs.	52,496	107,299	7.4

Source: Census of India reports; Natrajan 1998; NCAER 2002

Growth of personal vehicles

There were approximately 500,000 two-wheelers in Bangalore city in 1991. By 2002, their number had increased to 1,200,000. The annual rate of growth of 2-wheelers in Bangalore during 1991-2002 was 9.0%. The number of personal 4-wheelers (cars and jeeps) in Bangalore city has grown even faster. There were less than 100,000 four-wheelers in 1991. In 2002, their number had crossed 250,000. The annual rate of growth of 4-wheelers in Bangalore city during 1991-2002 was 9.9%.

In 1991, there were 108 two-wheelers per 1000 population in Bangalore. In 2002, there were 205 two-wheelers per 1000 population. In other words, ownership of 2-wheelers had nearly doubled during this period. The same is true for ownership of personal 4-wheelers in the city. Whereas there were 21 four-wheelers per 1000 population in 1991, by 2002 this number had risen to 44.

Table 2: Growth of personal vehicles in Bangalore city (1991-2002)

	Unit	2–W	4–W
Number of vehicles			
• 1991	no.	502,707	98,702
• 2002	no.	1,192,228	252,984
• CAGR	%	9.02	9.87
Vehicles per 1000 population			
• 1991	no.	108	21
• 2002	no.	205	44

Modal split

We have come across only two recent studies that provide the modal split of traffic in Bangalore city. The first is the "Feasibility Study of the Bangalore MRTS" by Infrastructure Leasing and Financial Services Limited (IL&FS), which was carried out in 1994. The other study is the "Detailed Project Report for the MRTS", prepared by RITES in 2002. We have compared the estimates of total trips and the modal split as reported by ILFS and RITES in 1994 and 2002 respectively (see table 3). In order to focus on vehicular travel we have excluded walk trips in both cases.

Table 3: Modal-split information on Bangalore city

Mode of travel	ILFS (1994)		RITES (2002)	
	Trips	(%)	Trips	(%)
Car	93600	2.38	270862	5.44
Two-wheeler	881550	22.45	1806651	36.31
Autorickshaw	207450	5.28	343153	6.90
Bus	2363850	60.19	2433913	48.91
Bicycle	355500	9.05	99717	2.00
Others	25650	0.65	21935	0.44
Total	**3927600**	**100.00**	**4976231**	**100.00**

ILFS estimated 3.9 million total trips (excluding walk) in 1994. RITES estimates 5.0 million trips (excluding walk) in 2002. If we accept both estimates, it would imply that the average annual rate of growth of transportation demand in Bangalore city between 1994 and 2002 was about 3.3% per annum. The modal split estimated by the ILFS study differs significantly from the RITES study. The share of cars and two-wheelers in the RITES study is much higher. On the other hand the share of bus is much higher in the ILFS study. If we accept the two reports to be prima facie consistent, these results would imply that the share of personal transport (cars and 2-wheelers) has risen sharply and that of public transport (bus) has dropped substantially between 1994 and 2001 in Bangalore city.

Per capita travel

According to the ILFS study, the 'per capita trip rate' (PCTR) in 1994, excluding walk trips, was 0.87. According to the RITES study, the PCTR in 2002, excluding walk trips, was 0.86. There has been a lot of controversy about the PCTR estimates. A study by KAMPSAX consultants in 1998 used a figure of 1.2, which was criticized at that time. We have spoken to several transportation experts in Bangalore as part of this study. In their considered opinion, the vehicle PCTR in 2004 could be in the range of 1.0 to 1.2. None of the studies that we have reviewed provides any estimate of average trip length. According to the experts we interviewed, a good guesstimate for Bangalore would be 12-13 km.

Roads and traffic

Bangalore city has more than 3000 km of surfaced roads. However, average road width is small. Only one-third of the roads are more than 9 m wide. Less than 10% of the roads can be classified as major arterial roads. Predominantly narrow roads are a major cause of traffic congestion in the city. The recently completed outer ring road and the intermediate ring road have improved the flow of traffic in the city. A recent study by the Central Road Research Institute (CRRI) analysed traffic volumes on 25 major traffic corridors in the city in 1999. They found that all corridors are handling traffic which is more than their rated capacities for most of the day.

The city has extremely high level of traffic congestion at present. The factors responsible for this are – very high growth of personal vehicles, limitations of BMTC system to meet increasing demand for public transport and inadequate road network, especially arterial and sub-arterial roads. The road widening projects, flyovers and grade separators at busy intersections have helped to improve traffic flow but haven't made significant impact on traffic congestion. The outer ring road (eastern) has reduced congestion significantly by taking out inter-city traffic. The average speed of traffic in Bangalore city used to be 15-18 kmph in 1990. It is now less than 10 kmph.

Public transport

Bangalore is one of the few cities in India where there is a dedicated local bus service provider, the Bangalore Metropolitan Transport Company (BMTC). The BMTC has a fleet size of 2775 buses. In 2002-03, the BMTC buses carried 2.6 million passengers daily. In terms of fleet size and passengers carried, the level of service is comparable to Chennai and slightly lesser than Mumbai, after taking population differences into account. The bus service by BMTC is the only mass transport system in Bangalore. There are no local train services such as in Mumbai and no mass rapid transit system such as in Kolkata and Delhi. The citizens of Bangalore depend a great deal on intermediate public transport (IPT) in the form of 3-wheeler auto-rickshaws and taxies.

The general perception about the BMTC is that the system is improving. The increase in fleet size has improved services although a large number of buses are on contract to private companies. The proposed Metro Bus system (using two ringed buses) may not be feasible on internal routes in the city due to lack of adequate road space but could work effectively on circumferential routes on ring roads.

Parking facilities

With unabated growth of personal vehicles, the demand for parking space has exploded. The problems of parking are especially severe in the central zone of the city. Unregulated on-street parking reduces effective carriageway and hinders movement of vehicles. The city planners feel that off-street parking facilities, strict enforcement of on-street parking regulations and deterrent pricing of parking spaces are necessary steps to address. The construction of high-rise buildings at many locations is causing major increase in parking demand in the city. Space is becoming increasingly scarce. As a result, commercial areas are very congested.

Infrastructure projects and plans

A number of comprehensive traffic and transportation studies have been carried out in Bangalore city since the 1960s. In 1963-64, the Central Road Research Institute (CRRI) New Delhi prepared a comprehensive traffic and transportation plan for Greater Bangalore. They recommended development of a series of ring roads and some major arterial roads. The J.C. Lynn Committee (1981) also recommended development of ring roads, arterial roads and special schemes like railway over/under bridges and pedestrian subways. In 1987, Metropolitan Transport Project (Railway) Madras, recommended utilization of some existing railway lines; a new surface Rapid Transit Line; a new surface Ring Rail System and a new surface Rapid Transit System.

Subsequent to these studies, a number of road infrastructure projects have been implemented in Bangalore. These include construction of several flyovers, bridges and grade separators; construction of the Intermediate Ring Road and the Outer Ring Road; and several road widening and improvement projects within the BMP area under the Bonds Scheme. An Elevated Light Rail Transit System (ELRTS) was proposed in 1998. However, no progress has been made on this project and possibly it may have been dropped.

The most recent project proposed for the city is the Bangalore Metro Project to be implemented by the Bangalore Mass Rapid Transit Limited (BMRTL). The Metro Rail Project would have two

corridors – East/West and North/South – of 33 km length. The system would be underground, elevated and at-grade. The Metro Rail is expected to carry .8 million passengers daily in 2007 and 1.0 million passengers daily in 2011. 166 trains will be run in each direction of each corridor every day. The project is expected to commence in 2005 and be completed by 2010.

TRAVEL DEMAND FORECASTING MODEL

To forecast the future travel demand in Bangalore city, a travel characteristics model was developed. This is a simulation model based on the functional relationship between mobility rates, population growth and alternative modes of transport at city-level. The model is used to forecast travel demand in Bangalore city up to the year 2014. Four alternative scenarios are analysed to predict the number of vehicles of different types and to show the trade-offs between private and public modes of transport.

Model structure

The travel demand forecasting model is driven by the following variables, which are exogenously specified:

1. **Population:** projected population of the city for each year of the forecasting period
2. **Per capita trip rate:** estimated number of trips per person per day
3. **Modal split:** the relative share (%) of each alternative mode of transport in the total number of trips generated
4. **Average trip length:** the average distance traveled per person per trip in the city

The model projects total travel demand in the city for each year of the projection period. This is computed as follows:

$$TTD_t = [PCTR_t \times POP_t \times MODS_t] \times ATL_t$$

Where,

TTD_t : Total daily travel demand in year t
$PCTR_t$: Per capita trip rate in year t
POP_t : City population in year t
$MODS_t$: Share of each mode of travel
ATL_t : Average Trip Length

The ratio of total vehicles to total travel demand is obtained from the observed values for the year 2002. This is assumed to remain constant through the projection period. Using the relationship, vehicle projections are derived from projected total travel demand.

Alternative Scenarios

The final forecasts of travel demand are based on four alternative scenarios of future transport infrastructure development in Bangalore city. The scenarios and the associated assumptions are described below:

Scenario 1: Business as usual (BAU)

In this scenario, it is assumed that the current trends of population and income growth would continue. Similarly urban growth and infrastructure development would follow the pattern of the preceding decade. Further, the public bus service of BMTC would be maintained at current performance level with normal expansion of fleet and routes.

Scenario 2: Major upgradation of bus services (BMTC-Plus)

This scenario, termed BMTC-Plus, assumes rapid expansion of fleet size and service routes by the BMTC. It also assumes major improvement in the quality of bus services in the city through optimisation of operations, customer responsiveness and good management practices.

Scenario 3: Metro-rail with low ridership (MRTS-L)

The scenario assumes that proposed Mass Rapid Transit System (MRTS) would become operational in the year 2010. However, the system would achieve only 40% level of ridership by 2014. This scenario is in addition to scenario 2, that is, it also includes expanded bus services of BMTC'S.

Scenario 4: Metro-rail with high ridership (MRTS-H)

In this scenario, it is assumed that the MRTS project would be fully operational by 2010 and that by 2014, it would achieve 90% level of ridership. Expanded bus services of BMTC are also assumed.

Assumptions and specifications

a. The vehicle PCTR for Bangalore city is estimated to be 1.1 in the year 2002. Further, it is assumed that the PCTR value would grow at the rate of 3% per year for the next ten years. These assumptions are based on review of Bangalore specific studies by ILFS and RITES.

b. Average trip length is estimated from a study by RITES.

c. Assumed values of various parameters (PCTR, modal split, average trip length and population) involved in the calculations related to the Model are presented in the table below:

Parameter	2002	2014	Growth function
PCTR	1.1	1.57	3% per annum
Average trip length	12.0 km	15.0 km	Linear
Population	5.8 mil	7.8 mil	2.5% per annum

d. The modal share of 2-wheelers and 4-wheelers is taken from the Detailed Feasibility Report of the proposed Mass Rapid Transit System, prepared by RITES.

Mode	Unit	2002	2014			
			BAU	BMTC Plus	MRTS (L)	MRTS (H)
2 – W	%	36.0	39.0	35.0	33.0	30.0
4 – W	%	5.5	7.0	5.0	4.0	3.0
Bus	%	49.0	46.0	52.0	52.0	52.0
MRTS	%	-	-	-	3.0	8.0
Auto	%	7.0	5.5	5.5	5.5	5.0
Others	%	2.5	2.5	2.5	2.5	2.0

Model validation

The travel characteristics model is a deterministic model which incorporates specific factors that affect demand for personal transportation, such as per capita trip rate, modal split and average trip length. The problem is that the empirical data on these variables are not readily available and measurement is both difficult and costly. Further, the model requires that we first forecast values each of these variables into the future before we can forecast travel demand. Thus the robustness of this model depends entirely on the reliability of empirical data and validity of assumptions.

In order to validate the model, an alternative set of forecasts were obtained by trend extrapolation of the data on motor vehicles (2-W and 4-W) in Bangalore city. Two forecasts were made using annual growth rate of vehicles during the previous ten years (1991-2002) and the more recent trend from 1997 to 2002.

The Table 4 shows the comparative forecasts of number of two-wheelers and four-wheelers using the "travel demand forecasting model" and those obtained by trend extrapolation.

The annual growth rate of two-wheelers as predicted by the model under the "business as usual" scenario is 8.3%. This lies in the middle of the trends observed during the last ten years and five years respectively. The annual growth rate of four-wheelers as predicted by the model is 9.8% which is very close to the trend observed during the last ten years. Thus, the robustness of the model is clearly validated.

Table 4: Comparison of forecasts for model validation

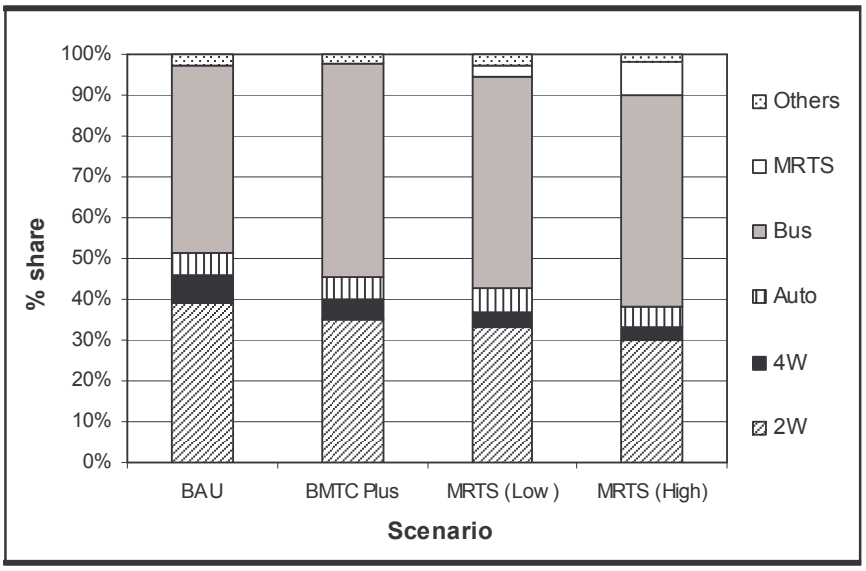
	2-W		4-W	
	No. of vehicles 2014	**CAGR (2002-2014)**	**No. of vehicles 2014**	**CAGR (2002-2014)**
Model forecast (BAU)	3,095,861	8.3%	773,047	9.8%
Trend (1991-2002)	3,360,567	9.0%	782,733	9.9%
Trend (1997-2002)	2,950,805	7.8%	819,620	10.3%

MODEL RESULTS

The travel demand model described above has been used to forecast the total travel demand and total number of vehicles for each mode under the four alternative scenarios. The key results are described below:

Total travel demand

Fig. 2: Share of different modes in total travel demand by scenario (2014)



The forecasts of total travel demand in Bangalore city in 2014 is 183.8 million person kilometers. The share of different modes of transport under each of the four scenarios is shown in Fig. 2. This is essentially similar to the modal split in trip generation. The combined share of personal vehicles (2-W and 4-W) is 46% in the BAU scenario. This reduces to 40% under BMTC-Plus, 37% under MRTS (L), and 33% under MRTS (H).

Number of vehicles

In the BAU scenario, the model forecasts over 3 million two-wheelers and 0.77 million four-wheelers in Bangalore city in 2014. This corresponds to annual growth rate of 8.3% and 9.8% for two-wheelers and four-wheelers respectively. The fleet size of buses operated by the public bus service provider BMTC is expected to grow at 7.0% per year while the number of three-wheeler auto-rickshaws grows at 5.4% per year.

Under the BMTC plus scenario, addition of 735 buses results in slowing down the annual growth rate of two-wheelers by one percentage point and of four-wheelers by over three percentage points.

Table 5: Travel demand forecasts (number of vehicles)

Mode (vehicle)	Base year 2002	Forecasts for 2014 under various scenarios			
		BAU	BMTC Plus	MRTS (L)	MRTS (H)
Two-wheeler					
- Number (000)	1191	3095	2778	2620	2381
- CAGR (%)	-	8.3	7.3	6.8	5.9
Four-wheeler					
- Number (000)	253	773	552	442	331
- CAGR (%)	-	9.8	6.7	4.8	2.3
Bus					
- Number	2500	5631	6366	6366	6366
- CAGR (%)	-	7.0	8.1	8.1	8.1
Autorickshaw					
- Number (000)	67	126	126	126	115
- CAGR (%)	-	5.4	5.4	5.4	4.6

In the MRTS (L) scenario, introduction of metro-rail in addition to expanded bus services of BMTC results in further reduction in the annual growth rate of two-wheelers by 0.5 percentage points and of four-wheelers by nearly two-percentage points. In the MRTS (H) scenario, signifying high ridership in the metro-rail system, the annual growth rate of two-wheelers drops to 5.9% while that of four-wheelers comes down to 2.3% per year.

Table 6: Change in number of vehicles as compared to BAU

Mode	Increase/decrease in number of vehicles (2014)			
	BAU	BMTC Plus	MRTS (low)	MRTS (high)
Two-wheeler	*	-10.26 %	-15.38 %	-23.08 %
Four-wheeler	*	-28.57 %	-42.86 %	-57.15 %
Bus	*	13.04 %	13.04 %	13.04 %
Autorickshaw	*	0.00 %	0.00 %	-9.10 %

The model results show that the number of two-wheelers on the streets of Bangalore can be reduced by more than 10% by upgrading the bus services of BMTC from the situation expected under BAU. Additionally, if an MRTS is provided in the city reduction in the range of 15-23% can be achieved. Scope for reducing the number of four-wheelers by introducing expanded bus transport and MRTS is even greater. The total number of four-wheelers can be brought down by 28-57% compared to the BAU scenario.

Fig. 3: Growth in number of 2-wheelers in different scenarios

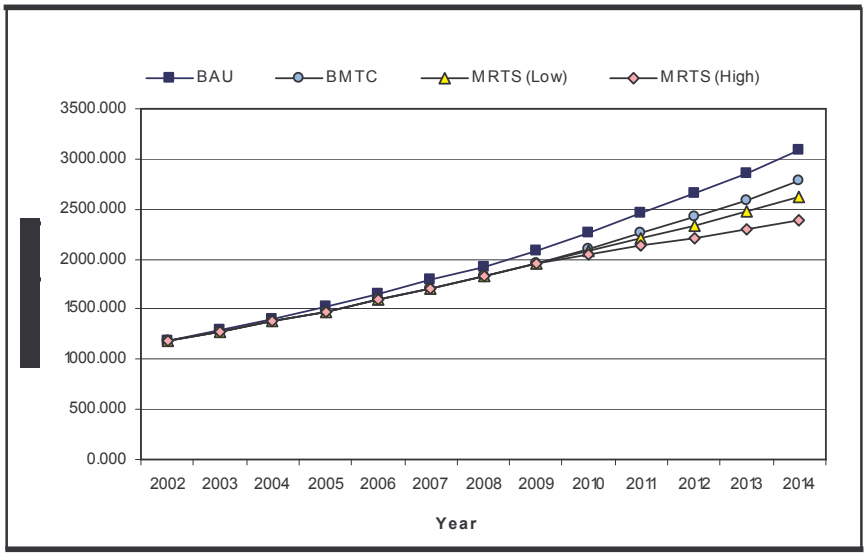


Fig. 4: Growth in number of 4-wheelers in different scenarios

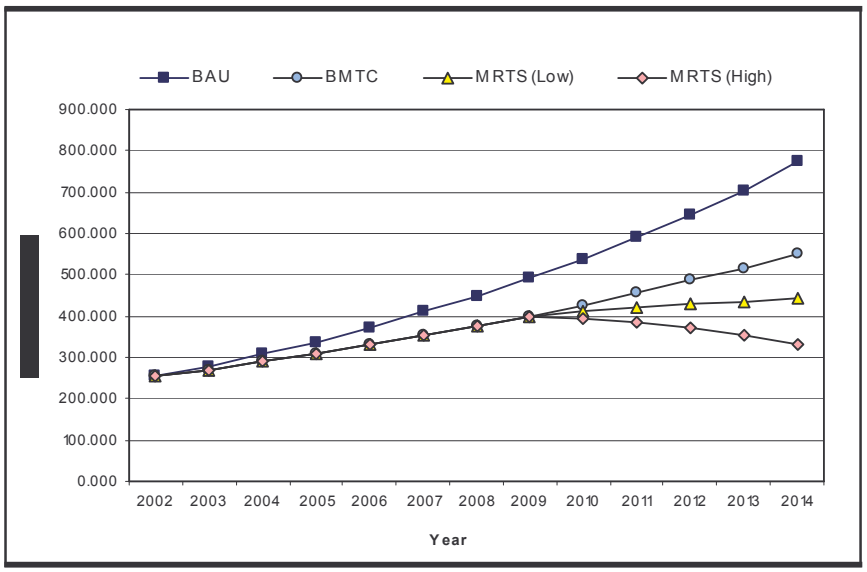


Fig. 5: Growth in number of Buses in different scenarios

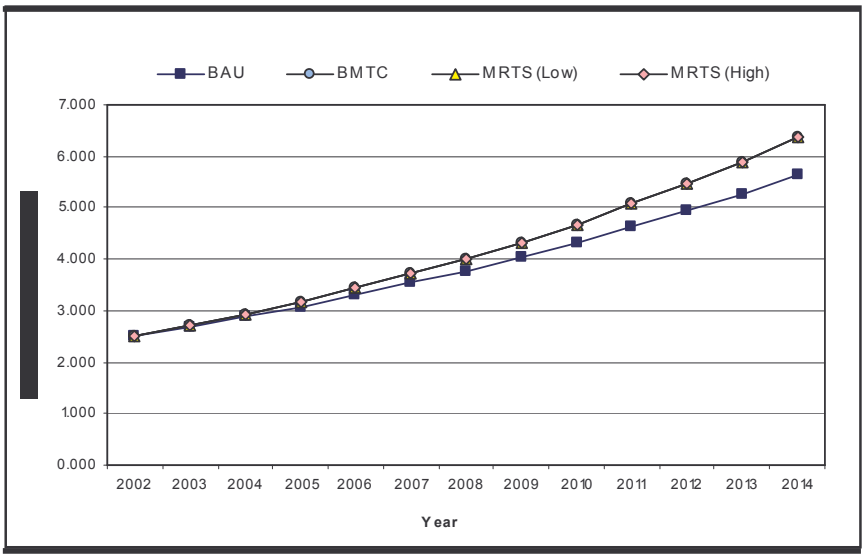
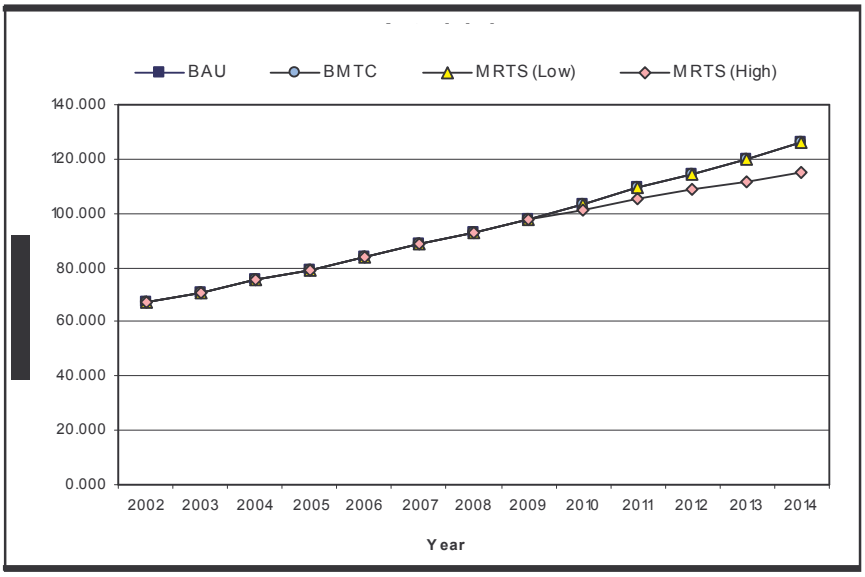


Fig. 6: Growth in number of Autorickshaws in different scenarios



CONCLUSIONS AND IMPLICATIONS

1. The travel demand forecasting model provides a useful framework for analyzing alternative scenarios of urban transport systems. The main limitation of this model is that empirical data on per capita trip rate (PCTR), modal-split and average trip-length are not readily available and measurement is both difficult and costly. However, given the severity of urban transport problems and the scale of adverse impacts of poorly planned systems, it is necessary for all large cities to develop a comprehensive database for transportation planning.

2. The model results for Bangalore city show that adequate public bus services and modern mass rapid transit systems can have a significant impact on reducing the growth of personal vehicles. However, to actually make this transition happen the public transport system has to meet the real needs of commuters – speed, convenience, comfort, connectivity and economy.

3. It is also evident from the findings of this case study that public bus services would continue to play the central role in urban public transport systems even after mass rapid transit systems are introduced. In Bangalore, for example, the bus system is projected to have a share of 52% in total travel demand in 2014 compared to only 8% for MRTS. This implies that expanding and improving bus services and integrating land use and transportation planning would be the major challenges for Indian cities in the near future.

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