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Potential demand and cost-benefit analysis of electric cars

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Abstract

In this study an analysis of electric family car performances is carried out. In particular, the aim of this research is to appraise the possibility of introducing electric cars in urban mobility and the evaluation of its economic feasibility. First of all, we determined the potential electric car demand, which was forecasted using a stated preference (SP) analysis. The survey was carried out at the University of Palermo considering a particular target of consumer: "the hybrid household". A logit demand model was calibrated using the SP technique to model the choice between the electric car and the conventional one.

In the second part of the work, the economic feasibility of the electric car is analysed by comparing the operating cost per kilometre of the internal combustion car with that of the electric one. Two options were analysed for electric cars: car purchase and car sharing.

Keywords: Cost/benefit analysis; Logit model; Electric cars.

Introduction

The diffusion of electric cars for urban mobility is one of the possible strategies to reduce air pollution caused by road traffic in urban areas, thus realising more sustainable mobility. Road transport is one of the main factors responsible for pollutant emissions. In 1997, it was estimated that road traffic was responsible for about 72% of carbon monoxide, 46% of particulate matter, 53% of nitrogen oxide, and 24% of carbon dioxide emitted during that year. In all European urban areas the emission levels are increasing. Urban paths are often short so that the thermal engine does not have enough time to warm up and along with the repeated stop and go of the vehicle cause a major increase in consumption and pollutant emissions. It has been estimated that the cost for the Community due to diseases caused by pollutant emissions (like respiratory or cardiovascular disease) is about 1.7% of the GDP (Gross Domestic Product).

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Car factories have been obliged to reduce the emission levels of heat engines by increasingly stringent environmental standards determined by European laws.

In Italy 42% of the car fleet is not catalytic. This value is higher than the average recorded in the European Union countries, and it is much higher in the south of Italy.

Electric car performances

Among new vehicles technologies, the electric one is more suitable than the conventional car for being used in urban areas for range, speed, energy saving and lower pollutant emissions. The limits of electric vehicles should be overcome by the introduction of new batteries, peak power units like the flywheel and super capacitors, or fuel cell technology. Vehicles based on fuel cell technology will permit energy saving, very low emission and a higher range.

Batteries are the main element of the propulsion system of the electric vehicle, but at the same time they are the main reason for the low performances and the limited range. Table 1 reports the main characteristics of new batteries for electric vehicles.

Table 1: Characteristics of batteries for electric vehicle [(*) prototype].

	PB – ACID	*NI-CD*	*NI-MH*	*LI-ION*	*NA-NICL$_2$*	*NA-S*	*ZN-BR$_2$*
Specific energy [Wh/kg]	35-60	40-60	70-95	80-130	90-120	150-240	70-85
Specific power [W/kg]	100-150	80-160	200-350	200-300	130-160	230	90-110
Working temperature [C°]	0 – 45	0 - 50	-40 – 50	-40 - 60	300-350	300-350	20-40
Average life [10^3 Cycle]	0,6-1	0,8	0,75-1,2	1	1,2	0,8	0,5-2
Range [km]	100-120	150	120	180	250	300	200
Cost [€/kWh]	50-75	80-115	65-115	65	75-110$_{(*)}$	80-144$_{(*)}$	65-80$_{(*)}$

The performances of electric vehicles seem to correspond better to the characteristics of the private transport demand in urban areas because over 80% of urban trips amount to less than 50 km per day. This datum is important for evaluating the range of electric vehicles, which is generally between 100 and 120 km (see table 2).

Table 2: Performances of some electric and hybrid cars.

MODEL	*VEHICLE'S TYPOLOGY*	*MOTOR'S TYPOLOGY*	*BATTERY*	*WEIGHT [KG]*	*PASSENGER*	*RANGE*	*MAX SPEED AND ACCELERATION*
Fiat Panda Elettra	Electric	d.c. motor	Pb-gel	1050	2	100 km	70 km/h 0 – 40 km/h in 10 s
Fiat 600 Elettra	Electric	a. c. induction motor	Pb-gel Ni-MH Li-Ion	1240 1110 1020	4	100 km 120 km 180 km	100 km/h 0 – 50 km/h in 8 s
Citroen Saxo	Electric	d.c. motor	Ni-Cd	1087	4	75 km	90 km/h 0 – 50 km/h in 8.3 s
Citroen Berlingo	Electric	d.c. motor	Ni-Cd	1450	4	80 km	95 km/h 0 – 50 km/h in 8.5 s
Peugeot 106	Electric	d.c. motor	Ni-Cd	1077	4	80 km	90 km/h 0 – 50 km/h in 8.5 s
Toyota RAV4I-EV	Electric	a. c. P.M. synchronous motor	Ni-MH	1460	4	200 km	130 km/h 0 – 100 km/h in 17.5 s
Toyota Prius	Hybrid parallel	a. c. P.M. synchronous motor	Ni-MH	1240	5	900 km	160 km/h 0 – 100 km/h in 13.0 s
Honda Insight	Hybrid parallel	a. c. P.M. synchronous motor	Ni-MH	850	2	1250 km	180 km/h 0 – 100 km/h in 10.6 s

[d.c. ⇒ direct current / a.c. ⇒ alternating current]

Forecasting electric car demand by SP analysis

Carrying out an economic analysis on electric cars means facing some important problems like the absence of a real market for the electric car. The main reason for this absence is the high purchase price. Other reasons are the limited performance reached by an electric engine, especially if compared to a conventional one and the difficulties of recharging, due to the absence of recharging infrastructures.

In order to overcome some of these problems and to evaluate the market share and economic feasibility of electric cars, a demand sample analysis was carried out. A calibration of the demand choice model for the electric car was made using a stated preference technique (Pearmain et al., 1991) and carrying out a destination survey at the University of Palermo. To this purpose a questionnaire was constructed and submitted to the sample chosen. A part of the questionnaire was devoted to the decision maker's socio-economic characteristics, useful for identifying him or her, like: sex, age, ownership of two or more cars, ownership of a garage, average number of kilometres travelled per day and household income. The importance of the number of cars owned is related to the main characteristics of an electric car, which is more suitable for urban transport. Indeed, according to the literature (Kurani et al., 1996), it was expected that families which met criteria such as ownership of two or more cars and limited commuting distance, the so-called "hybrid household", should have a greater propensity to purchase and use electric cars. The lower electric vehicle performances can thus be overcome considering the target of the "hybrid household". The hybrid household, as mentioned, is a family unit which owns at least two cars: an electric one, used only within the urban area, and a conventional one used for longer trips.

In order to maintain the scenario realistic, the quantitative attributes able to explain the choice demand model and their values were also identified by a pilot survey. These attributes were: the annual cost for the electric (EC) and internal combustion car (ICC), the average time spent to travel by car per day and the average life of the car. In particular, the ICC running time from different origins to the University Campus was estimated elaborating a D.U.E. (Deterministic User Equilibrium) process of assignment of the private car O/D matrix (related to the rush hour and the average working day) to the urban network (Comune di Palermo, 1997).

The running time saved by using the electric car was calculated considering its possibility of entering reserved lanes and LTA (Limited Traffic Areas). The annual costs of EC and ICC were calculated considering not only the cost per year related to the average life of the car but also fuel or electric energy cost, maintenance costs, motor vehicle tax, civil liability and the number of kilometres travelled per year, which we supposed to be equal to 10,000 km. All the values were referred to the FIAT Seicento Elettra (EC) and to the Fiat Seicento SX (ICC). The EC annual cost includes the subsidies determined by the law in force (no motor vehicle tax for the first five years and 50% reduction of civil liability insurance). The subsidies for the EC purchasing price were assumed to be higher than those determined by the law in force. Finally, the average life of the EC was considered equal to that of the battery and it was estimated considering the number of charging/discharging cycles declared by FIAT. The ICC average life is seven years (ACI, 2002).

The identified levels of the EC purchasing cost were 19,446 and 15,831 euro, while the ICC purchasing cost was 8,551 euro. These costs were then transformed into annual costs related to the car's average life (Amoroso, 2002). The identified levels for the ICC's running time were 135 and 105 minutes per day, while the running time for the EC was 75 minutes per day. The average life levels for the EC are 6 and 10 years (for both the kinds of cars the characteristics are showed in table 3).

Table 3: Characteristics of the electric car versus conventional car.

CHARACTERISTICS:	CONVENTIONAL CAR:	ELECTRIC CAR:
range:	315 km with a full	100 km with a recharge
Fuel type:	Petrol	Electric energy
Purchase price:	8,551 €	19,446 € or 15,831 €
Fuel costs per year (taking into account 10000 km/year):	921.3 €	238 €
The average running time (minutes per day):	2 hour and 15 minutes per day or 1 hour and 45 minutes per day	1 hour and 15 minutes per day
Time of refuelling:	5 minutes	8 hours
Place of refuelling:	Filling station	Garage or Box (night recharge)
Speed max:	150 km/h	100 km/h
Motor vehicle tax:	77.47 €/year	none
Civil liability insurance:	620 €/year	310 €/year
Average life of car:	7 years	6 years or 10 years

Once all the levels 'n' for each attribute 'a' were established, the complete factorial plan was constructed according to the following relationship: $n^a = 2^3 = 8$.

Hence the complete factorial plan is made up of 8 scenarios only, so it was not necessary to divide them (Cascetta, 1998). Finally, all the scenarios were presented to each decision-maker who in his questionnaire reported the choice between the competitive alternatives. 469 questionnaires (3752 observations) were successfully carried out, so we analysed a sample of 0.11%. Actually the number of households in Palermo is 414,155 (ISTAT, 2002).

Let U_{ICC} be the conventional car utility function; U_{EC} the electric car utility function; cost the cost per year (€ per year); time the average running time (minutes per day); life the average life of the car (years); age the decision-maker's age (years); sex 1 if the decision-maker is a female, 0 a male; garage 1 if the decision-maker owns a garage, 0 none; β_0 a constant; β_1 the cost coefficient; β_2 the running time coefficient; β_3 the average life coefficient; β_4 the age coefficient; β_5 the sex coefficient; β_6 the garage ownership coefficient.

The utility functions of the competitive alternatives are:

$$U_{ICC} = \beta_1 \cdot \text{cost} + \beta_2 \cdot \text{time} + \beta_3 \cdot \text{life} + \beta_0 \quad (1)$$

$$U_{EC} = \beta_1 \cdot \text{cost} + \beta_2 \cdot \text{time} + \beta_3 \cdot \text{life} + \beta_4 \cdot \text{age} + \beta_5 \cdot \text{sex} + \beta_6 \cdot \text{garage}. \quad (2)$$

We expected who is younger (age), female (sex) and has got a garage (garage) should be mainly influenced by choice of the electric car. The calibration of the binomial logit model was made using the maximum likelihood technique (Ortùzar, 1996) with the Limpdep® 8.0 software.

The results of the calibration process are reported in table 4.

Table 4: Binomial logit car-choice model results.

Attribute	*Coeff.*	*Value*	*Stand. error*	*t-student*	*p-value*
Cost	β_1	-0.00163305	0.000142156	-11.4877	0.00000
Time	β_2	-0.0122307	0.00239746	-5.10151	0.00000
Life	β_3	0.276977	0.019385	14.2882	0.00000
Age	β_4	-0.0805219	0.0373323	-2.1569	0.0310
Sex	β_5	0.209702	0.0815229	2.57231	0.0101
Garage	β_6	0.147276	0.0759454	1.93923	0.0525
ICC	β_0	0.411817	0.133113	3.09374	0.0020
$\rho^2 = 0.12565$		V.O.T. = 60* β_1/β_2 = 2.07 €/h			
χ^2 [6] = 649.53437		Significance (χ^2) = 1,00000			

The results of the calibration process show the correctness of the signs and the p-value shows the significance of each attribute. The constant of garage ownership has poor significance, probably because other variables simulated the a priori preference of the decision-makers for the car. The overall significance of the demand model is shown by χ^2 test.

According to the literature (Kurani et al., 1996), it was expected that SP respondents who met criteria such as ownership of two or more cars (85% of the sample), living in Palermo and having a limited commuting distance (94% of the sample), the so-called “hybrid household”, should have a greater propensity to purchase and use electric cars. The sample analysed shows these characteristics, but unfortunately it was not possible to have reliable data about household income because of the great resistance to answering about it.

The model’s predicted probability of the electric car choice is 54.61%, while 45.39% will probably choose the conventional one.

The importance of the variables cost and time in the demand model can also be analysed calculating the Value Of Time (VOT), which is equal to €2.07 per hour. It is interesting to note that this value is confirmed by the data obtained in the Urban Transport Plan of Palermo (Comune di Palermo, 1997). This confirms the reliability of the model here reported.

Useful information is given by the elasticity of the attributes annual cost and average time. The direct elasticity shows the effect due to a change in the value of the independent variable on the value of the dependent one. Table 5 shows the values related to the direct elasticity effect of the analysed attributes of transport supply on the probability of choosing between the two alternatives (ICC, EC), averaged over the set of observations.

Table 5: Direct elasticity split by choice alternative.

Alternative	*Cost per year [€/y]*	*Average life [y]*	*Average running time [min/day]*
Conventional car	-2.205	0.885	-0.669
Electric car	-1.960	0.826	-0.348

These data show how an increment in annual cost equal to 1% induces an average reduction of choice probability equal to 2.21% for the ICC and to 1.96% for EC. They also highlight a high cost-related demand elasticity. The average life shows perfect elasticity because this value is very near to the one for ICC and also for the EC. Finally, the average running time demand elasticity found for the calibrated model is inelastic, and indeed its value is lower than one. At all events, we have to remember that the average running time variable was expressed in minutes per day.

It should be stressed that the direct elasticity value found for the demand model calibrated is also due to the sample distribution among the two transport alternatives. The probability distribution is near to 50%, as mentioned before, and it highlights major indecision between the alternatives presented in the scenarios.

Cost-benefit analysis of electric and internal combustion car

This analysis aims to compare from an economic point of view the individual use of a heat engine car with that of an electric one in specific applications. Indeed, although the cost involved in buying and keeping a traditional car is widely known, the same cannot be said for electric cars powered by batteries, which are built according to specific functional, constructional and legal requirements. Therefore, the cost analysis involves the life cycle of vehicles, and it is first and foremost a quality-oriented analysis, rather than a quantitative one. It will be focused on the identification of the new fixed and variable costs, which the individual use of these kinds of vehicles entail.

In order to compare these two different technologies, electric vehicles (EC) versus internal combustion vehicle (ICC), the study takes into account their operating costs per kilometre, obtained by the following equations:

$$OCK_{EC} = [(P - RV)/(n \cdot VKT)] + \left\{ [(1+i)^n \cdot P - P]/(n \cdot VKT) \right\} + \frac{I}{VKT} + \frac{(L \cdot C)}{100} \quad (3)$$

$$OCK_{ICC} = \frac{(P - RV)}{(n \cdot VKT)} + \frac{[(1+i)^n \cdot P] - P}{(n \cdot VKT)} + \frac{(I + MVT)}{VKT} + \frac{(OM + EM)}{VKT} + \frac{(L \cdot C)}{100} \quad (4)$$

Let P be purchase price; RV residual value; n number of years since purchase; VKT kilometres travelled per year; ì interest rate (4.3%); I insurance cost; MVT motor vehicle tax; OM ordinary repairs; EM extraordinary maintenance; L energy and fuel price (€ per KWh or € per litre); C consumption per 100 km.

In particular, purchase price, insurance cost and motor vehicle tax are referred to the Fiat Seicento SX and to the Seicento Elettra. Of course, the electric vehicle purchase price includes the subsidies determined by the law in force. A 50% reduction was also considered for civil liability insurance and the absence of motor vehicle tax for the first five years.

The maintenance costs of the electric car are negligible because it does not need any mechanical assistance for the entire battery life cycle. This is due to the high reliability and robustness of the electric power train system.

The absence of a used car market does not make it possible to have a correct evaluation of the residual value of electric cars, which can only be hypothesised. On the basis of the efficiency of the electric engine, some authors believe that the electric car devaluation rate should be lower than that of the internal combustion one (De Carli, 1997). This hypothesis seems to be too optimistic, especially if evaluated in relation to the battery life cycle (see table 6) and its cost. The cost of the battery is equal to 16% of the electric car's purchase cost. In the analysis presented here the devaluation rate of the electric car was considered equal to that of the internal combustion one.

Table seven shows the costs per kilometre of the owned electric and conventional car calculated considering a different number of years since purchase.

The analysis is made considering a utility car used in the urban area. It is assumed that a vehicle runs for 10,000 kilometres per year in the ECE urban cycle (around 38 km per day 24 days per month 11 months per year).

Table 6: Battery's life cycle.

Km/year	*Battery life Pb-gel [year]*		
	High	Low	Average
6000	17	10	13
7000	14	9	11
8000	13	8	10
9000	11	7	9
10000	10	6	8
11000	9	5	7
12000	8	5	7
13000	8	5	6
14000	7	4	6
15000	7	4	5

Table 7: Cost per kilometre of electric and conventional car

Year	*OCK IC [€]*	*OCK EC [€]*
1	0.425	0.625
2	0.362	0.481
3	0.327	0.402
4	0.321	0.387
5	0.309	0.360
6	0.301	0.356
7	0.296	0.344
8	0.292	0.336
9	0.290	0.330
10	0.288	0.326
11	0.287	0.323
12	0.286	0.321
13	0.285	0.319

Table 8: Annual cost for 10,000 km/year.

Year	*IC cost per year [€]*	*EC cost per year [€]*
1	4251.62	6249.57
2	3618.28	4809.26
3	3270.19	4017.68
4	3207.38	3874.84
5	3087.81	3602.91
6	3011.24	3557.79
7	2959.37	3439.83
8	2923.04	3357.20
9	2897.16	3298.35
10	2878.70	3256.37
11	2865.71	3226.84
12	2856.93	3206.86
13	2851.44	3194.39

As is highlighted in table 8, there is no economic feasibility for electric car purchase if we consider 10,000 kilometres travelled per year. Moreover, if we consider the battery life cycle it is not possible to evaluate the results reported after the eighth year.

It is very interesting to evaluate the annual cost for electric and internal combustion cars related to the battery life cycle and to a different number of kilometres travelled per year (VKT). The data obtained (table 9) highlight the economic feasibility of the internal combustion car, if we consider the actual purchase price and the subsidies determined by the law in force.

Table 9: Annual cost related to different VKT and average battery's life cycle.

Km/year	Average Battery life	IC Cost per Year [€]	EC Cost per Year [€]
15000	5	3526.31	3721.91
14000	6	3362.04	3652.99
13000	6	3274.34	3629.19
12000	7	3134.77	3487.43
11000	7	3047.07	3463.63
10000	8	2923.04	3357.20
9000	9	2809.46	3274.55
8000	10	2703.30	3208.77
7000	11	2602.61	3155.44
6000	13	2500.64	3099.19

If we consider a higher level of subsidies equal to 30% of the electric car purchase price, like the one determined by the regional law in force in Emilia Romagna (Regional Law 13th November 1995), the electric car becomes economically feasible at the fifth year after the purchase date, considering 10,000 km travelled per year.

Table 10 shows the data for the annual cost of electric and internal combustion cars related to a different number of kilometres travelled per year and to the average battery life, considering a purchase price subsidy equal to 30% of the electric car's cost. It is interesting to highlight the fact that the electric car becomes economically feasible at 10,000 km travelled per year.

Table 10: Annual cost related to different VKT and average battery's life cycle (with subsides of 30%).

km/year	*Battery's average life [year]*	*Annual cost EC [€]*	*Annual cost IC [€]*
15000	5	3203.02	3526.31
14000	6	3163.68	3362.04
13000	6	3139.88	3274.34
12000	7	3018.15	3134.77
11000	7	2994.35	3047.07
10000	8	2901.95	2923.04
9000	9	2829.30	2809.46
8000	10	2770.65	2703.30
7000	11	2722.34	2602.61
6000	13	2671.60	2500.64

The analysis reported on before highlights the fact that the high purchase cost of the electric car, along with battery life, have a major influence on economic feasibility. We can guess that a household will only substitute a conventional car with an electric one with a subsidy equal to 30% of the electric car purchase cost.

These reasons, together with the evolution of new ways of using private cars (like leasing or car pooling) that are alternatives to ownership, led us to evaluate a different possibility of electric car boosting: car sharing.

In order to compare the economic feasibility of electric car sharing, its annual cost was evaluated calculating the operating cost per kilometre and the annual cost related to the number of kilometres travelled per year. For this analysis the following equation was adopted:

$$OCK_{CS} = FK \cdot VKT + HF \cdot \frac{VKT}{AS} + SR \qquad (5)$$

Let FK be cost per kilometre; VKT kilometres travelled per year; HF hourly cost; AS average speed; SR subscription rate per year to the sharing club.

The annual subscription rate to the car sharing club is equal to €77.47, the hourly cost is €1.65 and the cost per kilometre is equal to €0.20. The total cost of electric car sharing is due to the cost per kilometre and to the hourly cost. So it was necessary to forecast not only the number of kilometres travelled per year but also the time taken for travelling, which depends on the average speed. The average speed was obtained from the data reported in the Urban Traffic Plan of Palermo (Comune di Palermo, 1997), also considering the running time saved thanks to the possibility of using electric cars in reserved lanes and in Limited Traffic Areas (LTA). The average speed obtained is 28 km/h.

As highlighted in table 11, the electric car only becomes economically feasible for a high number of kilometres travelled per year (over 14,000 km/year); by contrast, car sharing is suitable for a number of kilometres travelled per year lower than 14,000 km/year, which is more realistic if we think of its use in urban area.

Table 11: Annual cost of electric car sharing compared to electric car owned related to battery's average life and kilometres travelled per year

km/year	*Battery's average life [year]*	*Annual cost of EC Sharing [€]*	*Annual cost of EC owned [€]*
15000	5	3961.40	3721.91
14000	6	3702.47	3652.99
13000	6	3443.54	3629.19
12000	7	3184.61	3487.43
11000	7	2925.68	3463.63
10000	8	2666.76	3357.20
9000	9	2407.83	3274.55
8000	10	2148.90	3208.77
7000	11	1889.97	3155.44
6000	13	1631.04	3099.19

It could be interesting to compare all the alternatives considered in order to evaluate their economic feasibility. Figures 1, 2 and 3, shown below, compare the three hypotheses of electric car sharing, electric car purchase and conventional car purchase considering three different numbers of kilometre travelled per year.

The comparison points out the clear economic feasibility of car sharing with regard to electric and conventional car purchase considering 9,000 kilometres travelled per year. This advantage becomes lower if related to 11,000 kilometres travelled per year. It is possible to notice that economic feasibility is attained in both cases presented before the limit imposed by the average battery life.

If we consider 13,000 kilometres travelled per year it is possible to note that conventional car ownership is more profitable than electric car sharing and purchase starting from the fourth year (see figure 3).

Fig. 1: Annual cost of electric car sharing , electric car owned and internal combustion car owned related to 9,000 kilometres travelled per year.

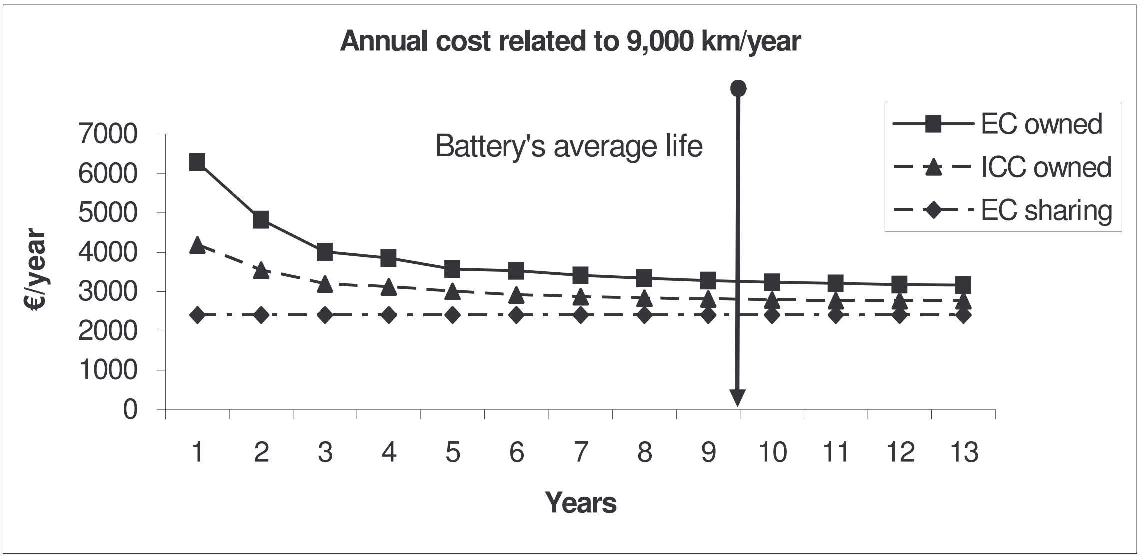
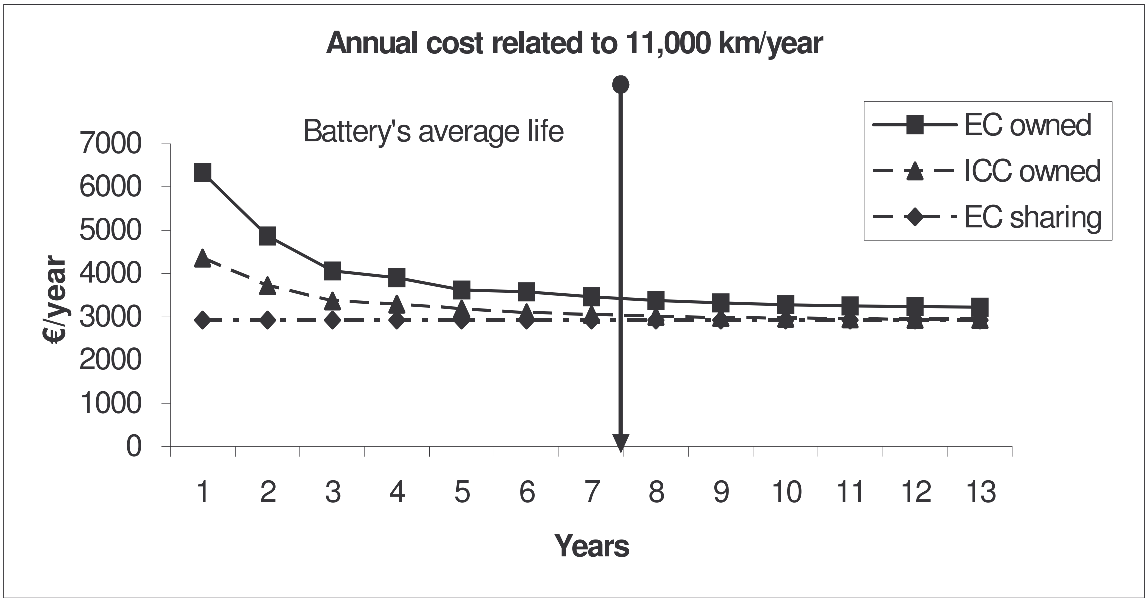
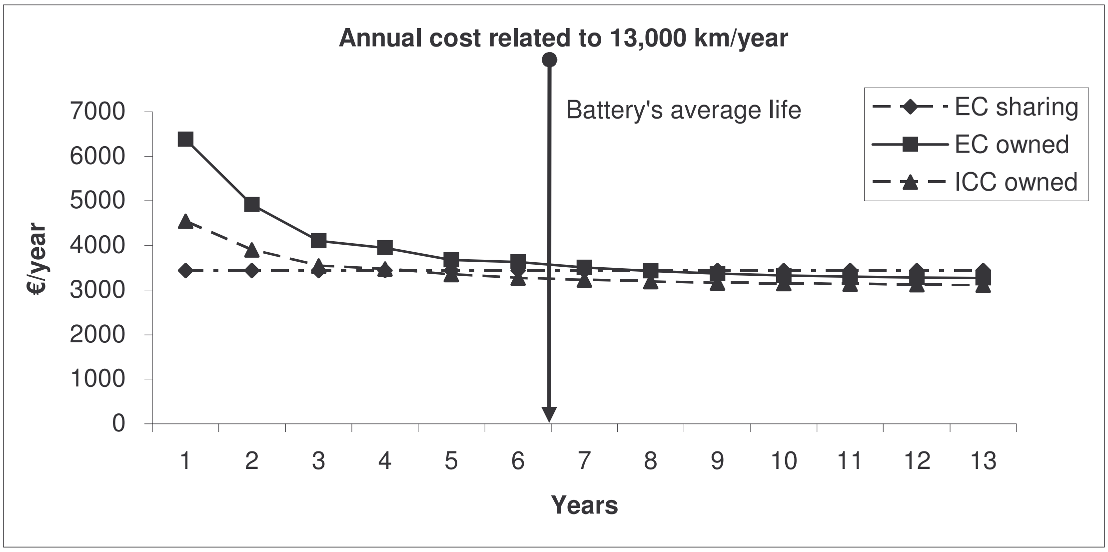


Fig. 2: Annual cost of electric car sharing , electric car owned and internal combustion car owned related to 11,000 kilometres travelled per year.



At all events, it is worth stressing that 13,000 kilometres travelled per year means covering 50 kilometres per day. It is difficult to imagine that people who exclusively travel within an urban area will cover 50 kilometres per day.

Fig. 3: Annual cost of electric car sharing , electric car owned and internal combustion car owned related to 13,000 kilometres travelled per year.



Conclusion

As highlighted by the operating costs per kilometre, the main problem about the introduction of electric cars is the high purchase price. The high cost of battery increases the initial cost of the electric car and also replacement costs are a significant component of the total lifecycle of EC (Delucchi et al., 2001). Our question is whether the government should finance by subsides the introduction of the electric cars on large scale. According to the analysis carried out by Carlsson (2003) the answer was negative, due to the substantial loss in tax revenue that the government would face if a consumer switched to EC. Nevertheless the lower electric vehicle performances can be overcome considering the so-called target of the "hybrid household". As mentioned, the hybrid household is a family unit which owns at least two cars, one used only within the urban area and the other for longer trips. We have to remember that electric vehicle performances seem to correspond better to the characteristics of private transport demand in urban areas. Indeed, over 80% of urban trips amount to less than 50 km per day.

The cost-benefit analysis allowed to identify the level of incentives to be adopted in SP analysis highlighting as the decision maker was interested in the EC. Therefore the electric car can be economic under some conditions, such as the level of incentives and subsidies introduced in Emilia Romagna, or notably for commercial fleet vehicles or different transport services like car sharing and car pooling. Actually, the high purchase price and the low incentives do not allow us to forecast a market share for the electric car. For this reason in the demand analysis two different levels were taken into account for the cost of purchase attribute: one considered the actual level of subsidies for electric car purchase; the other considered a double level of subsidies for electric car purchase.

However, the market share found in the demand analysis reflects people's willingness to pay and their sensitivity concerning health and environmental themes. Of course, the electric vehicle in particular and low emission vehicles in general give major environmental benefits compared to existing vehicles. Thus market penetration of the electric car could depend on pricing of environmental benefits. New fiscal, regulatory, planning and policy instruments which reflect environmental benefits (such as vehicle purchase taxes, fuel taxes, road pricing and so on) should be addressed in the urban areas where the damage due to road transport emissions is greater.

Another policy that should be addressed to introduce electric cars in urban areas is car sharing. The cost-benefit analysis pointed out the economic feasibility of electric car sharing. Anyway, we believe that for a real development of electric car sharing in urban private transport some further advantages should be offered, like free parking and a door-to-door service.

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International competitors and Chinese ports

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Abstract

The aim of the paper is to inquire on how and why large liner shipping companies and international terminal operators have achieved power over Chinese ports.
Liner shipping companies and large terminal operators are fighting for control over the extensive web of commercial relations that China has set up within a short span of time in Asia, acquiring space in the terminals. The increase of throughput in the Chinese ports also underlines the need for the development of ports infrastructures, services and high level of management.
Firstly we describe the network of trade through which China is engaged in commercial relations with the rest of the world, and in particular with the other Asian countries. Secondly we underline the structural and management peculiarities of most important ports of the three main Chinese zones and the presence of large lines companies and terminal operators. Thirdly we outline in short the cooperative action shown by the Chinese and by the great liner shipping companies to jointly manage the Chinese ports.

Keywords: Ports; Shipping companies; Sea transport; Joint ventures.

1. The extensive web of commercial China relations

The intensification of the international division of labour is taking place at a worldwide level but also within the three areas of worldwide economic influence, namely Asia, Europe, the Americas as a result of multilateral trade agreements (Nafta, Mercosud, Afta-Asean, UE etc.[1]).

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[1] *Nafta* includes Usa, Canada, Messico; *Caricom* includes Caribbean islands excepted Cuba; *Andean Pact* includes Bolivia, Colombia, Equador, Peru, Venezuela; *Mercosur* includes Brazil, Argentina, Uruguay, Paraguay; UE + Messico; *Efta* includes Norway, Island, CH, Liechtenstein; *UE* includes 15 new countries; *Gulf Cooperation Council* includes Bahrain, Kuwait, Oman, Qatar, South Arabia, Emirates; *Sacu* includes South Africa, Botswana, Lesotho, Namibia, Swaziland; *Saarc* includes India, Pakistan, Sri Lanka, Bangladesh, Nepal, Bhutan, Maldives; *Afta-Asean* includes Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippine, Singapore, Thailand, Vietnam. We can note that China wants achieve an agreement with Saarc e Afta-Asean to strengthening intra-Asiatic trade. Japan has an agreement only with Singapore. Some experts consider that 'regionalism' shelves WTO 'multilateral' efforts, others that

It is thus important to underline that the influence of Chinese development is crucial not only for maritime trade with the West, but also within one particular zone of the three economic zones that make up the present-day world, namely that of Asia.
The importance of maritime trade within Asia is confirmed by the numbers in Tab. 1a and 1b which show that among countries that trade with China as suppliers /users of raw materials, semi-finished products, products and also as final consumers, a prime role is played by Asian countries, all of which are strongly linked to maritime services[2].

Table 1a: Chinese import 1998-2002 Billion US dollars and var. %.

Range	Country	1998	1999	2000	2001	2002	% total 2002	VAR.% 02/ 01
	Total	140,4	165,7	225,1	243,6	295,2	100	21,2
1	Japan	28,3	33,8	41,5	42,8	53,4	18,1	25,0
2	Taiwan	17,0	19,5	25,5	27,3	38,0	12,8	39,2
3	Korea	15,0	17,2	23,2	23,4	28,5	9,6	22,2
4	U.S.A.	16,7	19,5	22,4	26,2	27,2	9,2	3,9
5	Germany	7,0	8,3	10,4	13,7	16,4	5,5	19,3
6	Hong Kong	6,7	6,9	9,4	9,4	10,7	3,6	14,0
7	Malaysia	2,7	3,6	5,5	6.2	9,2	3,1	49,8
8	Russia	3,6	4,2	5,8	8,0	8,4	2,8	5,6
9	Singapore	2,7	4,1	5,1	5,1	7,1	2,4	37,5
10	Australia	4,2	3,6	5,0	5,4	5,8	1,9	7,8
11	Tailandia	2,4	2,8	4,4	4,7	5,6	1,8	18,8
12	**Italy**	2,3	2,7	3,1	3,8	4,3	1,5	14,2
13	Indonesia	2,5	3,1	4,4	3,9	4,5	1,5	15,8
14	France	3,2	3,8	3,9	4,1	4,2	1,4	3,6
15	Canada	2,2	2,3	3,7	4,0	3,6	1,2	-10,0
16	UK	2,0	3,0	3,6	3,5	3,3	1,1	-5,4

Source: World Trade Atlas. ICE Pecking Database

In conclusion, the extensive web of commercial relations[3] that China has set up within a short span of time indicates the complexity of the maritime legs that involve China, and justifies the battle between the liner shipping companies in their attempt to acquire

'regionalism' helps free trade, others that 'regionalism' set up chaotic trade agreements. USA try to achieve bilateral agreements to deteriorate the solidarity of emergent countries.

[2] Japan is the first supplier of semi finished goods to China, followed by Taiwan, South Korea, and then Hong Kong, Malaysia, Singapore, etc.
With regard to the export trade, the USA ranks top of the list as China's main purchaser, but China also has a thriving export trade to Hong Kong, Japan, South Korea and then Singapore and Taiwan.

[3] This on the one hand demonstrates the growth of the Chinese liner shipping companies and on the other hand it implies that the China is opposing Japanese domination in Asia also at sea. The fact that China is becoming the driving force of the Asian economy is closely linked to the positive factors which, together with China's own internal resources in terms of raw materials and its geographic extension, have favoured its particular type of growth (liberalization of the economy, favourable attitude towards direct foreign investment, high propensity to save and to invest, the link with the US currency, fairly satisfactory balance between imports and exports etc.). These factor, apart from the low labour costs, are different from those that previously motivated Japanese development or, more recently, the development of the Indian economy. The difference is that the Chinese economic growth model is not based essentially on exports, because domestic demand within China also plays a major role.

space in the terminals. China's new commercial network calls for increasingly reliable infrastructures, qualified management of ports and maritime services. The *growth* of Chinese maritime services out of the worldwide share rose from little more than 5% in 1983 to roughly 14% in 2003. (Source: FMI, database 2003).

Table 1b: Chinese exports 1998-2002 bill $ - var. %.

Range	Country	1998	1999	2000	2001	2002	% total 2002	VAR. % 02/01
	Total ⇓	183,8	194,9	249,2	266,9	325,6	100	22,3
1	U.S.A.	38,0	41,9	52,1	54,3	69,9	21,4	28,9
2	Hong Kong	38,8	36,9	44,5	46,5	58,4	17,9	25,6
3	Japan	29,7	32,4	41,7	45,1	48,4	14,8	7,8
4	Korea	6,3	7,8	11,2	12,5	15,4	4,7	23,8
5	Germany	7,4	7,8	9,3	9,8	11,3	3,4	16,6
6	TheNederlands	5,2	5,4	6,7	7,3	9,1	2,7	25,1
7	UK	4,6	4,9	6,3	5,8	8,1	2,4	18,9
8	Singapore	3,9	4,5	5,8	5,8	6,9	2,1	20,3
9	Taiwan	3,9	3,9	5,0	5,0	6,5	1,9	31,7
10	**Italy**	2,6	2,9	3,8	4,0	4,8	1,4	20,9

Source: World Trade Atlas ICE Pecking Database

2. Consequences of the great increase in containers in Chinese ports

By virtue of its ports China has now reached a world-class position for container traffic. All the ports are experiencing a great increase in container movement. As a consequence all the ports are aiming at developing not only their own infrastructures but also the necessary management of the ports.

Shanghai has become the third world port for container throughput and Shenzhen the fourth in a tremendous upsurge. See tab. n. 2.

Table 2: Rank of the world ports (TEU 2003).

1-Hong Kong	20.000	+4%
2-Singapore	18.300	+8%
3-Shangai	11.280	+31%
4-Shenzen	10.800	+42%
5-Busan	10.370	+11%
6-Kaohsiung	9.000	+6%
7-LosAngeles	7.020	+7%
8-Rotterdam	7.005	+7%
9-Amburgo	6.003	+11%
10-Anversa	5.450	+14%

Source: Containerisation International 2004

The ports in the following table are the top 10 in China and maintained the same ranking in 2003, although the quantity of containers handled once again rose sharply.

Table 3: Top 10 Chinese ports up to December 2001.

Grade	Port	Mil TEU	% Growth prev. year
1	Shanghai	6,3304	112.8
2	Shenzhen	5,0745	127.2
3	Quingdao	2,6385	124.4
4	Tianjin	2,0110	117.7
5	Guangzhou	1,6283	113.8
6	Xiamen	1,2948	119.4
7	Ningbo	1,2131	134.5
8	Dalian	1,2089	119.6
9	Zhongshan	0,5464	108.0
10	Fuzhou	0,4176	104.3

Source: International Economic and Trading Information, 19 January 2002**.**

The construction of ports has been the government's *prime objective* in order to ensure both the import of raw materials and machinery and, in a further period, the export of its own goods in containers. At present, however, the government policy is changed: now for ports foreign investments and management are favoured.

As a consequence Chinese Authorities want to increase their relationships between the Chinese ports and the liner shipping companies/terminals operators (particularly from Hong Kong). From the point of view of foreign companies, they want to achieve not only the control of the throughput of the Chinese containers but also of the large web involving the Chinese trade by the means of a cooperative behaviour.

China may be divided into *three large productive zones* that are equipped with ports.

The zone in the north has Dalian, Tianjin (port of Peking) and Quingdao as ports of reference.

The central area has the great port of Shanghai, followed by Ningbo and Xiamen off the island of Taiwan, as ports of reference.

The southern zone relies on the ports of the province of Guangdong, namely the traditional port of Canton or Guangzhou and the three ports of Shenzhen. The most important port cities of China therefore extend from north to south and all have free zone depots (ICE, 2002; Guangdong Statistical Yearbook, 2003).

China needs to enlarge the ports, to fit in new equipments and to manage them with high level of experience.

3.The decisive presence of international liner and terminal operators companies in Chinese ports.

The port of the city of **Dalian** in the north is near to North Korea at the tip of the Liaotung peninsula, which represents the furthest point of Manchuria (fashion industry and components production, raw materials). The Singapore Port Authority (PSA, Singapore) manages 8 berths. The port of Dalian is the gateway to the regions of the north, the traditional centre of China's raw materials.

The port of the city of **Tianjin** in the north is situated on the Yongdinghe River less than 50 km from the mouth of the river. It is the port for Peking, about 100 km away (import-export of raw materials and products). It is managed by the American company CSX World Terminal in joint collaboration with the Port Authority and the Anglo-Dutch P&O.

The port of the city of **Quingdao** in the north, a former German protectorate located south of Tianjin, is situated on the Yellow Sea in the north east off South Korea (typical products served by the port are: beer, mineral water, metalworking and many other products); the Danish company APM Terminals manages 20% of the port's terminals. The forecast for 2004 amounts to 4 million TEU.

The port of the city of **Shanghai** in the centre is the largest traditional port of China. The port is on the River Yangtse (which has only 8.5m. of draught and so the city is reached by barge). The Shanghai Container Terminal SCT, the largest terminal, is managed by a joint venture between Shanghai Port Authority and the Hutchison Port Holdings of Hong Kong.

Hutchison is the company with the most shares in Chinese ports[4]. The port reached around 10 million TEU in 2003 (all types of freight). However, post-Panamax ships, i.e. ships larger than the Panama Canal, cannot dock at the port of Shanghai. This is a severe limitation because all modern container vessels show a marked tendency towards gigantisms in order to achieve economies of scale and rapid services by using the hub and spokes system. The port therefore needs new terminals and dredging for full-container ships of 6000/7000 TEU and over.

The new port will be built to a colossal design on the island of Yangshan in the bay of Hangzhou and will be 15 metres deep, with a 30 km bridge joining it to dry land and to Shanghai. It will have 52 terminals covering an area of 45 km^2; when it is finished, in 2010, it will be able to receive over 15 million TEU.

In addition to the Chinese shipping liner companies Cosco and China Shipping, the Danish company Maersk of the Moeller Group - the largest worldwide shipping company – as well as the Anglo- Dutch P&O ports and the American CSX World Terminals will all be involved in financing the new port and managing the terminals. The existing port has many services with the Mediterranean.

The port of the town of **Ningbo** in the centre is about 150 km south of Shanghai, and boasts a container port which showed a strong, roughly 50% growth in 2003 (toys, textiles, handicraft, light industry items). It will be capable of receiving 8200 TEU ships from the French-Chinese company CMA-CGM as it is 17 m deep.

Another company worth mentioning is Hutchison Port Holdings which, as noted above, has the highest number of investments in Chinese ports and terminals. In fact, at the start it held a virtual monopoly on account of its advantageous position in Hong Kong.

[4] Shares of Hutchison Whampoa in Chinese ports: 1-Shanghai Container Terminals (group's interest 37%), Shanghai Pudong International Container Terminals- Waigaoqiao phase I (group's interest 30%). 2-The Ningbo Beilun International Container Terminals (group's interest 49%). Moreover: the Hutchison Delta Ports (Pearl River Delta Ports in Southern China) has six joint venture river and coastal ports in 3-Jiuzhou, 4-Nanhai, 5-Gaolan, 6-Jiangmen (group's interest 3+4+5+6=50%), 7-Xiamen (group's interest 49%) and 8-Shantou (group's interest 70%). Source: Annual Report 2003 Hutchison Whampoa Limited, Operations Review Ports and Related Services.

The port of the city of **Xiamen** in the centre is on an island near the coast and is just 5 miles off the coast of Taiwan. It is linked to the mainland by a bridge with an airport and a fully equipped port (it handles extensive traffic including marble, granite and various products). The port is managed by Hutchison Port Holdings. We have to note the strong presence of Hong Kong societies in the Chinese ports in the northern zone as well in the southern zone of the country.

The port of the city of **Guangzhou (Canton)** on the Pearl River in the Guangdong is the port nearest to the manufacturing industries of the Pearl River Delta. South of the port of Canton is the city of Shenzhen and, still further south, Hong Kong.

The large liner shipping company Singapore PSA purchased 49% of Guangzhou Container Terminals in 2001; the remainder belongs to Guangzhou Harbour Bureau. In 2002 more than 120 million US dollars were invested in the port for improvements to infrastructures and transport, even though draught is still poor at only 11.5m at low tide. Owing to the shallow draught the port of Canton cannot really compete with Shenzhen and Hong Kong. There are plans for it to be dug out to 13.5 m. (and to maintain that depth by combating silting that affects ports on the mouth of a delta) in order to allow 4000 TEU ships to dock, because it is nearer to inland manufacturing areas, it is a cheaper port and inland transport distances are shorter and therefore less costly. But it is unlikely that the river could be dug out to more than 13 metres in depth; the port of the great district of Canton thus remains convenient only for small-medium tonnage vessels that *serve intra-Asia and Australia-Asia traffic.*

However, substantial investments are being made in the various terminals and on the docks in the port of Canton. In 2003 the port reached around 2 million TEU and aims to reach around 4 million in 2005.

The Guangzhou Container Terminal is the third important project in which PSA is investing in China, because it has a strongly developed inter-regional trade with Singapore and Japan which is complementary to its business activities. Moreover PSA engages in considerable intra-Asian trade from Singapore.

Shenzhen is the second port city in the Guangdong region on the Pearl River Delta. It is nearer to the sea compared to Canton and lies just 20 nautical miles north of Hong Kong (around 40 Km).

Shenzhen has not one port but three: Yantian, Chiwan and Shekou.

The total growth of containers in the 3 ports of Shenzhen has been considerable, reaching 10,800,000 TEU in 2003. Shenzhen holds fourth world position for container traffic after the Chinese port of Shanghai, which ranks third after the hub ports of Singapore and Hong Kong (see tab. 2&3). Yantian is seeking to become the hub port for Guangdong, rivalling the largest hub[5] port in the world, that of Hong Kong.

The other 2 ports remain below one million TEU and for now are mainly feeders for Hong Kong or rather complementary to Hong Kong.

[5] Hubs are ports which have seen massive investment in technology designed to cut container handling time, and they are endowed with deep draught enabling them to receive increasingly large mother ships with which they can obtain greater economies of scale. Hub ports are the reference point for collecting container goods from very extensive areas using the hub and spokes system. There is fierce competition among the world's largest liner shipping companies, in a tough battle to eliminate competitors and take control of container trade in the area

Table 4: Containers handled in the 3 ports of Shenzhen, '000TEU.

year	total TEU	Shekou SCT	Chiwan CCT	Yantian YICT
1994	177,9	87,1	9,1	13,3
1995	283,6	89,9	31,4	105,7
1996	589,0	89,9	49,6	353,5
1997	1,147,3	214,8	150,2	638,4
1998	1,951,7	463,1	203,3	1038,0
1999	2,986,5	574,1	350,1	1588,1
2000	3,993,7	721,0	450,0	2146,0
2001	5,074,5	753,6	643,7	2752,3

Source: Shenzhen Port Authority 2002.

Shenzhen, as stated, has three ports:

The port of **Yantian** with YICT container terminal already reaches about 15 metres draught and will reach 16. The growth of the container terminal of Yantian is particularly impressive, rising from 13,000 TEU in 1994 to 2,753,300 in 2001 and over 4 million TEU in 2003 (Source: Containerisation International).

Yantian International Container terminal (YICT) is owned to the extent of 50.5% by the company which owns the majority of Chinese terminals: Hutchison Port Holdings Group (which also owns the HIT terminal of Hong Kong, i.e. the largest terminal of that port). It can already receive ships up to 5000 TEU owing to its generous depth of over 14 metres.

The Chinese company Cosco and all the large international companies are customers of the terminal.

The port of **Chiwan**, with the CCT container terminal, which is the most important, has a draught of about 14.5 m. It is situated west of Shenzhen, and is managed by Modern Terminals Limited of Hong Kong, a terminal management company owned by the important China Merchant Holdings of Hong Kong. The latter company has investments in all sectors of Chinese ports and land logistics. The port handled less than 1 million TEU in 2003.

The terminal has made an agreement with the barge transport companies of the Delta to set up a joint service. Such barges transport containers from large and small company scattered through a complex district. The terminal is situated about 7 km. from Dachan Bay, where American investment by CSX World Terminals is expected (this company is the most recent newcomer in this type of business in China but it already boasts substantial achievements). The aim is to build a container terminal because Shekou and Chiwan cannot expand any further west in the Pearl Delta due to lack of land.

The port of **Shekou** (SCT terminal) handled about 800,000 TEU in 2003. Here too digging is under way to achieve a draught of 15m., with plans for a further increase to 17m in the future[6].

The Anglo-Dutch company P&O manages the terminal as a joint venture with MTL (Modern Terminal Ltd owned by China Merchants, Hong Kong) and in co-ownership with Swire Pacific and Cosco. The Israeli ZIM is the port's leading client.

These two ports, Chiwan and Shekou, remain below one million TEU and for now are mainly feeders for Hong Kong or rather complementary to Hong Kong[7].

[6] In 2003 a further 700m of dock was built for a container terminal, which will be followed by another two; in the future there will be 22 dock cranes.

4. Co-operation and Chinese ports.

All the largest international maritime operators and liner shipping companies take *part both in the management and in plans for expansion* of all the ports and terminals that handle Chinese containers. We have examined their impressive presence in all main Chinese ports. They are engaged in a complex policy the winner of which will be victorious in terms of influence on Chinese ports (and in terms of profit from the strong throughput of containers).

For the time being the companies are following a flexible policy whereby, on the one hand, they act as the best, traditional suppliers of maritime services and complementary services while, on the other hand, they are expanding their direct control over all Chinese ports in a policy of expansion that includes investments in infrastructures offered. Chinese authorities and foreign companies are both keen to strengthen the collaboration in terms of planning and developing the container terminals. This coalition is definitely helpful in getting the best out of combining commercial expertise of foreign societies with the huge market and resources of China, to the benefit of both sides.

At present, the Chinese government does not believe that the direct Chinese 'management' of the terminals is of strategic importance, since analysts have assured double figure annual growth of containers for all the ports.

Liner shipping companies, foreign operators and operators from Hong Kong[8] are investing enormous sums of money in rebuilding and deepening the Chinese ports in preparation for the arrival of increasingly large vessels. In addition they manage the ports as a joint venture with full approval and collaboration of the port Authorities and local Authorities .

This is significant because it shows the flexibility of the Chinese approach, which awards priority to efficiency and the ability to attract trade, an ability already confirmed by the experience of foreign companies which manage the ports in joint ventures (Yuan Lu, ed. Child J., 1995). This approach is clearly cooperative. A cooperative strategy is the attempt by organisations to realise their objectives via cooperation with other organisations, rather than in competition with them. The cooperative strategy puts its focus on the benefits which can be obtained through cooperation and on how to manage the cooperation in order to achieve them. The Chinese authorities have chosen a soft strategy which offers significant advantages for Chinese ports which are lacking in experience, particular competencies or resources. The cooperation may offer easier

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[7] The two smaller ports of Shekou and Chiwan compete with one another as well as with the large port of Yantian and with Hong Kong. In contrast, the three ports of Shenzhen are not in competition with Canton (Guangzhou), as the latter can receive only small or medium sized vessels because of the shallow draughts and problems of silting up.

Together, the Delta ports form a network that offers a diversified range with regard to depth, amount of equipment and number of berths. In the Delta ports one finds a clear distinction between *full container inter-oceanic* high tonnage traffic that requires deep ports of over 14-15 metres in depth, with huge dock aprons, versus *small-medium sized ships dealing with intra-Asian* and Asian-Australian traffic. Each port has its own specific characteristics, even if all of them are aiming to achieve greater depth in order to receive larger vessels.

[8] All the infra-structural investments in Guangdong take into account the proximity of Hong Kong. Although Hong Kong is more expensive, it provides high level of general offer, insurance and banking services etc. that are still only scantily available in Guangdong and are often run by Hong Kong companies.

access to new technologies (in favour of China), to new markets (in favour of foreign companies), and opportunities for mutual synergy and learning.

China is the magnet for international port investors in what promises to be a very tough battle, in particular if one bears in mind, that as from the end of 2004 they are allowed to become a majority share-holder in the terminals. Foreign companies were in effect previously restricted to holding a less than 50% share of a mainland terminal structure, but the Chinese government (which obviously retains the 'state ownership' of port land) has gradually taken measures to alleviate this rule in the run-up to the generalised opening set for 2005.

This more lenient approach is motivated by the advantage of having experienced, foreign companies both as investors and as management and also to attract ships and containers. However, the maritime shipping companies and international terminal operators state that despite the 'liberality' in the management of investors, duties on freight severely restrict final profits.

The government therefore on the one hand encourages foreign investors and joint management and on the other exploits them. But investors in container terminals nevertheless *believe that it is to their advantage to move into hub and feeder ports in China*, where growth in production and of import/export containers is undergoing a strong increase[9] and opens up the prospect of long and remunerative contracts (through which the companies will recoup their investments and will increase their market power), by providing services and cooperation for the great international manufacturing producers in China.

Given China growth in manufacturing and its high export rate, various foreign terminal managers already established in the hub port of Hong Kong have invested heavily in the Chinese ports and in three (prevalently feeder) ports of Shenzhen. This demonstrates that they intend to build up a favourable context for establishing activities in the area, whatever the future brings.

Meanwhile the supply of infrastructures and services sees Hong Kong companies ever more active in China and Guangdong[10]. The companies also if Hong Kong is the leading world port, cannot ignore the growth of Chinese ports in general and the three of Shenzhen in particular. As a consequence they offer the greatest cooperation to Chinese ports and in particular to Guangdong ports. Shenzhen, is situated just 20 nautical miles

[9] According to Ocean Shipping Consultants (2003), under the hypothesis of a scenario of normal growth, world container demand, which stood at 266 million TEU in 2002, will undergo a growth of around 74 % in 2010, with a further increase of 25% in 2015. A considerable proportion of this trade concerns China. For China the official growth rate published by UN ESCAP (Socio-Economic Commission for Asia and the Pacific), predicts an increase in volume of handling in the ports of the Far East and of South East Asia — taking 1999 data as reference — equivalent to 62% by 2006 and a further 40% by 2011.

[10] One of the characteristics of Hong Kong companies is therefore that of delocalizing manufacturing industries to China, where land and labour is cheaper, while keeping a tight control over the entire production supply chain included transports and the management of the ports. Head offices and the commercial management are maintained in Hong Kong. According to the *Bank of China Group Survey, Vol. IV No 4, 2000.* "Since the major resources of Delta and activities are under Hong Kong's control, Hong Kong has played a leading role in the economic development of the Pearl River Delta and thus has obtained huge benefits." It must be emphasised that in spite of Hong Kong's union with China in 1997, it still remains an independent customs area according to the Basic Law (a kind of small constitution for the territory of Hong Kong).

from Hong Kong and is up to 60% cheaper than the latter for the handling of containers, although time and service are far less reliable[11].

In this perspective, the independence of Hong Kong forms a unique situation for the promotion of co-operative interaction particularly with Guangdong. Such an approach may be evaluated by using various theoretical tools including game theory, strategic-management theory and organisation theory (Rumelt et al., 1997). These analytical tools can be effective in evaluating the growth of the market strength of liner and terminal management companies of both regions.

For example the largest port of Shenzhen, Yantan, is, as it has already been mentioned, managed by Yantian Container Terminal Limited, a joint venture between Hutchison Ports Yantian Container Terminal Ltd. and Shenzhen Yantian Port Group Company Ltd. *in a blend of specialised port expertise on the one hand, and management of political-bureaucratic relations on the other*[12]. Another co-operative attitude can be seen between Hong Kong Port and Maritime Board and Shenzhen Municipal Port Authority, which seeks to develop terminal containers by exploiting the expertise of Hong Kong and the resources and market of Shenzhen[13].

But the cooperative attitude can achieve an other goal from the point of view of large shipping companies and international operators: to be in good position to control not only the throughput of the containers in the Chinese ports but also the extensive web of commercial relations that China has set up. The complexity of the maritime legs that involve China justifies the effort between the liner shipping and terminal management companies in their attempt to acquire space in the terminals in order 1-to participate directly at the international market in which China acts as a protagonist and 2- to deepen the links with Far East countries where new terminals are building up.

5. Conclusions

The cooperative strategy can offer significant advantages for organizations that are poor in certain types of skills or resources as Chinese ports compared with terminal management companies and shipping companies. It concentrates on the benefits that can be obtained through careful management of cooperation (Child and Faulkner, 1998). Therefore the cooperative enterprises form agreements with subjects that possess skills or assets that are complementary to one another. In this manner, cooperation can facilitate access to new markets and provides opportunities for mutual synergies or exchange of knowledge.

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[11] This explains why highly valuable goods or those that require precise delivery times, often for just in time production or to meet sales deadlines pre-established by the market, will accept Hong Kong's high prices.

[12] Child, J. and Faulkner, D. (1998), Strategies of Cooperation *: Managing Alliances, Networks and Joint Ventures*, Oxford University Press, Oxford.

[13] Given the delocalisation of many Hong Kong companies to the Guangdong, it is also worth noting the Governor of Hong Kong's proposal for a *free trade area with Macao and the Region of Guangdong,* with the aim of completely liberalizing trade with the area across the border (Source: Hong Kong Trade Development Council)

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Urbanization and urban transport in india: the search for a policy

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Abstract

Urban population in India has increased significantly from 62 million in 1951 to 285 million in 2001 and is estimated to be around 540 million by the year 2021. In terms of percentage of total population, the urban population has gone up from 17% in 1951 to 29% in 2001 and is expected to increase up to around 37% by the year 2021. Consequently, the number and size of cities have also increased significantly. Although circumstances differ considerably across cities in India, certain basic trends which determine transport demand (such as substantial increase in urban population, household incomes, and industrial and commercial activities) are the same. These changes have placed heavy demands on urban transport systems, demand that many Indian cities have been unable to meet.

This paper attempts to highlight the need for a cogent urban transport policy without which there will be ad hoc interventions. Such interventions, apart from not adding up to a comprehensive approach, will result in greater confusion. Furthermore, it emphasizes that if there is no worthwhile public transport, it will still need to be reinvented to promote a better quality of life. The need of the hour is formulation of an urban transport strategy that is both pragmatic and holistic in its approach.

Keywords: Urbanization; Urban Transport Policy.

1. The present context

The making of transport policy is a tricky affair. Transport being essentially a derived activity its conceptualization and articulation depends upon a variety of social and economic issues and longer-term goals. India has however attempted twice to evolve a transport policy. The first in 1966 when the dreams of independence were still alive and the second in 1980 under the shadow of zooming oil prices. In a typically oriental fashion, on both the occasions, the policies were accepted in toto by the government and subsequently subjected to studied neglect. The silver lining however was the establishment of State Transport Undertakings (STUs) which in the 1960s and the 1970s did an enormous service in linking up towns and villages across the country, particularly

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in the western and the southern parts. Even though the service may leave much to be desired in terms of quality, STUs' importance lies in the fact that unlike in most other developing countries one can reach out in India to almost every village.Urban areas in India, which include a wide range of mega cities, cities, towns etc. are not all that lucky in terms of intra-city transportation. Transport in this context has been a victim of ignorance, neglect and confusion – or all these at once.[1] This is perhaps due to the fact that the majority of urban population was relatively recent migrants and has yet to develop a sense of belonging in order to influence policies. Whatever influence the public had was not so much for improving the quality of transport but in reducing the fares which further added to inadequacy and inefficiency. There is absence of policy in urban areas. Indeed policies are most needed here in view of the complexities in urban infrastructure and the need for greater integration in providing, maintaining and managing urban public utilities. The political and bureaucratic set up has done little to introduce professionalism without which the planning and regulatory measures can only be inadequate, inefficient and at the most half-baked. It is essentially for these reasons that new threats are emerging in the shape of congestion and pollution. In other words, whatever be the transport system, people will move but the modes they choose and the manner in which they travel will tend to be unsafe and inefficient without careful articulation and planning. This paper is essentially a status paper arguing for greater attention to policy making and its implementation.

2. Urbanization pattern in India

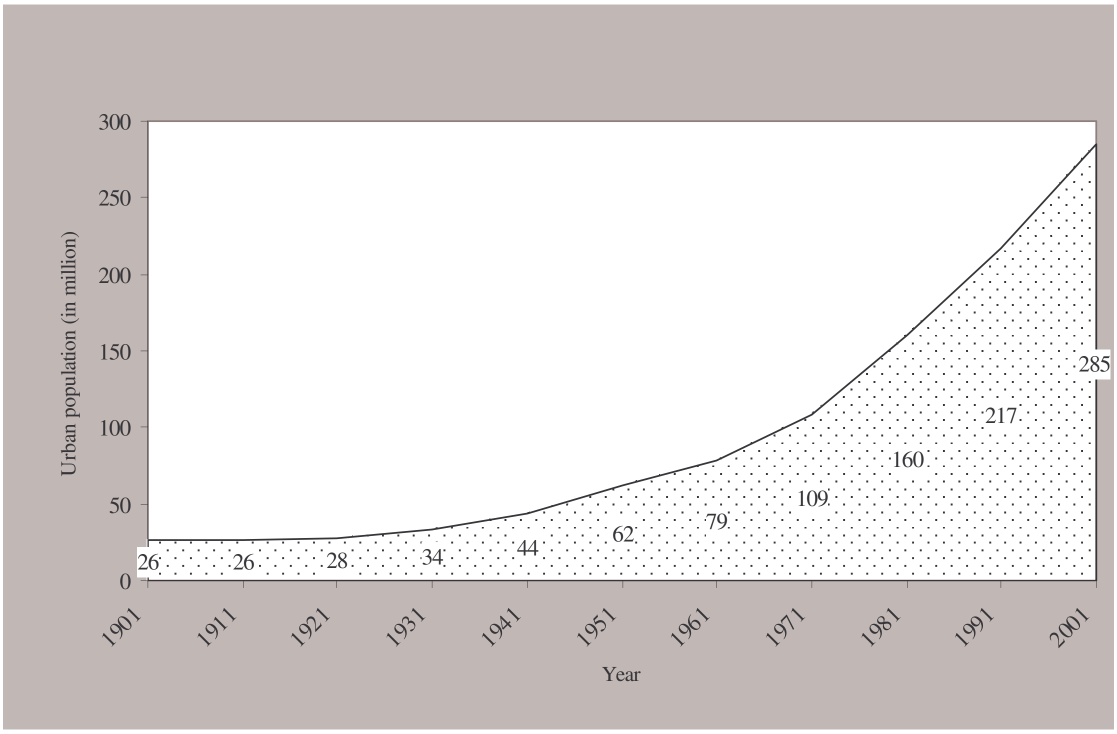
India's urban population is growing at an average rate of around 3 percent per annum. It has almost doubled during the period between 1981 and 2001 from 160 million to 285 million (Figure 1). The average rate of growth of the urban population is not expected to change significantly during next twenty years. Assuming decadal increase of around 37%, India's urban population is expected to be around 540 million during 2021. In terms of percentage of total population, the urban population has gone up from 17% in 1951 to 29% in 2001 and is expected to increase up to around 37% by the year 2021 (Figure 2). Consequently, the number and size of cities have also increased considerably.

During the 1990s, 68 million people joined the ranks of urban dwellers – which imply a slower decadal growth of 31 percent when compared to the growth of 36 percent during 1980s. Although urbanization has slowed down in India during the 1990s, the number of metropolitan cities – those with a million plus population – has increased over this period. From 23 in 1991, the number of metropolitan rose to 35 according to the Census of India, 2001. India's metropolises grew rapidly during the 1990s with Surat registering the fastest growth of 85.1 percent followed by Faridabad (70.8 percent), Nashik (58.8 percent), Patna (55.3 percent), Jaipur (53.1 percent), Delhi (51.9 percent), Pune (50.6 percent), and Indore (47.8 percent).[2] The overall decadal growth rate of the 35 metropolises worked out to be around 34 percent, which is higher than urban India's growth of 31 percent. India's big cities now account for a larger share of total urban population – a trend that has been observed since Independence. In 2001, the

[1] *Supra* note no. 1.
[2] Mohan, N. C., (2001), "The Paradox of Urbanisation", *The Financial Express*, July 26th.

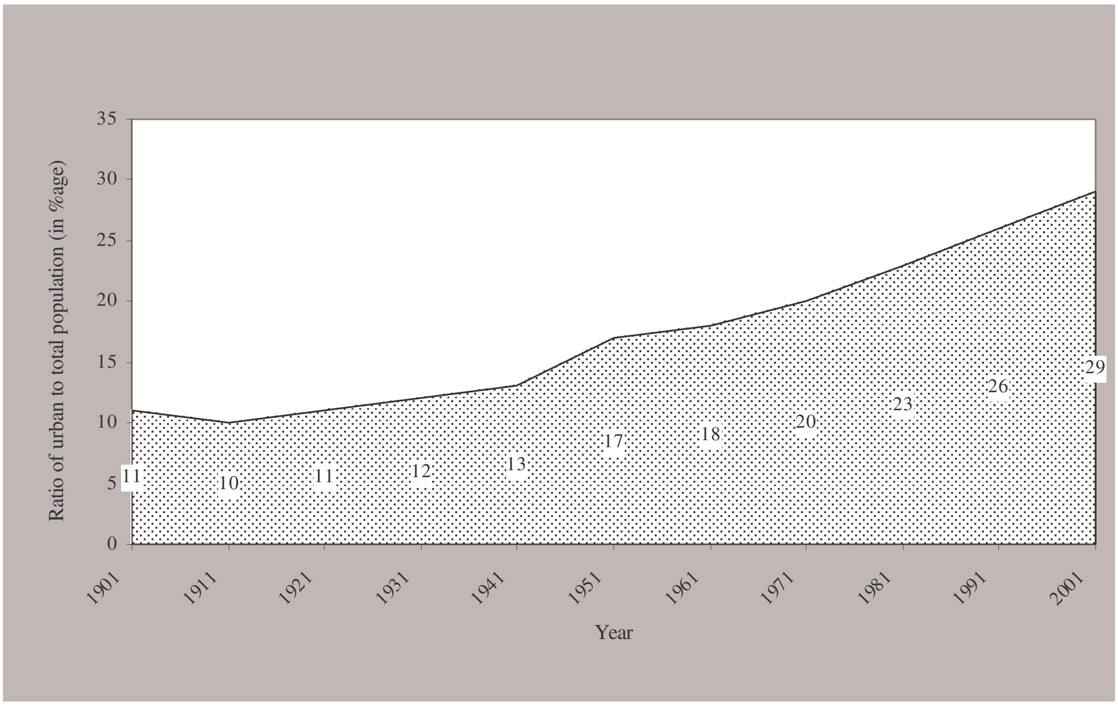
share of metropolitan cities was 37.8 percent, up from 32.5 percent in 1991 and 26.4 percent in 1981.

Figure 1: Urban Population in India.



Sources: (1) Census of India 1991. Registrar General & Census Commissioner, Ministry of Home Affairs, Government of India, New Delhi. (2) Mohan, N. C., (2001).

Figure 2: Share of urban population in India.



Sources: (1) Census of India 1991. Registrar General & Census Commissioner, Ministry of Home Affairs, Government of India, New Delhi. (2) Mohan, N. C., (2001).

The pattern of urbanization has many distinguishing characteristics. There is a great variation across states. The range is from around 8% for Himachal Pradesh to around 35% for Maharashtra.[3] Many factors contribute to this variation. Transport is one of them. It is interesting to note that the level of economic development is higher in those states where urbanization level is high indicating a positive correlation between urbanization and economic development.

The distribution of urban population by city size widely varies and is skewed towards larger cities. One specific feature of India's urbanization is the increasing metropolitanization, that is, growth in the number and size of cities with a million plus population. The trends indicate the continued urbanization and metropolitaniztion in the years to come.

3. Urbanization – inevitable and desirable

The urbanization pattern and trends raise a number of issues. There is a debate as to whether it is an index of development or distress. The very process of urbanization has often been looked as something undesirable. While the objections used to be on social and moral grounds earlier, the criticism lately is more on economic grounds such as provision of requisite infrastructure and civic amenities at rapidly escalating per capita costs. Despite all the objections, the rate of urbanization has not even retarded, not to speak of its being halted. Certain inevitability about the process is being accepted steadily. It is felt that urbanization is necessary for the benefits of sharing modern technology for the growth and development of the entire national economy. In India, urban areas contribute more than sixty percent of the national income. It is expected that they will assume greater economic importance in the coming years.

Until recently policies towards urban areas have often been apologetic. The focus has been on rural areas where the poorest of the poor were said to live, and from where, it was argued agriculture-led growth must emanate. It was also argued that cities should be restricted in size, and action to tackle their problems should be limited to avoid increasing their attraction. This strategy was directed to limit migration towards cities and thereby promoting growth and balanced development of the country. Several facts reveal the weaknesses of this approach, which lead to a reappraisal of the strategy. It is clear that the ambiguity, which often underpinned discussion on urban policy, is presently undergoing rapid change towards a new and positive stance.

4. Urban transport and city efficiency

Many cities in India have grown at an unprecedented rate in recent years, and this growth is expected to continue in the foreseeable future. In 1951 only five cities in India had populations in excess of 1 million: Kolkata (4.67 million), Mumbai (2.97 million), Delhi (1.43 million), Chennai (1.54 million), and Hyderabad (1.13 million). By 2001, however, there are 35 cities in India whose population topped 1 million, and by the end of the year 2021 they are expected to be at least fifty.

Fast-growing cities in India have nurtured business and industry and have provided jobs and higher incomes to many migrants from rural areas. Thus, it is important that

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[3] Ranganathan, N., (1995), "National Urban Transport Policy – A Framework", *Indian Journal of Transport Management*, Vol. 19, No. 2, pp. 85-98.

cities function efficiently – that their resources are used to maximize the cities' contribution to national income. Economic efficiency of cities and well-being of urban inhabitants are directly influenced by mobility or the lack of it. City efficiency largely depends upon the effectiveness of its transport systems, i.e., efficacy with which people and goods are moved throughout the city. Poor transport systems stifle economic growth and development, and the net effect may be a loss of competitiveness in both domestic as well as international markets.

Although Indian cities have lower vehicle ownership rate (number of vehicles per capita) than their counterparts in developed countries, they suffer from worse congestion, delay, accidents, air and noise pollution, energy wastage etc. than cities in industrialized countries. In Kolkata, for example, average speed during peak hours in Central Business District (CBD) area goes down as low as around 10 kms per hour. This indicates both the amount of time and energy that are wasted and the scale of opportunity for improvement.

Public transport systems in Indian cities have not been able to keep pace with the rapid and substantial increases in demand over the past few decades. Bus services in particular have deteriorated, and their relative output has been further reduced as passengers have turned to personalized modes and intermediate public transport, adding to traffic congestion which has had its impact on quality as well. It is often thought to be inegalitarian to provide special services such as air-conditioned buses, express buses, and premium or guaranteed seats in return for higher fares. Experience shows that the public welcomes a wide choice of transport, but despite the clear need for greater variety in public transport, there is a tendency in established monolithic corporations to offer very limited choice.

Spending on transport is too often influenced by notion of political prestige than by rational calculations of economic growth. Most Indian cities spend too much on politically attractive but costly facilities, such as elevated roadways and mass rail transit systems, instead of making modest labor-intensive road improvements, extending city streets, and promoting low-cost bus operations. As per a World Bank Study, the money spent building just a few meters of subway could be used instead to construct or upgrade several miles of streets.[4]

The city cannot afford to cater only to the private cars and two-wheelers and there has to be a general recognition that without public transport cities would be even less viable. Much needs to be done if public transport is to play a significant role in the life of a city. Measures need to be taken in the short-run to enhance the quality of public transport service and to impose constraints on the use of private vehicles in cities. In the long-run, there needs to be effective land use planning and the introduction of new transit systems to keep the city moving. It must not be forgotten that cities are the major contributors to economic growth and movement in and between cities is crucial for improved quality of life.[5]

5. Current urban transport scenario in India

On an average, during peak hours in Mumbai, the actual occupancy in a suburban train is in excess of 4000 passengers, which have maximum desirable capacity of 2600

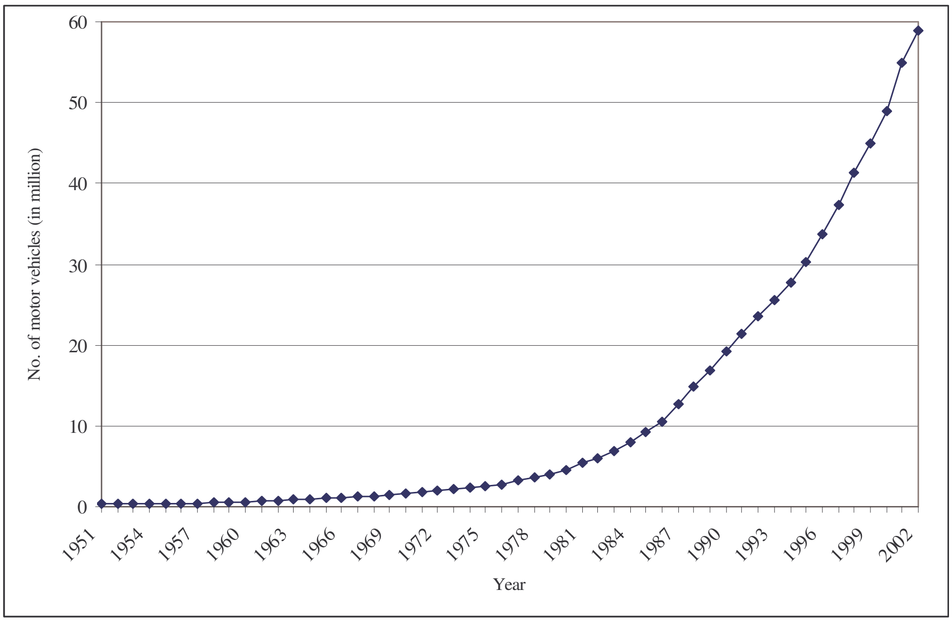
[4] World Bank, (1986), "Urban Transport, a World Bank Policy Study", World Bank, Washington, D.C.
[5] *Supra* note no. 1.

passengers.[6] Most of the Indian cities have more or less similar demand supply mismatch. Estimates for the metropolitan cities show that approximately 80 million trips will need to be catered per day whereas, only 37 million trips are being provided by the available rail and bus mass transport facilities.[7] Furthermore, as per a World Bank study, for every extra one million people in a developing city an extra 3.5 to 4 million public transport trips per day are generated.[8] Considering the population growth in most Indian cities, the urban transport infrastructure thus needs to be increased manifold in the decade or so, if the gap in the demand and supply has to be eliminated.

5.1. Vehicular growth

According to Motor Transport Statistics[9], the annual rate of growth of motor vehicles in India is around 10 percent during last decade (see also Figure 3). In 1991 there were 21.7 million vehicles. After 10 years in 2001, this number increased by nearly three times to 55 million. The basic problem is not the number of vehicles in the country but their over concentration in a few selected cities, particularly in metropolitan cities. If one compares the vehicle as well as car ownership rate across countries, India fares poorly vis-à-vis even most developing countries. India, where more than 15% of the world's human population lives, constitutes just 5% of the world's motor vehicle population. As far as cars are concerned, its share is even less than 1%.

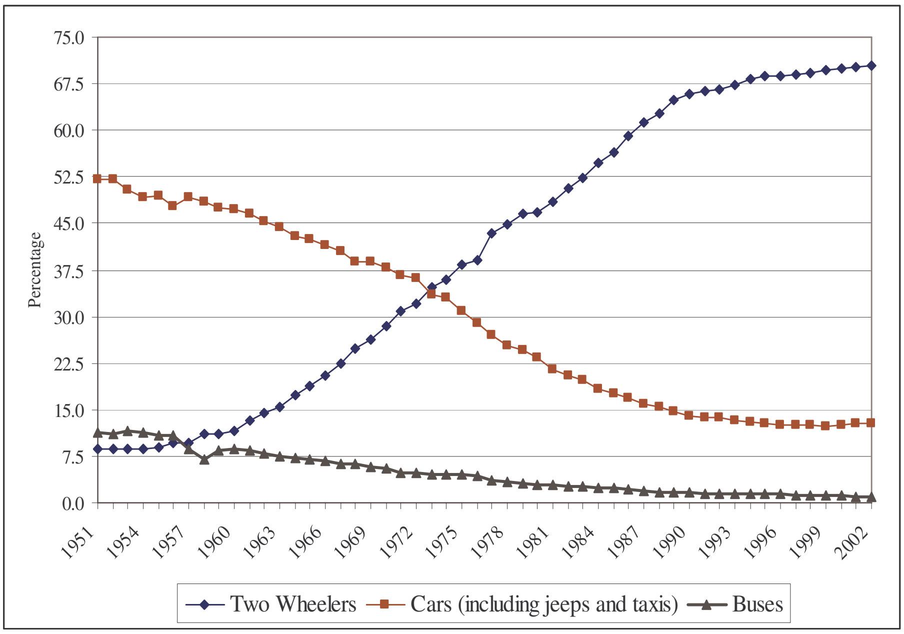
Figure 3: Motor vehicle population in India; 1951 to 2002.



Source: Motor Transport Statistics of India, (Various Issues), Transport Research Wing, Ministry of Road Transport & Highways, Government of India, New Delhi.

[6] Draft Regional Plan for Bombay Metropolitan Region 1996-2011, (1995), Bombay Metropolitan Regional Development Authority.
[7] Traffic and Transportation Policies and Strategies in Urban Areas in India, (1998), Final Report, Ministry of Urban Development, Government of India, New Delhi.
[8] *Supra* note no. 5.
[9] Motor Transport Statistics of India, (Various Issues), Transport Research Wing, Ministry of Road Transport & Highways, Government of India, New Delhi.

Figure 4: Share of two wheelers, cars, and buses in total motor vehicle population in India.



Source: Motor Transport Statistics of India, (Various Issues), Transport Research Wing, Ministry of Road Transport & Highways, Government of India, New Delhi.

The share of buses is negligible in most Indian cities when compared to two-wheelers and cars. For example, two-wheelers and cars together constitute more than 91% in Kanpur, 88% in Hyderabad, and 86% in Nagpur whereas buses constitute 0.5, 0.5, and 0.4 percent respectively.[10] The result is decline in the percentage share of buses from 11.1 percent in 1951 to 1.02 percent in 2001 at all India level.

In the absence of an adequate and efficient public transport, a large number of private and para-transit modes have entered into the market to meet the travel demand. Such a proliferation of vehicles results in acute congestion, inordinate delays, serious accidents, high-energy consumption particularly of fossil fuels, and intense pollution of the environment.

5.2. Travel demand

The level of urban travel demand in India is increasing substantially over the years. Three factors contribute to this. The first is the increase in population. The urbanization process has indicated that the population size of an urban area doubles in about two decades. The second factor is the mobility rate, that is, average trips per person per day. Mobility rate in urban India is continuously increasing over the years. For example, in Delhi, average number of trips per person per day have increased from 0.49 during 1969 to 1.10 during 2001 (Table 1). The trip rate for Mumbai, Kolkata, Chennai, Hyderabad, Bangalore, Ahmedabad, and Pune are 1.26, 1.26, 1.22, 1.05, 1.20, 1.57, and 1.48 respectively.[11] The third factor contributing to travel demand is the increase in trip length due to increase in the physical expansion of the city. For example, the average

[10] *Supra* note no. 8.

[11] Report of the Working Group on Urban Transport, (1996), Ministry of Urban Affairs and Employment, Government of India, New Delhi.

trip length in Delhi has increased from 5.4 kms in 1969 to about 13.5 kms in 2001. Currently, it is estimated that average trip length of four mega cities varies from 12.7 to 13.5 kms. There is also change in the pattern of trip distribution; more and more trips are being made in urban areas for work followed by education. For example, more than 60% of the total trips in Mumbai are meant for work and around 31% for education.[12]

Table 1: Average number of trips per person per day in Delhi.

Purpose	1969	1981	2001 (Estimated)
Work	0.29	0.35	0.45
Education	0.08	0.10	0.15
Others	0.12	0.27	0.50
All purpose	0.49	0.72	1.10

Source: Ranganathan, N. (1995).

The serious consequence of such development is a steep rise in demand for transport in almost all the cities in India. Table 2 presents desired shares of mass transport in Indian cities on the basis of their population levels. While the share of mass transport is well below the desired range, the share of personalized transport and para transit is already above the optimal range (Table 3). What is worse is that the modal split appears to be moving in the wrong direction. For example, share of mass transit in Delhi has stayed at the same low and unacceptable level for the last two decades (Table 4). Since its population is more than 10 million, mass transport should serve at least 75% of the total travel demand rather than the existing level of 62%. In Lucknow, which has a population of about 2 million, bus transport plays a negligible role in providing mobility to urban dwellers (Table 5). Table 3 clearly shows that the Intermediate Public Transport (IPT) modes play a significant role in meeting the transport demand in small and medium size cities in the absence of adequate public transport system. Share of trips made by personalized modes, particularly two-wheelers is very high in virtually all the cities. Percentage of trips by bicycle is seen to decrease with increase in city size.

Table 2: Desirable modal split for Indian cities of various sizes (as a %age of total trips by mechanical modes).

City size range (pop. In	Mass transport	Bicycle	Other modes
0.1 – 0.5	30 – 40	30 – 40	25 – 35
0.5 – 1.0	40 – 50	25 – 35	20 – 30
1.0 – 2.0	50 – 60	20 –30	15 – 25
2.0 – 5.0	60 – 70	15 – 25	10 – 20
5.0 plus	70 – 85	15 – 20	10 – 15

Source: Traffic and Transportation Policies and Strategies in Urban Areas in India, (1998), Final Report, Ministry of Urban Development, Government of India, New Delhi.

[12] *Supra* note no. 12.

Table 3: Existing modal split in Indian cities during 1994 (in %age).

City population (in million)	Walk	Mass transport	IPT Fast	IPT Slow	Car	Two wheeler	Bicycle	Total
0.10 – 0.25	37.1	16.4	10.4	20.1	3.3	24.1	25.7	100.0
0.25 – 0.50	37.8	20.6	8.9	17.2	2.6	29.8	20.9	100.0
0.50 – 1.0	30.7	25.4	8.2	12.0	9.5	29.1	15.9	100.0
1.0 – 2.0	29.6	30.6	6.4	8.1	3.3	39.6	12.1	100.0
2.0 – 5.0	28.7	42.3	4.9	3.0	5.0	28.9	15.9	100.0
5.0 plus	28.4	62.8	3.3	3.7	6.1	14.8	9.4	100.0

Source: Traffic and Transportation Policies and Strategies in Urban Areas in India, (1998), Final Report, Ministry of Urban Development, Government of India, New Delhi.

Table 4: Modal split trend in Delhi.

Mode	Modal split (in percent)			
	1969	1981	1986	1994
Bus	41	62	62	62.0
Car				6.9
Two-wheeler				17.6
Bicycle	59	38	38	6.6
Cycle				3.5
Others				3.4

Source: Singal, B. I., (2000).

Table 5: Modal split trend in Lucknow.

Mode	Modal split (in percent)		
	1963-64	1984-85	1997-98
Bus	2.6	3.4	4.3
Car	1.1	1.3	3.4
Two-wheeler	0.8	8.2	26.7
Tempo	-	4.6	9.2
Bicycle	26.3	30.1	23.4
Cycle	2.8	16.8	14.9
Other	0.2	2.7	0.4
Walk	66.3	33.0	17.7

Source: Singal, B. I. (2000).
Note: (-) indicates unavailability of data.

5.3. Existing transport infrastructure

The percentage of space used for transportation in cities in India is far less when viewed in comparison to its counterparts in the developed world. In general, the road space in Indian cities is grossly insufficient. To make the situation worse, most of the major roads and junctions in Indian cities are heavily encroached by parked vehicles, roadside hawkers, and pavement dwellers. As a consequence of these factors, the already deficient space for movement of vehicles is further reduced.[13] Even though urbanization has been growing rapidly in India, little attention has been paid to urban mass transport systems. The present urban rail services in India are extremely limited. Bus transit is the backbone of urban transport in most metropolitan cities except a few where it has never developed to be a significant mode (e.g., Lucknow where the share of person trips by public transit is less than 5 percent). Services are mostly run by publicly owned state transport undertakings. Qualitatively, the available transport services are overcrowded, unreliable, and involve long waiting periods. As a result, there is a massive shift to personalized transport, specially two-wheelers and also proliferation of various types of intermediate public transport modes such as three-wheeler auto-rickshaws, taxis and mini-buses. In almost all metropolitan cities in India, intermediate public transport provides a viable supplement to buses and suburban rail. People in upcoming urban areas rely heavily on auto-rickshaws and taxis for transportation.

6. Road safety in india

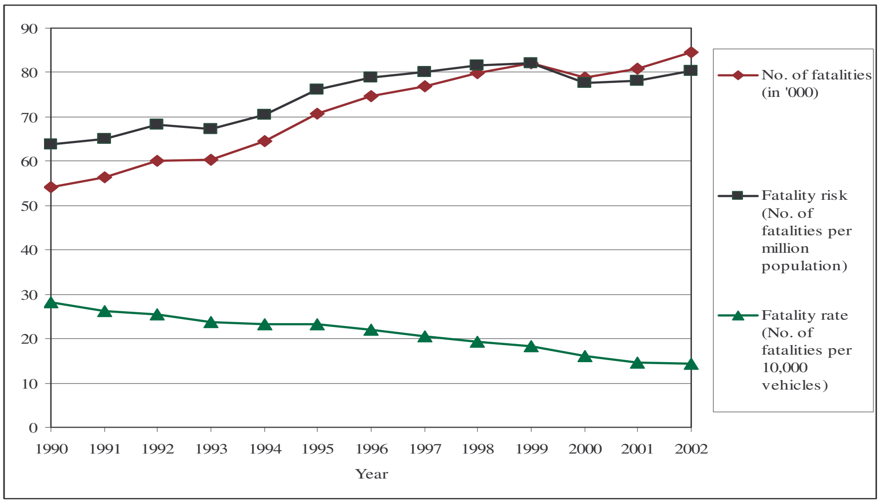
Many developing countries including India have serious road accident problems. Fatality rates are quite high in comparison with developed countries. While in Europe and North America the situation is generally improving, many developing countries face a worsening situation. A large number of deaths in developing world are due to road accidents. Apart from the humanitarian aspects of the problem, road accidents cost countries of developing world at least one percent of their Gross National Product (GNP) each year – sums they can ill-afford to lose.[14] The nature of the problem in developing countries is in many ways different from that in the industrialized world. The proportion of commercial and public service vehicles involved in road accidents are often much greater. Pedestrians and cyclists are often the most vulnerable. Given the fact that the poorest of the poor in urban India cannot even afford to use public transport, they resort to cycling or walking. Since cyclists and pedestrians are the prime victims of the road accidents, there must be a serious attempt to either make public transport available to them through targeted subsidization or to make the road safer to cycle and walk.

During the year 2002, nearly 85,000 people died due to road accidents in India (Figure 5). Fatality risk (defined as, road accidental deaths per million population) in India is increasing over the years, from 64 in 1990 to 80 in 2002. During the same period, road accidental deaths have increased at a rate of 3.8 percent per annum while the population of the country has increased by only 1.8 percent per annum. Although

[13] *Supra* note no. 1.
[14] Ghee, C., et al., (1997), "Socio Economic Aspects of Road Accidents in Developing Countries", TRL Report, TRL 247, Transport Research Laboratory, Crowthorne.

fatality rate (defined as, number of fatalities per 10,000 vehicles) in India is declining over the years, it is still quite high in comparison to developed world.

Figure 5: Rate of road accidental deaths in India.



Source: Accidental Deaths & Suicides in India, (Various Issues), National Crime Records Bureau, Ministry of Home Affairs, Government of India, New Delhi.

Although, Indian national highways are notorious for road accidents, there are serious road safety problems in Indian cities as well. It is alarming to note that more than 38 people die per week due to road accidents in Delhi alone. Between the year 1990 and 2000, number of road accidental casualties has increased in almost all the metropolitan cities in India (Table 6). Analysis of Table 6 shows that except Kolkata, Mumbai, and Nagpur all sample cities are showing very high growth rate in fatalities over the sample period. Accident severity index (defined as, number of fatalities per 100 accidents) is also very high for all the sample cities other than Ahmedabad, Bangalore, Kolkata, and Mumbai.

Table 6: Road accidental casualties in selected metropolitan cities in India.

Metropolitan cities	1990			2000		
	Fatalities	Accidents	ASI	Fatalities	Accidents	ASI
Ahmedabad	195	2873	7	223	3014	7
Bangalore	562	6729	8	659	8391	8
Chennai	507	5877	9	692	4878	14
Delhi	1670	7697	22	1989	10245	19
Hyderabad	276	1412	20	425	2492	17
Jaipur	235	1062	22	312	2474	13
Kolkata	463	10911	4	452	11036	4
Mumbai	400	25331	2	449	26450	2
Nagpur	166	1139	15	255	1569	16
Pune	275	1387	20	306	2384	13

Source: State Transport Undertakings – Profile and Performance, (Various Issues), Central Institute of Road Transport, Pune, India.
Note: ASI indicates Accident Severity Index (defined as, number of fatalities per 100 accidents).

7. Environmental impact of urban transport

The Indian metropolitan cities are facing serious environmental problem due to the growing air pollution caused by fuels used in vehicles. For example, 72% of air pollution in Delhi is caused by vehicular emission.[15] Atmospheric pollutants commonly associated with motor vehicles are nitrogen oxides, hydrocarbons, carbon monoxide, sulphur oxides, lead, and Suspended Particulate Matter (SPM). The ambient air pollution in terms of Suspended Particulate Matter (SPM) in all metropolitan cities in India exceeds the limit set by World Health Organization.[16] For example, in Kolkata, the average annual emission of SPM is 394 microgrammes per cubic meter while the World Health Organization standard is 75.[17] In fact, air pollution in many of India's cities has become atrocious, and has already had serious health effects, especially in the form of respiratory diseases.

There is a direct relationship between transport system and air pollution in a city. Vehicular emissions depend on vehicle-km, vehicle speed, age of vehicle, and of course emission rate of different vehicle categories. The average peak hour speed in Indian cities is far less than the optimum one. According to Centre for Science and Environment (CSE), the quantity of all the three major air pollutants (namely, nitrogen oxides, hydrocarbons, and carbon monoxide) drastically increases with reduction in motor vehicle speeds. For example, at a speed of 75 kmph, emission of carbon monoxides is 6.4 gm/veh.-km, which increases by five times to 33.0 gm/veh.-km at a speed of 10 kmph. Similarly, emission of other pollutants increases with the reduction in vehicle speed. Thus, traffic congestion not only increases the delay but also increase the pollution level.[18] Table 7 presents emission factors for different types of vehicles, under typical conditions, in Indian cities. One can see that emission rate, defined as quantity of pollutants emitted per vehicle-km, pertaining to carbon monoxide and hydrocarbons is very high for personalized modes (e.g., cars and two-wheelers) and para transit modes (e.g., three-wheelers) in comparison to buses, trucks, and Light Commercial Vehicles (LCVs). With deteriorating level of mass transport services and increasing use of personalized motor vehicles, vehicular emission is assuming serious dimensions in most of the Indian cities (see also Table 8).

Table 7: Emission rate of different vehicles in a typical Indian city (in gms/km).

Vehicle	CO	HC	NO_x	SO_2	Pb	TSP
Two-wheeler	8.30	5.18	-	0.013	0.004	-
Car	24.03	3.57	1.57	0.053	0.012	-
Three-wheeler	12.25	7.77	-	0.029	0.009	-
Bus	4.38	1.33	8.28	1.441	-	0.275
Truck	3.43	1.33	6.48	1.127	-	0.450
LCV	1.30	0.50	2.50	0.400	-	0.100

Source: Sibal, V., and Y., Sachdeva, (2001).
Note: (-) indicates negligible quantity.

[15] Economic Survey of Delhi 1999-00, (2000), Planning Department, Government of NCT of Delhi, India.
[16] Sharma, N. P., and S., Mishra, (1998), "Transport for Healthy Tomorrow, Issues and Options", Presented during the Seminar on Planning Delhi: Healthy City in the next Millennium, DRC, ITPI, New Delhi, 1998.
[17] *Supra* note no. 1.
[18] *Supra* note no. 1.

Table 8: Estimated vehicular emission load in selected metropolitan cities in India.

Name of the city	Vehicular pollution load (tonnes per day)					
	Particulates	Sulphur dioxide	Oxide of the Nitrogen	Hydrocarbons	Carbon monoxide	Total
Delhi	10.30	8.96	126.46	249.57	651.01	1046.30
Mumbai	5.59	4.03	70.82	108.21	469.92	659.57
Banglore	2.62	1.76	26.22	78.51	195.36	304.47
Kolkata	3.25	3.65	54.69	43.88	188.24	239.71
Ahmedabad	2.95	2.89	40.00	67.75	179.14	292.71
Pune	2.39	1.28	16.20	73.20	162.24	255.31
Chennai	2.34	2.02	28.21	50.46	143.22	226.25
Hyderabad	1.94	1.56	16.84	56.33	126.17	202.84
Jaipur	1.18	1.25	15.29	20.99	51.28	88.99
Kanpur	1.06	1.08	13.37	22.24	48.42	86.17
Lucknow	1.14	0.95	9.68	22.50	49.22	83.49
Nagpur	0.55	0.41	5.10	16.32	34.99	57.37
Grand total	35.31	29.84	422.88	809.96	2299.21	3597.20

Source: Urban Statistics, (1996), Central Pollution Control Board, New Delhi, India.

8. Energy consumption in the transport sector

In general, energy consumed in urban transport sector are petroleum products mainly gasoline and High Speed Diesel (HSD). The energy consumption in urban transport largely depends on the modal split as well as speed of the vehicle. On an average, energy consumption per pass.-km by bus is the least and by car is the highest among different modes of road-based passenger transport (last column of Table 9). Estimated energy consumption in urban India during 1994 is presented in Table 10. On an average, a car consumes nearly six times more energy than an average bus to provide passenger mobility (in terms of pass.-km), while two-wheelers consume about 2.5 times and three-wheelers 4.7 times more energy (last column of Table 9). In terms of fuel cost per pass.-km, a two-wheeler is 6.8 times, three-wheeler 7.0 times, and a car is 11.8 times costlier than a bus. Furthermore, a car occupies over 38 times more road space in comparison to a bus to provide same level of passenger mobility (in terms of pass.-kms). The corresponding figures for two- and three-wheelers are 54 and 15 respectively. This shows that bus transportation is not only favorable in terms of environmental consideration but also in terms of energy efficiency and best possible use of scarce road space.

Table 9: Energy efficiency of various modes of passenger transport.

Mode	Fuel type	Fuel efficiency (Km/litre)	Operating energy intensity (litre/PKm)	Relative energy efficiency
Bus	Diesel	4.30	0.006	1.00
Two-wheeler	Petrol	44.40	0.015	2.50
Three-wheeler	Petrol	20.00	0.028	4.70
Car	Petrol	10.90	0.038	6.30

Source: Sibal, V. and Sachdeva, Y. (2001).

Table 10: Estimated annual energy consumption in urban India during 1994.

City size (Pop. in million)	No. of cities	Annual fuel consumption (in thousand tons)						
		2-wheelers	Cars/ Jeeps	3-wheelers	Buses	Trucks	Rail	Total
0.1 – 0.5	281	567	325	74	546	857	-	2369
0.5 – 1.0	34	215	198	52	230	405	-	1100
1.0 – 2.0	15	402	150	41	162	203	-	958
2.0 – 5.0	5	272	130	31	147	87	-	667
5.0 plus	5	403	373	51	528	213	6	1574
Total	340	1859	1176	249	1613	1765	6	6668

Source: Traffic and Transportation Policies and Strategies in Urban Areas in India, (1998), Final Report, Ministry of Urban Development, Government of India, New Delhi.
Note: (-) indicates unavailability of data.

9. Need for an urban transport policy

Urban transportation is the single most important component instrumental in shaping urban development and urban living. While urban areas may be viewed as engines of growth, urban transport is, figuratively and literally, the wheel of that engine. The test of urban governance depends upon the quality of life the city or town offers.[19] Since transport is one of the prime determinants of quality of life, it is for the government to articulate the need for mobility and facilitate it through an appropriate mechanism. In fact, efficiency of cities greatly depends on the development of transport systems, as urban transport is a catalyst for overall development. However, the cities in India suffer from the absence of a cogent urban transport policy.

Urban transportation problems in India are manifested in the form of congestion, delay, accidents, energy wastage, and pollution. All these have very heavy economic, social, and environmental costs. The need of the hour is therefore a sound urban transport policy. The major thrust of such an urban transport policy should include integrated planning, an optimum share between public and private modes, choice of relevant technology for public transport systems, optimal use and management of available resources, restructuring of monetary and fiscal policy to encourage and promote public transport, and establishment of institutional arrangements, at all levels of governance, particularly at the city level, for planning, development, operation, management, and coordination of urban transport systems.

10. Policy measures

Road transport plays major role in providing passenger mobility in urban India. Although rail based transport services are available in few mega cities, they hardly play

[19] Padam, S. (2001), "Transport and Urban Governance", *Urban Transport Journal*, Vol. 2, No. 1, pp. 30-33.

any role in meeting the transport demand in rest of the million plus cities. Considering the financial constraint in improving the rail-based mass transport system, it is evident that bus transport will have to play a major role in providing passenger transport services in Indian cities in the years to come. Bus transport is favorable over its other counterparts not only from energy efficiency but also from an environmental point of view. There is a need to maximize its potential by encouraging promotional measures.[20]

Although, attracting private vehicle owners to switch to bus transport is not easy, however, high quality bus transport services have proven to be quite successful in attracting users of para-transit modes such as auto-rickshaws and taxis. Therefore, there is a need to introduce variety of bus transport services in Indian cities to cater the need and demand of different segment. Given the opportunity, people reveal widely divergent transport preferences, but in many places city authorities favor a basic standard of bus services. Government regulation and control have exacerbated the poor operational and financial performance of the publicly owned STUs which are the main providers of passenger transport services. Generally, public transport services work most efficiently with a minimum government control. In particular, the freedom to set fares in response to market forces is more likely to mean that supply and demand balance each other. In addition, the freedom to determine the routes, size of vehicles, quality of services, frequency of services etc. enhances the likelihood of economic viability and public satisfaction. Too often unnecessary regulations discourage innovation, which results in limiting the range and quality of bus transport services. Furthermore, publicly owned urban bus transport undertakings in India often lack the flexibility of organization, the ability to hire and fire staff, or the financial discretion needed to adapt to changing conditions. In such circumstances, a policy, which encourages private participation in the provision of bus services, should be welcomed. One should note that under competition, operators tend to become more responsive to customers' needs and more innovative in finding ways to cut costs. Moreover, the alleged disadvantages of competition seldom are found to be real problems and if, they do arise, can usually be overcome by minimal regulatory intervention.

Considering the forecasts of rapid growth in urban travel demand, the need for bus services can be expected to intensify greatly in the years to come. If the private and the public sectors play their appropriate roles, most Indian cities will have the opportunity to develop vigorous and viable public transport systems. Because of rapid growth in travel demand, considerable expansion of public transport systems in most cities will be an absolute necessity. If a knowledge-based regulatory and planning authority for public transport is installed in every city, there can be a healthy coordination of private and public sectors, complementary rather than uneconomically competing with one another.

In general, Indian cities have not made much progress in implementing the demand side management measures, such as congestion pricing, restraints on parking etc. Although policy measures that involve restraining the use of private cars and two-wheelers are likely to be unpopular, a gradualist approach of progressively introducing restraints on road use, while at the same time improving public transport, is more likely to lead to greater acceptance. It is believed that improved public transport and more efficient management of demand would help to combat the trend away from public transport vehicles towards greater use of personalized modes.[21]

[20] *Supra* note no. 1.
[21] *Supra* note no. 1.

The transport system management strategy like one way traffic system, improvement of signals, bus priority lane etc. should be introduced in all cities especially in metropolitan cities so that the existing road capacity and road user safety is increased. Road infrastructure improvement measures like new road alignments, hierarchy of roads, provision of service roads, bye passes, ring roads, bus bays, wide medians, intersection improvements, construction and repair of footpaths and roads, removal of encroachments, good surface drainage etc. should also be introduced at least in metropolitan cities. In case of mega cities, it is essential to have long-term measures as well, involving technology upgradation and introduction of high speed, high capacity public transport system particularly along high-density traffic corridors. One should note that capital-intensive projects should be considered if and only if it is absolutely necessary. In many cases, instead of building underground railways or elevated highways, government would have done better to have increased the capacity of existing bus services through bus priority measures, such as exclusive busways and better road access. In some case, of course, capital-intensive investments, such as elevated highways or rapid rail systems, may be the best approach. However, there should be careful appraisal of all capital-intensive projects before implementing them. In addition, there should be determined effort to develop alternative pollution free fuels in the long run.

In many Indian cities, non-motorized vehicles are a major transport mode and source of employment for the poor. However, it is found that transport planning in Indian cities does not include non-motorized vehicles and pedestrians in its consideration. An urban transport policy should encourage the need for developing ‘green’ modes like bicycle, walk, provision of pedestrian paths and cycle tracks especially in new development areas of metropolitan cities.

All these measures suggested above would require a policy framework encompassing regulatory, pricing, and taxation mechanisms. They would have to be reinforced with effective enforcement to encourage the use of clean vehicles and fuels, restrict the use of polluting vehicles and fuels, and modify travel behavior and transport demand using regulatory and pricing instruments.

11. Concluding remarks

Urban transport situation in large cities in India is deteriorating. Commuters in these cities are faced with acute road congestion, rising air pollution, and a high rate of accident risk. It is no longer safe to walk on the road or to ride a bicycle. Mass transport is scarce, overcrowded, unreliable, and involves long walking periods. The transport crisis faced by most of the metropolitan cities in India harms business efficiency, threatens to undermine the city’s competitive position, and worsen the people’s quality of life. Without vigorous action, all of these problems would intensify, as rising population over the coming decades and the goal of growing economic prosperity put more pressure on the system. Achieving this requires not only overcoming chronic under-investment, but also a complete overhaul of public transport management. It is high time the decision-makers take necessary action to make cities viable.

The complexities of urban transport cannot be resolved without a concise and cogent policy. Urban areas, whether mega-cities, cities or towns, have grown and are growing. The demands they are making have remained largely unmet. The deteriorating quality of public transport is driving people to personalized transport, most of which are fuel-inefficient, congesting and unsafe. While it is not the intention of this paper to make a case against large capital intensive metro systems, the realities demand solutions which are within the reach. Bus as a mode of public transport, has a potential which is yet to be fully exploited. Given the priority that it deserves, bus can ensure safety, act against pollution and promote mobility for the poor and not the so poor.

In a nutshell, transport strategy should support the following objectives:

- Provide and promote sustainable high quality links for people, goods, and services to, from and within the city to benefit economic growth and environmental quality of city;
- Improve the efficiency and effectiveness of city's transport systems;
- Planning development in a way which reduce the need to travel by personalized modes and increase of public transport system;
- Improvement of public transport system and its efficiency;
- Optimization of existing transport infrastructure and give precedence to low cost and affordable technology, at least as a short-term measure, especially bus technology;
- Promote the health of the people by encouraging more walking and cycling; and
- Ensure that the development of the transport system contributes to the protection and enhancement of the natural and built environment.

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Modeling of Congestion: A Tool for Urban Traffic Management in Developing Countries

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Abstract

In order to formulate rational traffic management measures for urban roads, it is essential to understand the effect of different types of vehicle on congestion. The effect of different types of vehicle on congestion has been captured on the basis of marginal congestion. Using congestion models, the marginal congestions have been estimated for different road widths, traffic compositions and on-street parking levels. The peak hour vehicular composition and volume level vary for different roads in an urban area. Therefore, for assessing the operating conditions for different roads based on a comparable quantitative measure, the marginal congestion caused per Passenger Car Unit (PCU) of mixed traffic stream has been estimated and denominated 'Marginal Congestion Index (MCI)'. The use of MCI for prioritization of management actions for different urban roads is discussed. It is shown that a congestion model explicitly accounts for the effects of traffic composition and volume level. Therefore, the effect of different types of vehicles on congestion at all traffic volumes could be estimated using congestion models. Altogether, modeling of congestion is established as a tool for formulating rational traffic management measures for urban roads in developing countries.

Keywords: Congestion; Urban transport; Traffic management; Developing countries.

Introduction

The rapid growth of traffic congestion on urban roads and the resulting impediment to urban mobility is a serious concern to urban management professionals and decision makers. In attempting to alleviate the congestion on urban roads, it is commonly found that the expansion and improvement of roads is restricted by increasingly tight fiscal and physical constraints. However, addressing the problem through rational traffic management measures like restricting the entry of certain types of vehicle during peak periods of traffic flow or enforcing congestion pricing is considered to be a more acceptable alternative.

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Urban traffic in most of the developing countries is heterogeneous in nature, and the effects of different types of vehicle on congestion are unlikely to exert the same influence. For formulating rational traffic management measures, it is necessary to quantify the effect of different types of vehicle on congestion under prevailing roadway, traffic and control conditions. In the present paper, this has been achieved by estimating incremental and marginal congestions caused by different types of vehicle in a mixed traffic stream. Modeling of congestion has been used as a tool for estimating incremental and marginal congestions.

Any change in prevailing roadway and control condition is likely to influence the congestion level as well as the effect of different types of vehicle on congestion. Therefore, the effect of road width and control condition (i.e. on-street parking level) on similar vehicle types has been studied at different flow levels. The role of marginal congestion in improving the rationality of traffic management measures has been discussed. In order to account for dissimilar roadway, traffic and control conditions for different roads in an urban area, the marginal congestion caused per Passenger Car Unit (PCU) of mixed traffic stream under prevailing roadway, traffic and control conditions, has been estimated and defined as 'Marginal Congestion Index (MCI)'. The use of operating MCI in prioritization of management actions has been discussed.

Modelling of Congestion

A measure of congestion should be simple, well defined and easily understood. The method of measuring congestion should also be cost effective, accurate and easy for implementation. A balanced quantification of congestion should embody a combination of volume (e.g. total traffic volume, volume to capacity ratio, traffic volume per lane etc.) and operational (e.g. speed, delay, travel time, density etc.) characteristics of traffic stream (Pignataro 1973). However, the traditional measures of congestion (Lomax 1988; Witheford 1988; Hashimoto 1990; Turner 1992; Lakshmana Rao & Sridhar 1995; Parbat 1996) are based on either volume or operational characteristics of traffic stream. Combining volume and operational characteristics of traffic movement, Maitra, Sikdar & Dhingra (1999) developed a methodology for the quantification and modeling of congestion on urban roads, which has been followed in the present paper. The area under the observed speed-flow curve is used as a measure of loss in freedom of movement; and congestion is expressed as a percentage loss in freedom of movement. Therefore, the measured congestion is a dimensionless quantity. A road is considered to have a congestion value of zero at free-flow operation, a 100 per cent congestion at maximum flow, and more than 100 per cent congestion at unstable or forced-flow operations. Therefore, any operating condition in the stable flow zone will have a congestion value between zero and 100 per cent.

On a road, the congestion level (CG_V) at a traffic volume *'V'* is expressed as given in *Equation 1*.

$$CG_V = \left(\frac{V}{V_L}\right)^{\sum_{i=1}^{n} p_i m_i + 1} * 100 \qquad (1)$$

where,
n =number of vehicle types in mixed traffic stream,
i =a vehicle type (e.g. car, bus, truck etc.) present in mixed traffic stream,
p_i =proportion of vehicle type 'i' in mixed traffic stream and
V_L =limiting traffic volume representing 100 per cent congested operation, which is estimated as given in *Equation 2*.

$$V_L = \left[\frac{1}{a}\left(1 - \frac{S_L}{S_f}\right)\right]^{\frac{1}{\sum_{i=1}^{n} p_i m_i}} \qquad (2)$$

where,
S_f =free-flow speed of traffic,
S_L =speed at or near capacity representing 100 per cent congested operation. *'a'* and *'m_i'* (i= 1,…,n) are model coefficients, which are calibrated from speed-flow relationship given in *Equation 3*.

$$S_V = S_f\left[1 - a\left(\frac{V}{C}\right)^{\sum_{i=1}^{n} p_i m_i}\right] \qquad (3)$$

where,
S_V =speed of traffic stream at a traffic volume 'V' and
C =traffic capacity of the road under consideration.

A large number of observations are required to calibrate the speed-flow model given by *Equation 3*. The derived coefficients *'a'* and *'m_i'* (i= 1,…,n) are then used to calculate the limiting traffic volume *(V_L)* representing 100 per cent congested operation as given by *Equation 2*. The derived coefficients and estimated limiting traffic volume are then used in *Equation 1* for estimating congestion level *(CG_V)* corresponding to a given traffic volume *'V'*.

Data Base and Congestion Models

In order to demonstrate the methodology for quantifying the effects of different types of vehicle on congestion and also for studying the variations for different road widths and on-street parking levels, several congestion models were necessary. In the present paper, congestion models developed by Maitra, Sikdar & Dhingra (1999, 2000) have been used to study the effect of road width/ parking intensity on the contributions of different types of vehicle on congestion. In order to study the effect of different types of vehicle on congestion for various levels of on-street parking, about 1.1m carriageway of a study road (A. S. Marg Road, Mumbai, India) having 5.2m width in one direction was occupied by parked vehicles and thereby leaving a clear width of 4.1m for unidirectional through traffic movement. Level of on-street parking was defined based on the intensity of uniformly spaced vehicles parked parallel (using part of the shoulder and part of the carriageway) along the side of the study road. For defining heavy intensity of on-street parking, maximum possible number of cars were parked parallel along one side of the study road. For defining medium level of on-street parking every alternative parked vehicles used for defining heavy parking level, was removed and therefore, the number of uniformly placed parked vehicles was 50% of that used for creating heavy parking level. Similarly, for defining low level of on-street parking, every alternative parked vehicles used for defining medium parking level was removed. Therefore, the number of parked vehicles for defining low level of on-street parking was 50% of that used for defining medium level of on-street parking. For defining no parking condition on the same study road, all parked vehicles were removed. *Table 1* summarises the congestion models used in the present work. Each congestion model was accepted after a careful review of R^2 value, t-values, F-value and sign of the coefficients.

Table 1: Coefficients of Congestion Models for Different Road Widths and Levels of On-street Parking .

Name of the Road, Level of Parking and Model R2	Road Width (m)	'a'	m_i for different vehicle types						
			C	N	B	T	L	W	A
B.S. Ambedkar Marg: (No Parking) *(R2=0.882)*	13.0	0.601	---- 0.610 ----		-------- 0.937 ----------			1.273	NA
Eastern Express Highway: (No Parking) *(R2=0.935)*	10.3	0.605	----1.257 -----		--------- 0.657 ----------			0.643	0.465
M. Karve Road: (No Parking) *(R2= 0.942)*	7.0	0.660	0.748	0.746	0.982	0.424	0.513	0.562	NA
L.B.S. Marg: (No Parking) *(R2= 0.907)*	6.8	0.612	---- 1.073----		--------- 1.598 ----------			0.626	0.876
N.S. Patkar Marg: (No Parking) *(R2= 0.871)*	6.5	0.691	---- 0.827 ----		--------- 1.619 ----------			0.562	NA
A.S. Marg: (No Parking) *(R2=0.951)*	5.2	0.724	1.381	1.817	2.296	1.613	1.675	1.016	0.676
A.S. Marg: (Low Parking) *(R2=0.930)*	4.1	0.800	1.821	1.958	1.456	0.357	2.154	1.055	0.838
A.S.Marg: (Medium Parking) *(R2=0.874)*	4.1	0.816	1.732	1.203	1.480	1.783	0.240	0.901	1.032
A.S. Marg: (Heavy Parking) *(R2=0.885)*	4.1	0.830	0.968	1.666	1.159	0.627	1.033	1.397	0.783

Note C: Old Technology Car, N: New Technology Car, B: Bus, T: Truck, L: Light Commercial Vehicle, W: Two Wheeler, A: Auto (Three Wheeler) and NA: Vehicle type not present on the particular road

During the last decade, several new models of passenger car have been launched in the Indian market. These cars are called "New Technology Cars". In general, most of these cars are smaller in size with superior speed capabilities and acceleration/deceleration characteristics as compared to the cars, which were dominating the Indian market in the past (Kadiyali & Viswanathan 1993). The traditional cars, which are still in use, are referred to as "Old Technology Cars". For some of the study roads, separate data was available for old and new technology cars. For these roads, old and new technology cars have been considered separately in congestion models. For other roads, old and new technology cars have been considered together. Similarly, wherever separate data was available for bus, truck and light commercial vehicles, they have been considered separately in congestion models. For other roads, these three vehicle categories have been considered together in congestion models.

Incremental and Marginal Congestions

On the basis of congestion model developed for a road, the level of congestion at different traffic compositions and volume levels can be estimated. In reality, the traffic composition and volume level vary with time. Also, the increase in congestion due to the addition of a new vehicle will depend on the type of vehicle, volume level, composition of traffic stream, roadway width, etc. In the present paper, the increase in congestion level caused by each vehicle type present in a mixed traffic stream has been estimated using the congestion model *(Equation 1)*. The volume and composition of traffic stream before the addition of a new vehicle are called 'base volume' and 'base composition' respectively. Similarly, the increase in congestion level due to the addition of a new vehicle at a base volume is termed 'incremental congestion'. Naturally, for a base volume and base composition, the incremental congestions will be different for different types of vehicle. As the hourly traffic volumes used in congestion models were based on 5-minute duration traffic data, an addition of 1 vehicle in 5-minute interval resulted in an increase in the hourly volume by 12 vehicles, which was expressed in Passenger Car Unit (PCU) using appropriate PCU values recommended for Indian conditions (CRRI 1988; IRC 1990). The incremental congestion caused by vehicle type *'i'* at a base volume *'V'* is estimated as given in *Equation 4*.

$$IC_{iV} = \left(\frac{V_i^*}{V_{Li}^*}\right)^{\sum_{i=1}^{n} p_i^* m_i + 1} - \left(\frac{V}{V_L}\right)^{\sum_{i=1}^{n} p_i m_i + 1} \qquad (4)$$

where,

IC_{iv} = Incremental congestion caused by vehicle type 'i' at a base volume 'V'

V_i^* = Traffic volume after the addition of vehicle type 'i' at a base volume 'V'

p^*_i *(i=1,2,….n)* is the composition of traffic stream after addition of vehicle type *'i'* at a base volume *'V'*. Certainly, this will be different from the base composition. The traffic volume after joining of vehicle type 'i' is estimated by *Equation 5*.

$$V_i^* = V + 12\ PCU_i \qquad (5)$$

where, PCU_i = Passenger Car Unit (PCU) value for vehicle type *'i'*.

V_{Li}^* is limiting traffic volume representing 100% congested operation after the change in composition due to the addition of vehicle type *'i'* in the stream. A change in traffic composition due to the joining of vehicle type *'i'* at base volume *V*, results V_{Li}^* to be different from V_L.

Incremental congestion is actually felt by all the vehicles in a traffic stream. Therefore, the total additional congestion to the traffic stream due to the addition of a vehicle type was estimated and termed as marginal congestion *(MC)*. The concept of marginal cost has been used widely in transportation economics (Small 1992; Khisty & Lal 2002), especially in the context of congestion pricing. Existing literature consists of significant contributions made by researchers in conceptualizing the framework for road pricing with reference to marginal cost (Newbery 1990; Hau 1992a, 1992b; Rosenberg 2002; Michael 2002; Nakamura & Kochelman 2002; Paulley 2002). However, most of these works considered homogeneous traffic stream dominated by passenger cars, as the use of private vehicles has been a major cause of congestion in most of the developed countries. There has not been adequate emphasis on the applicability of congestion pricing for mixed traffic operations, where the effect of different types of vehicle on congestion is different. The concept of variable pricing for different types of vehicle is becoming increasingly popular in developing countries. In some of the recent road projects in India, different charges have been fixed for different types of vehicle (Bongirwar & Momin 2000; Rao et al. 2002). However, currently there is no rational basis for the variation of charges for different types of vehicle. Using the congestion model developed for mixed traffic environment, the marginal congestion caused by different types of vehicle has been estimated. The marginal congestion *(MC)* caused by vehicle type *'i'* at a volume level *'V'* is computed as given in *Equation 6*.

$$MC_{iv} = \frac{\left[V_i^* \left(\frac{V_i^*}{V_{Li}^*} \right)^{\sum_{i=1}^{n} p_i^* m_i + 1} - V \left(\frac{V}{V_L} \right)^{\sum_{i=1}^{n} p_i m_i + 1} \right]}{12} \qquad (6)$$

Marginal congestion for different types of vehicle has been estimated using *Equation 6* for all the study roads. The estimated *MC* values for A.S. Marg road are shown in *Fig. 1*. It is observed that marginal congestion varies with vehicle type and traffic flow level. The value of marginal congestion is negligible at lower traffic volume but becomes significant with increase in volume. Although, all types of vehicle cause more marginal congestion at higher traffic volumes, the effect is significant for larger vehicles like buses or trucks.

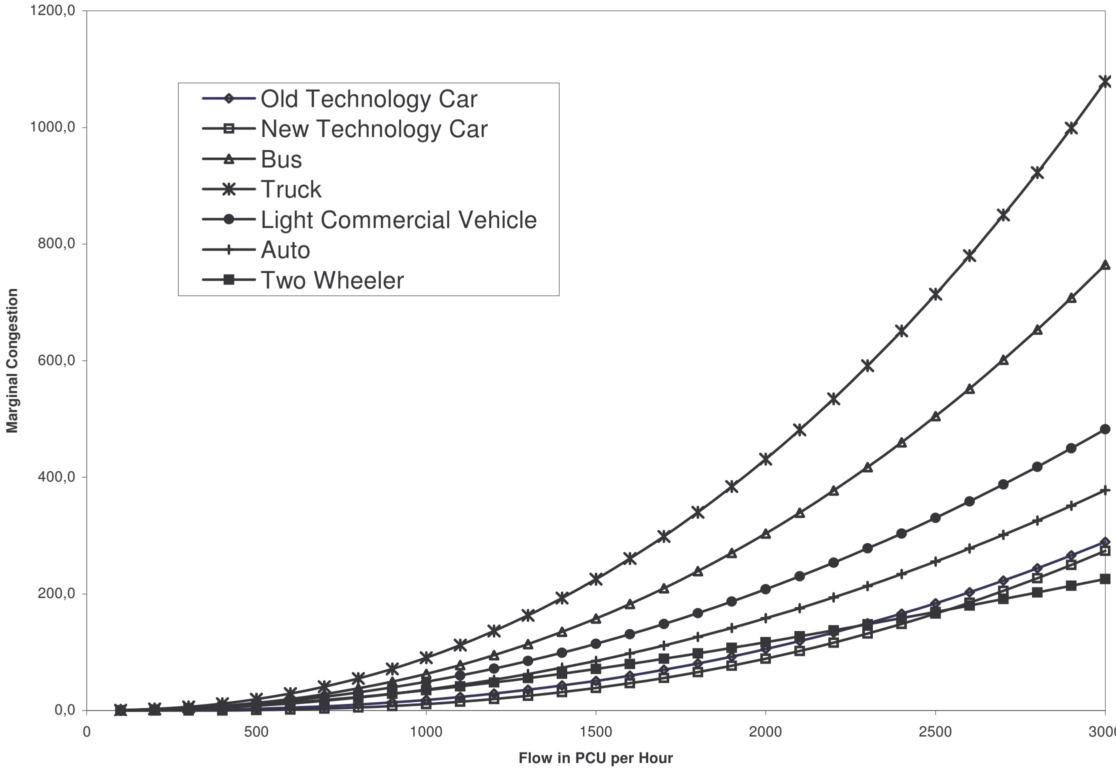

Figure 1: Marginal Congestion Caused by Different Types of Vehicle for A.S. Marg Road.

The knowledge of marginal congestion caused by different types of vehicle can be used as a basis for formulating traffic management measures like restricting the entry of certain types of vehicle on congested roads. For prevailing roadway, traffic and control conditions, if it is required to reduce the level of congestion, the marginal congestions caused by different types of vehicle for the given flow level can be studied and the entry of the vehicle type causing the maximum marginal congestion can be restricted. For the A.S. Marg road, it is found that larger vehicles like trucks cause more congestion than other types of vehicle at higher traffic volumes. Therefore, on A. S. Marg road, restricting the entry of trucks during the peak hours of traffic flow will be beneficial. The concept of marginal congestion can be used as a basis to improve the rationality of traffic management measures for a road.

The estimated *MC* can be utilised for providing a basis for charging different types of vehicle in a mixed traffic stream. For a road, *MC* depends on the flow level and composition of traffic. Therefore, in the case of electronic road pricing system, the marginal congestion caused by different types of vehicle can be calculated in a dynamic manner based on the volume and composition of traffic for each of the pre-specified time intervals (e.g. 5 min, 10 min etc.). However, even in the absence of sophisticated electronic instruments, *MC* can be used as a basis for congestion pricing. Congestion is normally severe during the peak periods of traffic flow and the duration of these peak periods (say, 8.00 a.m. to 10 a.m. and 5.00 p.m. to 7 p.m.) can be ascertained using traffic flow data. Based on average volume and composition of traffic during peak period, *MC* caused by different types of vehicle can be estimated and used for variable pricing in mixed traffic operations.

Marginal congestion caused by different types of vehicle has been estimated for all the study roads. *Table 2* shows the variation of marginal congestion values for different road widths. The *MC* values shown in *Table 2* correspond to a flow level of 3000 PCU per hour. It is clearly observed that for all the vehicle types, *MC* values are greater when the carriageway width is smaller. However, the increase in marginal congestion due to reduction in road width is not the same for all types of vehicle due to the variations in vehicle size and maneuverability. As two-wheeler is the smallest vehicle, the increase in *MC* is the least due to the reduction in available carriageway width. On the other hand, the increase in *MC* for trucks is the maximum and trucks remain as the most detrimental vehicle type to the traffic stream. The marginal congestion caused to the traffic stream by other types of vehicle lies in between the above two extreme cases (i.e. two-wheelers and trucks) depending upon the size and ease of maneuverability of vehicle types. A comparison of *MC* caused by trucks for different roads clearly justifies the need for banning the entry of trucks on narrower roads, especially at higher flow levels.

Table 2: Variation of Marginal Congestion for Different Road Widths.

Name of the Road	Available Road Width (m)	C	N	B	T	L	W	A
B. S. Ambedkar	13.0	--------- 84 ---------		-------------- 300 -------------			80	NA
E.E. Highway	10.3	--------- 139 --------		-------------- 481 -------------			104	167
M. Karve Road	7.0	208	212	133	526	314	133	NA
N. S. Patkar	6.5	--------- 221 --------		------------- 597 --------------			156	NA
A.S. Marg	5.2	289	274	226	1079	483	226	378

Note C: Old Technology Car, N: New Technology Car, B: Bus, T: Truck, L: Light Commercial Vehicle, W: Two Wheeler, A: Auto (Three Wheeler) and NA: Vehicle type not present on the particular road

The effect of on-street parking on the marginal congestion caused by different types of vehicle was also analysed. The marginal congestion caused by different types of vehicle corresponding to a flow level of 2000 PCUPH for various levels of on-street parking is shown in *Table 3*. It is observed that all types of vehicle become more detrimental to the traffic stream with an increase in the intensity of on-street parking. However, the effect for bigger vehicles like buses and trucks are predominant. *Table 2* and *Table 3* show that *MC* values vary logically with the change in roadway (e.g. width of carriageway) or control (e.g. level of on-street parking) condition.

Table 3: Variation of Marginal Congestion for A. S. Marg Road with Different Levels of On-street Parking.

Level of On-Street Parking	Available Road Width (m)	C	N	B	T	L	W	A
Zero	5.2	105	89	304	431	208	117	158
Low	4.1	125	150	433	525	262	158	202
Medium	4.1	185	167	450	731	291	189	243
Heavy	4.1	190	227	636	838	382	244	252

Note C: Old Technology Car, N: New Technology Car, B: Bus, T: Truck, L: Light Commercial Vehicle, W: Two Wheeler and A: Auto (Three Wheeler)

It is convenient to charge different types of vehicle on a road in proportion to *MC* values for operating traffic volume and composition. However, it is observed from *Table 2* and *Table 3* that *MC* values are sensitive in a logical manner to roadway width or control condition (e.g. on-street parking). Therefore, it is also necessary to understand the role of roadway or control conditions while formulating congestion mitigation measure like restricting the entry of certain types of vehicle or enforcing congestion charging mechanism. For example, if a road width is reduced due to roadside encroachment or vehicles parked on-street, it will result into a different nature of interactions among different types of vehicle in congestion. Accordingly, all the vehicle types, especially the larger vehicles may become more detrimental to the traffic stream. However, the urban management professional should also understand that a larger vehicle would be less damaging if the encroachment or the on-street parking is removed and the full carriageway width is available for through traffic movement. Level of congestion depends on roadway, traffic and control conditions; and therefore, the rationality of mitigation measures should be considered in relation to not only the traffic volume or composition, but also the roadway and control conditions.

Marginal Congestion Index

The marginal congestion caused by a vehicle type depends on the composition and volume of traffic on the road. However, the peak hour vehicular composition and traffic volume level normally vary for different roads in an urban area. In order to assess the operating conditions for different roads based on a comparable quantitative measure, the marginal congestion caused per PCU of mixed traffic stream is estimated. To account for dissimilar conditions of operation for different roads, the MCI for a road at a volume level *'V'* is estimated as shown in *Equation 7*.

$$MCI_v = \frac{\sum_{i=1}^{n} MC_{iv} * p_i}{\sum_{i=1}^{n} PCU_i * p_i} \qquad (7)$$

MCI values were estimated for all the study roads and a comparison of these values for different widths of road is shown in *Fig. 2*. Similarly, *Fig. 3* shows the variation of *MCI* value for different levels of on-street parking. It is observed that *MCI* value at different flow levels varies in a logical manner with available road width or level of parking. *MCI* values can be used to prioritise management actions of congestion mitigation measures such as congestion pricing, restricting the entry of certain categories of vehicles during peak period, etc. for different roads in an urban area, even when the road width, traffic composition and control conditions (e.g. parking) are different. Thus, as an added advantage, expert judgments for management actions can be provided using *MCI* values. Based on peak hour traffic flow and composition, the operating *MCI* values for different roads can be estimated and used for prioritization of management actions. Naturally, a road with maximum operating *MCI* should be taken first for implementing congestion mitigation measures.

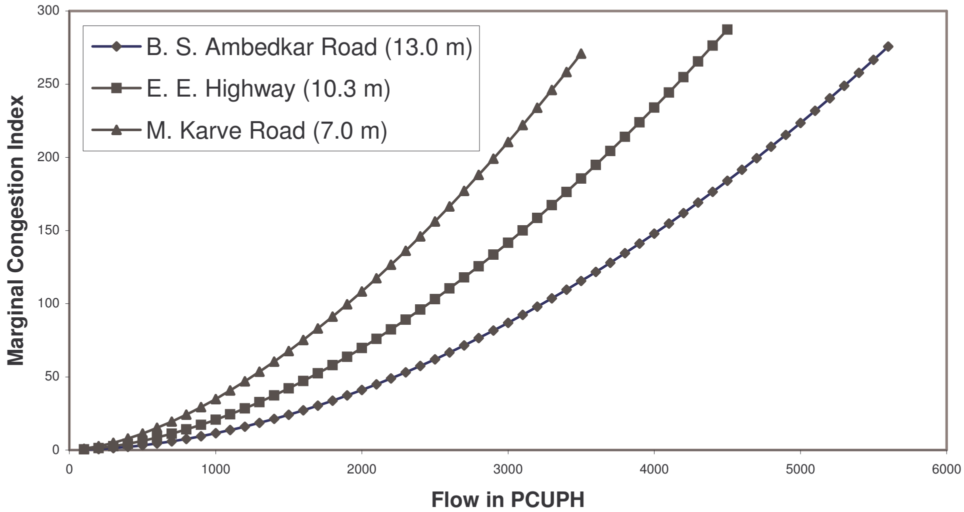

Figure 2: Marginal Congestion Index for Different Widths of Road.

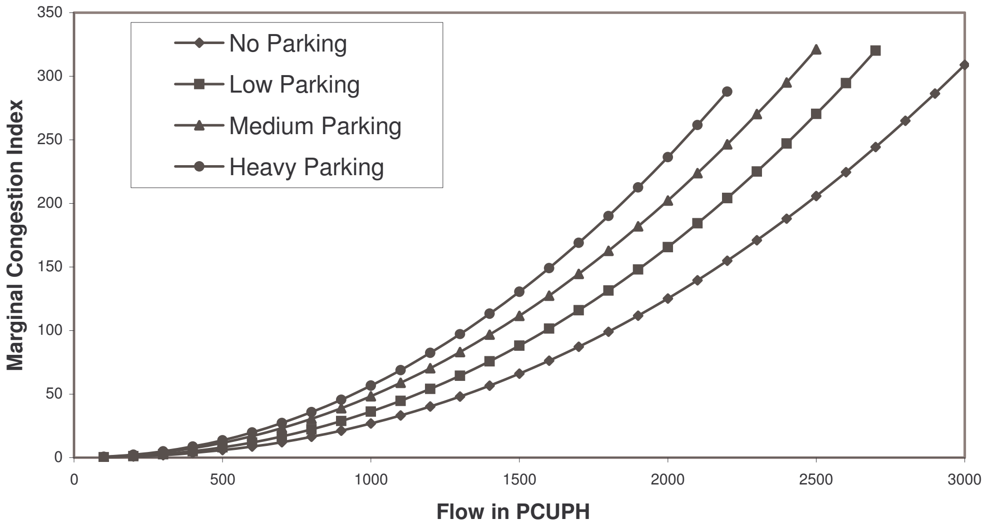

Figure 3: Marginal Congestion Index for Different Levels of On-street Parking.

Conclusions

The effect of different types of vehicle on congestion is one of the key information required for formulating rational traffic management measures in mixed traffic operations. In the present paper, the effect of different types of vehicle on congestion has been captured through marginal congestion. It has been shown that on a road, the amount of marginal congestion varies in a logical manner with vehicle type and flow level. Therefore, marginal congestion could form a basis for formulating rational traffic management measures like restricting the entry of heavy vehicles or enforcing variable pricing in mixed traffic operations. The variation of marginal congestion of similar vehicle types for different road widths and parking levels have been studied. A comparison of marginal congestions for different road widths or parking levels clearly brought out the necessity for considering the rationality of mitigation measures in relation to not only the traffic composition or volume level, but also the roadway and control conditions.

In an urban area, all the roads are unlikely to operate with the same vehicular composition and traffic volume. In order to prioritise management actions of congestion mitigation for different roads with dissimilar operating conditions, it was required to assess the performance of different roads based on a comparable quantitative measure. In the present paper, this has been achieved through the development of *MCI.* The use of *MCI* for prioritisation of management actions for different urban roads has been discussed.

While estimating marginal congestions, it has been shown a congestion model explicitly accounts for the effects of traffic composition and volume level. Therefore, the effect of different types of vehicle on congestion at all traffic volumes could be estimated using a congestion model. However, it may be noted that measurements like marginal congestions, as obtained from congestions models, are essentially traffic engineering based measurements. Such measures are extremely useful, but are based on theoretical perspective. Therefore, alongwith such measures it is also necessary to consider relevant social and political issues before recommending traffic management measures like road pricing in mixed traffic operations. Finally, the present study is focused on a single road and network effects are not explicitly considered. It will be meaningful to consider the network effects while formulating recommendations.

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Modeling Traffic Impact of Flyover at an Urban Intersection Under Mixed Traffic Environment

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Abstract

In order to ease transportation problems, many urban authorities in India have taken up initiative for construction of flyovers at major intersections. However, in most of the cases a comprehensive planning approach has not been adopted, either due to lack of fund or ignorance about the planning perspective of such proposals. The locations for flyovers have been decided based on present day operating conditions and the traffic impacts of such flyovers at adjacent intersections have not been analysed. In the present paper, the traffic impact of a flyover along with its adjacent intersection has been analysed, using a simulation model developed for mixed traffic operations and poor lane discipline prevailing in India. Through the case study presented in the paper, it has been demonstrated that an ill planned flyover only shifts the location of the problem without bringing any benefit to traffic. The potential use of simulation model for analyzing traffic impacts has been shown; and the need for such analysis for the planning of flyovers has been highlighted.

Keywords: Modelling traffic impact; Flyover; Urban intersection; Traffic environment.

1. Introduction

The increase in urban traffic congestion has become a serious concern to transportation professionals. Therefore, efforts have been made by researchers for obtaining rational quantification of congestion (Turner 1992; Thurgood 1995; Maitra, Sikdar & Dhingra 1999) and formulating appropriate measures for mitigation of congestion for urban roads (Pratsch 1986; Lindley 1989; Arnold 1993). Urban road network consists of large number of intersections at close proximity, which are potential sources of acute traffic congestion, especially during peak hours. Attempts have been made by researchers to improve traffic operations at urban intersections (Cronje 1983; Olszewski 1993; Chou, Chen & Li 2001). However, the scope of improvement of intersection at-grade or widening existing roads is very limited in urban areas. In order to minimise the surface level conflict and to provide a relief to mixed traffic, spatial separation in the form of flyovers is planned at major intersections in the congested cities of India. Flyovers at major urban intersections can be instrumental in reducing traffic congestion and delay. However, in most of the cases a comprehensive planning approach has not been adopted, either due to lack of fund or ignorance about the planning perspective of such proposals. The locations for flyovers have been decided based on present day operating conditions and the traffic impacts of such flyovers on adjacent intersections have not been analysed. A wrongly planned flyover may only shift the location of the traffic problem without offering remedies.

The objective of the paper is to analyse the traffic impact of such an independently designed flyover at an urban intersection. For the purpose of analysis, an intersection in Calcutta (Kolkata), where a flyover is being constructed, and another adjacent intersection in close proximity have been considered. The analysis shown in the paper can be used to answer queries like how effective it will be to construct flyovers at urban intersections or whether it will solve the congestion problem successfully etc.

Traffic in most of the developing countries is heterogeneous in nature. In order to achieve the above objective it is necessary to have a tool for analyzing mixed traffic operation at urban intersections. In recent years, the advent of high-speed computers has resulted in extensive use of computer simulations for analyzing transportation problems (Payne 1979; Leo and Pretty 1992; Wang and Prevedouros 1998; Chou, Chen & Li 2001; Wong et al. 2002; Olmos, Pierre & Boudreault 2003; Dion, Rakha & Kang 2004; Taniguchi and Shimamoto 2004; Hidas 2005). A Number of traffic simulation software like TRANSYT (Vincent, Mitchell & Robertson 1980), SATURN (Hall, Vliet & Willumsen 1980), CARSIM (Benekohal & Treiterer 1988), NETSIM (Rathi & Santiago 1990), etc., was developed for analyzing traffic operations. However, majority of works carried out by researchers considered homogeneous traffic stream and strict lane discipline. Therefore, in general, they are not directly applicable for heterogeneous traffic conditions and poor lane discipline prevailing in developing countries like India. Several researchers have also developed traffic simulation models considering mixed traffic operations (Arason & Jagdeesh 1995; Popat, Gupta & Khanna 1995; Hossain and McDonald 1997; Faghri and Egvhaziova 1999). These models have been extremely useful for addressing the issues related to mixed traffic operations. The potential use of computer simulation in formulating improvement measures under mixed traffic operations has been established through the development and application of these models. However, most of these simulation models were developed for specific purposes and are not generally available for use by others. In the present study, a simulation model has been developed for modeling traffic impact of flyover at an urban intersection in Calcutta (Kolkata).

A flyover was under construction at a major 4-arm intersection (i.e. Gariahat Intersection) in Calcutta (Kolkata). In the present paper, Gariahat intersection and the adjacent 5-arm Phari intersection have been considered for modeling the traffic impact of flyover at Gariahat. Due to the construction of flyover, the traffic flow at Gariahat and Phari intersections was disturbed and it was not possible to validate the simulation model for Gariahat or Phari intersection. Therefore, an adjacent intersection (i.e. Deshpriya Park) having similar road geometry and traffic environment to that of Gariahat Intersection, was considered for the validation of the simulation model. A sketch of intersections considered for validation and application of simulation model is shown in Fig. 1.

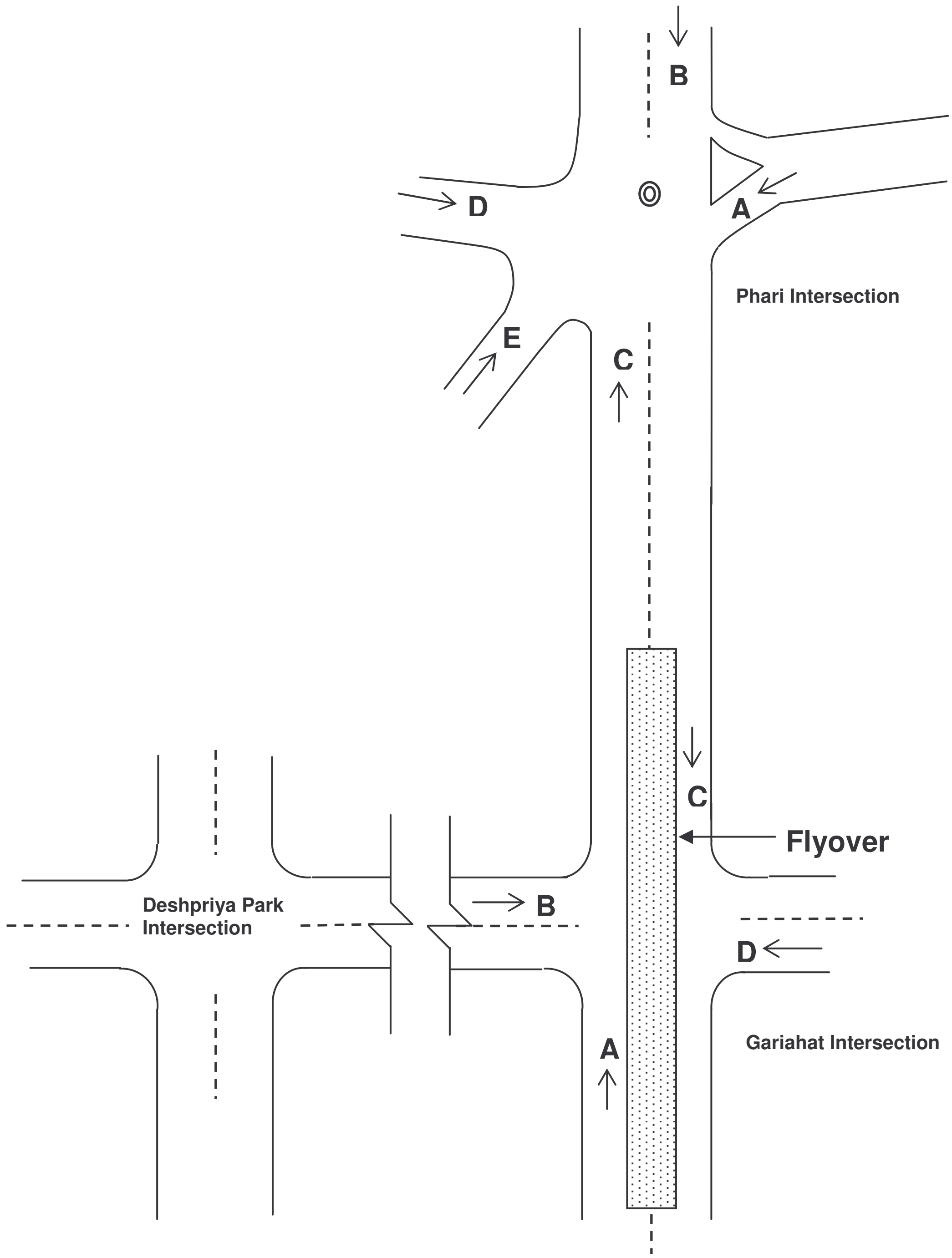

Figure 1. A sketch of Intersections Considered for Validation and Application of Simulation Model.

2. Development of a Traffic Simulation Model

An interval oriented traffic simulation model is developed considering the mixed traffic operations and poor lane discipline prevailing in Indian cities (Azmi 2002). The major inputs required by the model and the outputs obtained are given below. A brief description of the salient features and the parameters incorporated in the model is also included in the paper.

The major inputs required by the simulation model include, i) different types of vehicle and their dimensions, ii) volume of traffic in each approach of intersection, iii) composition and directional distribution of approaching traffic, iv) approach speed distributions and acceleration / deceleration characteristics for different types of vehicle, v) width of intersection approach and signal timings. The major outputs obtained from the model are overall delay and queue length.

Each approach of an intersection is simulated in the model. During the simulation process, the headway, type of vehicle, turn characteristic (i.e. left, straight or right going) and approach speed are generated by the model. Assuming a minimum headway of 0.5 second, the shifted negative exponential distribution is used to generate the time headways of vehicles. The type of vehicle and its turn characteristics are generated based on the cumulative probability distribution charts developed from the field observations, and acceleration/deceleration characteristics are assigned. In the process of generating approach speed of a vehicle, Box and Muller Technique is used to generate standard normal variants.

The action of a vehicle generated in the simulation model is guided by certain rules. A vehicle travels with its generated speed until there is a hindrance from another vehicle in front or the stop line appears along with red indication from the signal. A vehicle starts decelerating only when, the available sight distance is equal to the stopping sight distance. If there is no opportunity for overtaking then a vehicle decelerates to attain the speed of the slow moving vehicle in front and maintains a distance equals to the stopping sight distance. A stopped vehicle accelerates only when the available gap in front is at least equal to a predefined value. This predefined distance is a function of the type of vehicle and its value is given based on the field observations.

In the absence of strict lane discipline, vehicles tend to find gaps in the traffic stream and move forward to position them nearer to the stop line. This phenomenon is duly incorporated in the model by additional rules. It is assumed that right-turning vehicle can occupy either right lane or central lane to move as close as possible to the stop line. Similarly, left-turning vehicles can occupy either left lane or central lane; and straight going vehicle can occupy any lane to move as close as possible to the stop line. In the model, a scanner was used to scan the available gap in front of an approaching vehicle and compare the same with the effective width required by that vehicle type to move forward. The scanner also checked for the possible obstruction by any of the already positioned vehicles and accordingly the scanner width was reduced to the available width of the gap. The scanner and the vehicle following it continuously moved forward until the scanner width became lesser then the effective width of the vehicle.

Database

For the validation of the simulation model for Deshpriya Park intersection, all the required inputs were collected from the field and the model outputs were compared with field observations. Traffic at Deshpriya Park intersection was heterogeneous in nature and comprised of different modes like Two Wheelers, Three Wheelers (Autos), Cars, Buses and Minibuses. At the time of study, a two phase fixed time signal was in operation at the junction.

In order to obtain directional distribution of approaching traffic, a turning movement survey was conducted and vehicles were recorded in each five seconds interval. In order to understand the distribution of approach speed for different types of vehicle, spot speed data was collected by recording the time taken by individual vehicles to cover a short trap length of 37.7m. Queue length at the end of green to the start of next green was measured in terms of number of vehicles and also in meters. Pre-installed benchmarks at an interval of 10 meters were used to determine the length of queue in meters. The deceleration rates of different types of vehicle were recorded from the filed. Classified traffic volume count was also carried out during 8:00 A.M. to 1:00 P.M. The signal timings and existing road geometry of approach lanes e.g. approach width; number of lanes etc. was also recorded.

Validation of Model

For the validation of the simulation model, a number of simulation runs were taken using the inputs measured from the field during the peak hour of traffic flow. The outputs obtained from several model runs were compared with those observed in the field. The average queue length and average maximum queue length as obtained from several model runs during the peak hour, were compared with those observed in the field. A comparison of modeled and observed queue lengths is shown in *Table 1*. It may be noticed from *Table 1* that the modeled queue lengths are in agreement with the field observations. Similarly, the delays for different types of vehicle and average vehicular delay as obtained from different simulation runs were also compared with those observed in the field. A comparison of delays as obtained from model runs and as observed form field measurements is shown in *Table 2*. It is observed from *Table 2* that except for buses, the modeled delays for different types of vehicle are in agreement with those observed in the field.

Table 1: A Comparison of Modeled and Observed Queue Lengths.

Queue	Length of the Queue in ‘m’	
	Model Average	Field Observation
Maximum	122.6	139.7
Average	61.8	64.8

Table 2: A Comparison of Modeled and Observed Delays.

Type of Vehicle	Modeled Delay (Sec)	Observed Delay (Sec)
Auto	16.4	17.5
Bus	29.6	36.8
Car	19.5	20.7
Minibus	22.5	23.9
Two Wheeler	15.6	16.3
Average	*19.5*	*21.5*

In order to capture more passengers, bus drivers were found to spend more time while crossing the Deshpriya Park intersection. Moreover, due to the unhealthy competition among private bus operators, buses were placed in such a way that no other bus could overtake a bus in front. This phenomenon was not considered in the model and therefore, the average delay for buses as obtained from the model were lower than that measured in the field. It is assumed that in extremely busy intersections like Gariahat and Phari, such unhealthy competitions among private bus operators can be avoided under stringent supervision from the city traffic police. Therefore, the simulation model was applied to analyse the impact of the construction of a flyover at Gariahat intersection.

3. Application

The validated simulation model was applied to analyse delays for Gariahat and Phari intersections for the peak hour of traffic flow. Before the construction of flyover a two-phase signal was in operation at Gariahat intersection, while a three-phase signal was in use at Phari intersection. *Table 3* shows the traffic volume for different approaches of Gariahat and Phari intersections, while the directional distribution of traffic for different approaches are given in *Table 4*.

Table 3: Approaching Traffic Volumes at Gariahat and Phari Intersections.

Intersection	Approach and its Width	Car	Two Wheeler	Bus	Mini Bus	Auto	Total
Gariahat	A (9.35m)	791	128	85	64	0	1068
	B (11.45m)	323	78	77	17	189	684
	C (12.25m)	886	155	128	115	0	1284
	D (11.45m)	382	62	153	19	234	850
Phari	A (6.70m)	868	243	34	50	105	1300
	B (6.90m)	1307	194	81	97	21	1700
	C (10.30m)	1148	232	51	82	14	1527
	D (8.45m)	465	92	7	22	0	586
	E (10.60m)	363	93	23	26	206	711

Table 4: Directional Distributions of Traffic at Gariahat and Phari Intersections.

Intersection	Approach	Percentage of Traffic		
		Left Turning	Straight	Right Turning
Gariahat	A	12	88	NA
	B	27	73	NA
	C	15	85	NA
	D	12	70	18
Phari	A	21	42	37
	B	27	73	NA
	C	24	70	6
	D	41	15	44
	E	18	45	37

3.1 Analysis of Delay before the Construction of Flyover at Gariahat Intersection

Several simulation runs were taken to model the delays for different types of vehicle at each approach of Gariahat and Phari intersections. The delays for different types of vehicle and the average vehicular delay (considering all types of vehicles together) at each approach of Gariahat intersection are shown in *Table 5*. Similarly, the delays for different types of vehicle and the average vehicular delay for each approach of Phari intersection are shown in *Table 6*.

Table 5: Delays at Gariahat Intersection before the Construction of Flyover.

Vehicle Type	Average Vehicular Delay in Sec for Approach			
	A	B	C	D
Car	38.8	34.6	41.4	27.6
Two Wheeler	23.8	28.6	27.5	14.4
Bus	40.2	46.3	49.5	30.9
Mini Bus	38.7	42.8	48.6	28.2
Auto	NA	35.6	NA	15.1
Average	*37.1*	*35.7*	*41.2*	*23.8*

Table 6: Delays at Phari Intersection before the Construction of Flyover at Gariahat.

Vehicle Type	Average Vehicular Delay in Sec for Approach				
	A	B	C	D	E
Car	38.1	51.5	44.9	78.1	34.6
Two Wheeler	31.9	47.4	25.7	74.2	9.4
Bus	41.9	61.5	53	92.3	35.8
Mini Bus	42.5	61.5	48.6	81.4	33.4
Auto	37.3	50.5	37.4	NA	27.7
Average	*37.1*	*52.1*	*42.4*	*77.8*	*29.3*

When all four approaches of Gariahat intersection were considered together, the average vehicular delay was estimated as 35.3 sec. Similarly, the average vehicular delay at Phari intersection was estimated as 46.0 sec. Based on the approaching traffic volume and average delay, the total vehicle-hour delay during the peak hour was estimated as 38.1 for Gariahat and 74.4 for Phari. It may be observed that average vehicular delay was more at Phari intersection as compared to that of Gariahat intersection. The traffic handled by Gariahat intersection during peak hour was 3886 vehicles as compared to 5824 vehicles by Phari intersection. The total vehicle-hour delay at Phari was more, as both average vehicular delay and the traffic volume were more as compared to those at Gariahat. Apparently, it would have been logical, from the above point of view to plan for a grade separation at Phari intersection rather than a flyover at Gariahat. However, the local authorities planned for a flyover at Gariahat intersection. The analysis of delay for both intersections after the construction of flyover at Gariahat intersection is given in the following section.

3.2 Analysis of Delay after the Construction of Flyover at Gariahat Intersection

After the construction of flyover at Gariahat, the entire straight going traffic from approach A and approach C will use the flyover (*Fig. 1*). As the turning traffic from approaches A & C and the entire traffic from approaches B and D will continue to use the at-grade intersection, it will be necessary to redesign the signal for the at-grade traffic at Gariahat. The at-grade traffic movement after the construction of flyover at Gariahat intersection is summarised in *Table 7*. It may be mentioned that out of 3886 vehicles approaching Gariahat intersection, 2031 vehicles will use the flyover during the peak hour. A cycle time of 150 sec was estimated for the operation of at-grade traffic at Gariahat intersection and accordingly the delays at different approaches were estimated from model runs. *Table 8* summarises the average delays to at-grade traffic for different approaches of Gariahat intersection after the construction of flyover. A comparison of delays of different types of vehicle as shown in *Table 8* with the delays shown in *Table 5* clearly shows that there will be substantial benefit for the traffic that will continue to use the at-grade traffic signal at Gariahat.

Table 7: At Grade Traffic Volume at Gariahat Intersection after the Construction of Flyover.

Approach	Left Turning	Straight	Right Turning	Total
A	128	0	0	128
B	185	499	0	684
C	193	0	0	193
D	102	595	153	850

Table 8: Delays at Gariahat Intersection for at-grade Traffic after the Construction of Flyover.

Vehicle Type	Average Vehicular Delay in Sec for Approach			
	A	B	C	D
Car	9	22.7	13	19.4
Two Wheeler	3.1	12.5	4.1	9.6
Bus	27.5	31.5	24	24.5
Mini Bus	33.3	28.5	20.5	27.8
Auto	NA	24.1	NA	11.3
Average	*11.2*	*23.1*	*13.7*	*17.6*

When the total at-grade traffic on all approaches of Gariahat intersection were considered together, the average delay per vehicle was estimated as 18.7 sec. When entire traffic (i.e. traffic at-grade and traffic using flyover) was considered together the average delay per vehicle was estimated as 8.9 sec. A comparison of this average delay with the average vehicular delay of 35.3 sec. before the construction of flyover clearly indicates that there will be a reduction of average vehicular delay by 74.8% due to the construction of flyover at Gariahat intersection. This reduction in average vehicular delay is substantial for the traffic using Gariahat intersection during the peak hour of traffic flow. Probably, the local authorities realised this benefit and therefore, planned for the flyover at Gariahat without understanding the impact of this flyover on the adjacent Phari intersection. After the construction of flyover, the total vehicle-hour delay at Gariahat intersection was estimated as 9.7. This indicates a reduction of 28.4 vehicle-hour delay during the peak hour due to the construction of flyover.

For the Phari intersection, the pattern of traffic arrival for approach C (traffic approaching from Gariahat) will change after the construction of flyover at Gariahat. The inflow during the peak hour will increase substantially because of the uninterrupted flow of traffic approaching Phari using Gariahat flyover. Moreover, as only about 47.7% of the earlier total traffic will continue to use the traffic signal at Gariahat intersection, they will also be discharged with much lesser delay. Altogether, the inflow of traffic from Gariahat to Phari during the peak hour will be much higher after the construction of flyover at Gariahat. This change in the traffic arrival pattern was duly considered in the analysis and the average delays for different types of vehicles at approach C of Phari intersection were modeled. The estimated delays were 119.1 sec for Car, 65.0 sec for Two Wheeler, 125.0 sec for Bus, 102.3 sec for Minibus and 62.5 sec for Auto. When all vehicles of this approach (i.e. approach C) were considered together the average delay per vehicle was estimated as 110.3 sec. A comparison of this average vehicular delay with the average delay of 42.4 sec before the construction of flyover at Gariahat *(Table 6)* clearly shows that for approach C (at Phari), there will be more than 100% increase in delay because of the change in arrival pattern of traffic caused by the flyover at Gariahat. The delays for other approaches of Phari intersection are unlikely to be affected by the flyover at Gariahat. The signal timing could be readjusted to distribute some of the delay to the other arms though the average vehicular delay will not change significantly. Therefore, the modeled delays for other approaches as estimated earlier (*Table 6*), along with the newly estimated delay for approach C were used to estimate the average vehicular delay for Phari Intersection. The average vehicular delay for Phari was estimated as 70.4 sec. Similarly; the total vehicle-hour delay for Phari intersection was estimated as 132.6. It may be observed that both the average vehicular delay and the total vehicle-hour delay for Phari intersection will increase substantially after the construction of flyover at Gariahat intersection. A comparison of vehicle-hour delays for Gariahat and Phari intersections before and after the construction of flyover at Gariahat is shown in *Fig. 2.* If both Garihat and Phari intersections are considered together, the net change in vehicle hour-delay due the construction of flyover at Gariahat is also shown in *Fig. 2*. It may be observed from *Fig. 2* that after the construction of flyover at Gariahat, the increase in vehicle-hour delays for Phari intersection will be more than the reduction in vehicle-hour delays for Garihat intersection. As a result, if both Gariahat and Pharai intersections are considered together, there will be a net increase in vehicle-hour delay. The total increase in vehicle-hour delay for Phari intersection was estimated as 58.2. When both Gariahat and Phari intersections were considered together, the net increase in vehicle-hour delay was estimated as 29.8. *Fig. 2* clearly shows that the flyover at Gariahat will not solve the traffic problem. Rather, it will only shift the location of problem from Gariahat to Phari and also result into an increase in vehicle-hour delay.

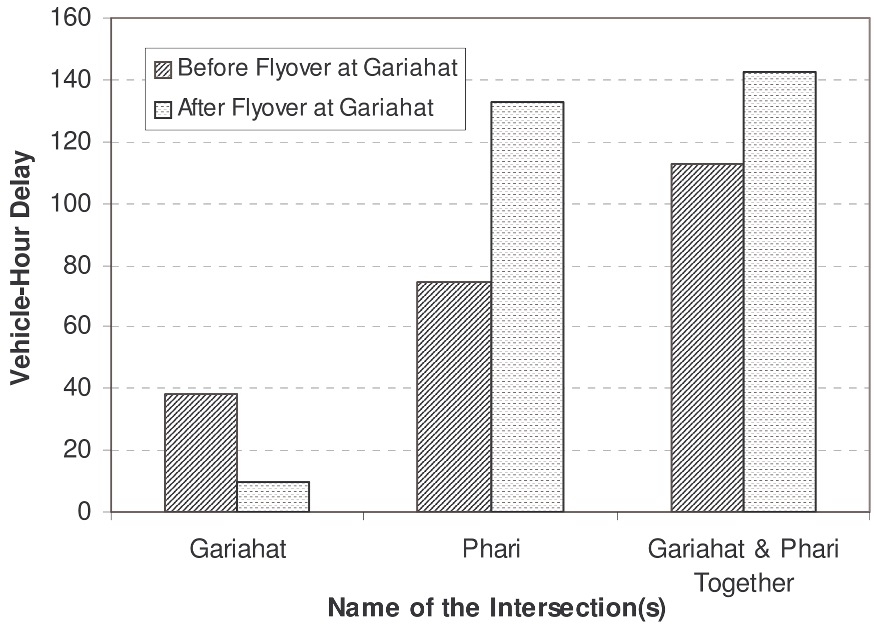

Figure 2: A Comparison of Delays due to the Construction of Flyover.

4. Conclusions

In order to mitigate road traffic congestion, several urban authorities in India have taken up initiatives for construction of flyovers at major intersections. However, a comprehensive planning approach is missing in most of the cases. The locations for flyovers have been decided based on present day operating conditions or some times even by the perceptions of the decision-making bodies without resorting to the analytical planning approach. The case study presented in the paper is an example of many such flyovers in Kolkata and other cities in India. It has been shown that instead of solving transportation problem, an ill planned flyover only shifts and / enhances the problem. It has been shown that how a simulation model can be used for assessing the traffic impact of a proposed flyover at an intersection, emphasising the need of a systematic approach and analysis at the planning stage.

In an urban network, one intersection may be more congested than other adjacent intersections. But, decision for construction of flyover at the most congested intersection should not be based on only the present day operating condition. This is because the less congested operating conditions for adjacent intersections can be simply due the bottleneck and constrained outflow from the existing congested intersection. If a flyover is planned and operating condition is improved, other adjacent intersections may become congested due to the change in traffic flow pattern. Therefore, during the planning of flyover, the traffic impact analysis should be carried out considering adjacent traffic intersections. It has been shown in the case study that how the average vehicular delay and total vehicle hour delay will increase for Phari intersection after the construction of the flyover at Gariahat intersection. Following similar method, the traffic impact on other adjacent intersections can also be modeled.

In the case study presented in the paper, only two intersections have been considered. However, the results indicate that it may be rational to consider one or more prioritised corridors in an urban area, and then analyse the traffic flow considering all intersections along each such selected corridor. Based on the traffic impact analysis considering adjacent intersections along the selected corridor, one or more flyovers may be recommended for improving operations of traffic at corridor level. This is contrary to the school of thoughts presently being followed by many urban authorities in India, where flyovers are constructed at a few congested intersections only based on present day operating conditions. As the selected intersections are spread over the whole city and do not serve as a part of any corridor, the construction of flyovers may only change the spatial nature of the traffic problem in the city without bringing the expected benefits.

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