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Impact of public transport and non-motorized transport infrastructure on travel mode shares, energy, emissions and safety: Case of Indian cities

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ABSTRACT

Current modal share in Indian cities is in favor of non-motorized transport (NMT) and public transport (PT), however historical trends shows decline in its use. Existing NMT and PT infrastructure in Indian cities is of poor quality resulting in increasing risk from road traffic crashes to these users. It is therefore likely that the current NMT and PT users will shift to personal motorized vehicles (PMV) as and when they can afford it. Share of NMT and PT users can be retained and possibly increased if safe and convenient facilities for them are created. This shall also have impact on reducing environment impacts of transport system.

We have studied travel behavior of three medium size cities – Udaipur, Rajkot and Vishakhapatnam. Later the impact of improving built environment and infrastructure on travel mode shares, fuel consumption, emission levels and traffic safety in Rajkot and Vishakhapatnam are analyzed. For the purpose three scenarios are developed – improving only NMT infrastructure, improving only bus infrastructure and improving both NMT and bus infrastructure.

The study shows the strong role of NMT infrastructure in both cities despite geographical dissimilarities. The scenario analysis shows maximum reduction in CO_2 emissions is achieved when both PT and NMT infrastructure are improved. Improvement in safety indicator is highest in this scenario. Improving only PT infrastructure may have marginal effect on overall reduction of CO_2 emissions and adverse effects on traffic safety. NMT infrastructure is crucial for maintaining the travel mode shares in favor of PT and NMT in future.

Introduction

India is the world's fourth largest consumer of oil and the third largest contributor to energy related CO_2 emissions (U.S. Energy Information Administration, 2015). However, per capita CO_2 emissions by transport sector of India are only one-sixth of the worlds' and one-third of China's per capita CO_2 emissions (U.S. Energy Information Administration, 2015). The relatively low level of per capita CO_2 emissions from the transport sector of India is associated with relatively high mode share of low carbon modes of transport (walk, bicycle and bus) (Wilbur Smith Associates, 2008).

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Historical trends shows constant decline in the use of NMT and PT. Existing NMT and PT infrastructure in Indian cities is in poor condition posing discomfort and high risk from traffic accident to these users (Ghate and Sundar, 2010; Tiwari and Jain, 2008). Majority of these users belong to low income groups and are therefore captive as they cannot afford PMV of transport. Most Indian cities are investing to ensure fast mobility of vehicles that includes road widening schemes and provision of flyovers and foot-over bridges (Jnnurm, 2009). While, there are minimal plans to invest in improving the basic transport infrastructure for pedestrians, bicyclists and bus users (Tiwari and Jain, 2013). Given the existing condition, the low carbon mode users are likely to shift to carbon intensive modes as and when they can afford it. The shift to PMV will result in higher emission levels (Dhar and Shukla, 2015).

Modal shift to NMT and PT has major impact on CO_2 emissions however; this modal shift is not possible without ensuring safety to NMT and PT users. Also CO_2 is a global pollution indicator, and traffic safety shows the local health impact. Therefore both are important for evaluating impacts of different scenarios.

Previous studies document the positive impacts of appropriate built environment and improving NMT and bus infrastructure on safety. This has resulted in modal shift from PMV to low carbon modes like PT and NMT (BUND and European Environmental Bureau, 2015; Tao et al., 2013; LTA Academy Singapore, 2011; Fietsberaad, 2010; Schiller et al., 2010; Lleras, 2003). Therefore a way to curb the increasing emission levels is by ensuring safety and comfort to both NMT and PT users such that captive users are transformed into choice users.

We aim to estimate the likely range of the impacts of appropriate built environment and NMT and bus infrastructure on energy consumption and equivalent CO_2 emissions in medium size Indian cities. Along with this, impact on safety under alternate scenarios is studied as it is a crucial factor to aggravate shift between modes. Three scenarios are developed for the study – improving only NMT infrastructure, improving only bus infrastructure and improving both NMT and bus infrastructure.

There are 4378 urban agglomerations and towns in India of which nearly 29% of the urban population lives in 77 medium size cities (Census of India, 2011). Medium size cities (0.5–2 million populations) are growing faster with higher rates of motorization (Indian Institute of Human Settlements, 2011). Appropriate built environment and infrastructure is necessary in these cities to ensure sustainable development and low carbon mobility. Travel characteristics vary with city size, city structure and available transport infrastructure. However, study by Wilbur Smith Associates (2008) shows that there is less variation in trip lengths and trip rates between cities of similar size. We have therefore conducted the study in medium size cities to understand the level of variation in travel behavior and type of infrastructure that needs to be improved in cities of similar size. For the purpose, three cities – Udaipur, Rajkot and Vishakhapatnam (Vizag) are selected belonging to different geographic locations but having similar population size. In the three cities primary surveys were conducted under the project "Promoting Low Carbon Transport in Indian cities" funded by UNEP. However detailed data was available for Rajkot and Vizag for which energy consumption and equivalent CO_2 emissions are estimated while safety indicators are estimated for Vizag only.

The paper is divided in three sections. First, travel trends of six Indian cities belonging to different population sizes are studied. Section 'Existing travel modes in Indian cities and trends' presents mobility and safety indicators for three cities – Udaipur, Rajkot and Vizag. In third section data from Rajkot and Vizag is used to develop three scenarios. The impact of change in built environment and infrastructure on mobility and emissions from passenger transport is analyzed. Impact of the three scenarios is analyzed on safety indicators for Vizag only as it requires detailed micro-level data for analysis.

Existing travel modes in Indian cities and trends

The NMT share is approximately 30% in cities with more than one million population and 60% in smaller cities (Wilbur Smith Associates, 2008). Approximately, 25% of the trips in cities with population more than 5 million are by PT while only 5–8% of the total trips are by PT in cities with population less than 0.5 million. Average trip length (ATL) in megacities of India (population > 8 million) is 10 km as compared to 6–7 km in medium size cities (population 4 million to 8 million).

The travel trends of three decades show a sharp decline in NMT trips while rise in motorized two wheeler (MTW) and car trips. Non-motorized travel modes include walk, bicycle and cycle rickshaw. Low income households are dependent on these modes to access employment, education and other essential services (Jain and Tiwari, 2009; Tiwari, 1999; Replogle, 1992). They are captive as they cannot afford motorized modes of transport. These users are dependent on walk and bicycle even for commuting longer distances (Mohan and Tiwari, 1999). Use of NMT has health benefits for all, however with rise in incomes and poor quality infrastructure, use of NMT has been declining.

City authorities and state governments have not invested in upgrading NMT infrastructure resulting in degrading level of service and increasing risk of road traffic crashes to pedestrians and bicyclists. This is one of the most important factors contributing to a decline in NMT trips in the past few years (Wilbur Smith Associates, 2008). Despite this, NMT dominates the travel mode share in Indian cities. This is also attributed to the dense mixed land use city structure enabling short trip lengths.

NMT is also used to access public transport system. Primarily, a PT user is a pedestrian for at least one part of the trip either during access or egress. Approximately 97% of the bus commuters surveyed in Delhi walk to access bus service (Advani and Tiwari, 2006). Provision of an appropriate well integrated infrastructure for NMT along with PT improves the utility of the public transport system and increases its catchment area. Though, dedicated infrastructure for pedestrians does not have direct impact on pedestrians' speed, however, it provides easy, comfortable and safe access. By providing appropriate parking facility for bicycles at or near bus stops and safe bicycle paths along the arterial roads number of bus users can increase as larger area around the bus stops becomes accessible. Provision of appropriate infrastructure for NMT provides equal access to all and is a major factor in determining the use of PT in the city. Thus a complete network plan must be in place for promoting the use of NMT that is also well integrated with the existing and proposed PT system in the city.

Trends in use of NMT

In the early 1980s, NMT i.e. bicycles and walk together accounted for approximately 40–60% of the total trips which has been reducing in all Indian cities except in Chennai and Patna. However, bicycle and walk trips have shown different trends.

Of the total trips bicycle share accounted for approximately 10–30%. Bicycles started to lose patronage in 1990s (Replogle, 1992). By 1995, the bicycle share declined by 22% in Kanpur as compared to 58% in Delhi and 86% in Jaipur (Fig. 1). In Ahmedabad, the bicycle share firstly increased by 15% till 1990s and then decreased by 27% by 2000. In Patna, the share of bicycles increased by 83% between 1990s and 2000s and by 6% between 2000 and 2008.

Trends observed in the share of bicycle trips are different from the trends observed in walk trips. Major changes have not taken place in the case of walk trips as compared to bicycle trips in Indian cities (Fig. 2). Walk trips still account for approximately 30–40% of the total trips. Delhi and Patna have shown similar trends where the share of walk trips declined from 1980s to 1990s and then started to increase after 1995.

Trends in PT trips

There is variation in the share of trips by PT, intermediate public transport (IPT) and PMV in Indian cities of similar size. Spatial and temporal availability, reliability, comfort and affordability are some of the important parameters that influence the use of bus service. Extensive bus network, having high frequency, available at affordable prices (often less than the marginal cost of using a two wheeler), is likely to attract a large number of commuters. Data from selected Indian cities shows the share of PT trips with respect to the city GDP (Table 1).

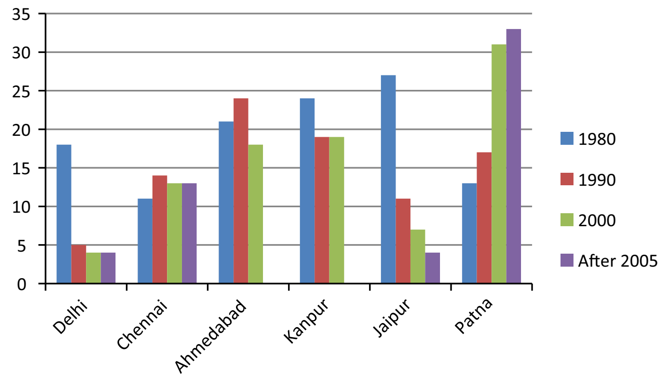

Fig. 1. Trends observed in modal share of bicycle trips since 1980s.

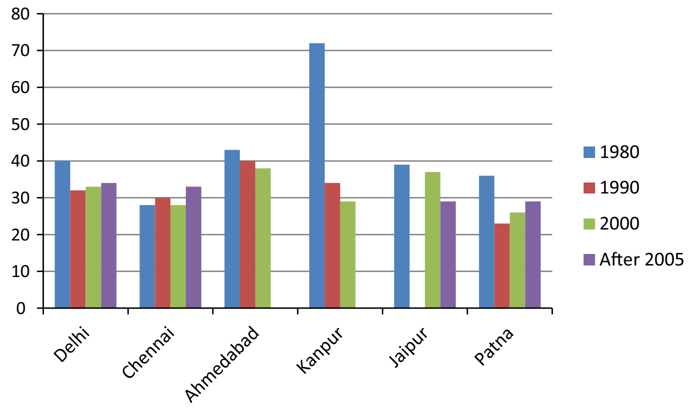

Fig. 2. Trend observed in modal share of walk trips since 1980s.

Table 1
Travel mode share (percentage) and GDP/person in selected Indian cities. *Source:* Demographia (2013), Department of Town and Country Planning Kerala (2012), DMRC (2012), DMRC (2011), Department of Town and Country Planning Kerala (2010), DDF Consultants Pvt Ltd (2010), Central Institute of Road Transport (2009), Bhopal Municipal Corporation (2006), Community Consulting India Pvt. Ltd. (2006).

City	GDP(INR)	Bus	IPT	Walk	Cycle	Car	MTW
Vizag	550	17	9	54	3	2	15
Bhubaneswar	594	4	4	28	22	12	30
Shimla	612	16	0	58	1	17	8
Raipur	734	11	2	29	26	3	29
Kanpur	890	9	7	29	19	16	20
Thiruvanthapuram	950	21	10	26	19	10	14
Kochi	1070	48	8	17	4	9	14
Jaipur	1120	22	4	26	14	8	26
Guwahati	1253	8	12	21	21	18	20
Surat	1788	6	7	35	21	10	21

Table 2
City profile of Udaipur, Rajkot and Vizag. *Source:* UMTC (2014), Munshi et al. (2014), Arora et al. (2014).

	Udaipur	Rajkot	Vizag
LCMP boundary	UUCA	RUDA	GVMC
Area (Ha)	34,791	26,124	53,000
Total population	0.64 million	1.48 million	1.73 million
Density (pp/ha)	18 pp/ha	57 pp/ha	33 pp/ha

City bus service provision also varies across cities. In some small Indian cities, bus service operates on a single route across the city. Often intercity buses run by the State Transport Undertaking are used for city operations. Scheduling of these services is not based on demand analysis. Many metropolitan cities have public owned transport companies for example Bangalore and Delhi. The services provided by these companies are based on travel demand. However, services needs to be further improved in terms of reliability, speed, availability and affordability. This can be achieved by improving scheduling, provision of feeder systems, change in road design, bus stop location, and signal systems. High capacity can be achieved by creating dedicated exclusive lanes for buses, locating bus stops close to intersections and bus stops design enabling level boarding. Depending on the type and frequency of bus, design of dedicated lanes and bus stops, the bus system can give a line capacity of about 40,000 persons per hour (Tiwari et al., 2014).

Mobility, environment and safety indicators in Udaipur, Rajkot and Vizag

City profile of Udaipur, Rajkot and Vizag

In 2011, the population of Udaipur Urban Control Area (UUCA), Rajkot Urban Development Area (RUDA) and Greater Visakhapatnam Municipal Corporation (GVMC) was 0.64, 1.48 and 1.73 million, respectively. Of the three cities Rajkot has the highest person density (Table 2). Both Udaipur and Visakhapatnam has physical growth constraints because of hilly land terrain while Rajkot is growing in all directions.

Rajkot and Vizag are industrial cities while Udaipur is a hub for tourist attractions. Vizag is a port city that has attracted large petroleum and chemical based industries in the city. Rajkot is one of the major business hubs in Gujarat and is one of the key nodes on the Delhi – Mumbai dedicated freight corridor. Udaipur has various lakes along with historical monuments attracting both domestic and foreign tourists. Udaipur also is considered as leading industrial centre of Rajasthan because of the availability of minerals and other resources in the region.

Transport infrastructure

Table 3 presents details of key transport infrastructure in Udaipur, Rajkot and Vizag.

Non-motorized transport

Rajkot can be rated better than Udaipur and Vizag in terms of availability of pedestrian infrastructure. All major roads in Rajkot have footpaths where 27% of the total roads have footpaths with width more than 2 m. However, most of these footpaths are discontinuous and encroached by other activities. Footpaths are present on only 7% and 4% of the total roads in Vizag and Udaipur, respectively. In Rajkot 87% and in Vizag 83% of the surveyed population feel safe and very safe while walking as compared to only 17% in Udaipur. Bicycle infrastructure is almost negligible in all the three cities. In Rajkot cycle track is present only on ring road provided along Bus Rapid Transit (BRT) corridor.

Table 3
Transport infrastructure profile in Udaipur, Rajkot and Vizag. *Source:* UMTC (2014), Munshi et al. (2014), Arora et al. (2014).

	Udaipur	Rajkot	Vizag
Total road length (km)	822 km	2290 km	3469 km
Road density (km/sq km)	2.4 km/sq km	8.8 km/sq km	6.5 km/sq km
Percentage of roads with footpaths	4%	15.85%	7%
Number of buses per 1000 population	NA	NA	0.003
Number of auto per 1000 population	14	7	14
Percentage people feeling safe to walk	17%	87%	83%

Public transport

There is limited city bus service in Udaipur operating on 5 routes. Para-transit system comprising of autos and tempos provide service in the city. In 2012, 6313 registered auto-rickshaws operated in Udaipur based on area-permit basis. Other than this, 2637 tempos operates on 27 designated routes with fix fare mechanism. Rajkot also lack appropriate bus service in the city. Both in Udaipur and Rajkot intra-city bus services are operated by respective city authorities. Because of profitability and related operational issues the system is not feasible. Vizag has comparatively robust bus system in the city comprising of 521 buses operated by the state agency (Andhra Pradesh State Road Transport Corporation). The system is also supported by IPT having a total fleet of 2500 registered auto rickshaws.

City investment plans

GVMC has planned investment of INR 62.40 billion for construction of 43 km of metro rail project spanning over a period of 7 years starting from 2007 (Cities Alliance, 2006). The investment plan discusses the need to discourage the use of PMV by congestion pricing and posing restriction on entry of vehicles. In Udaipur there is no separate head for traffic and transportation related works in Udaipur city budgets. Expenditures are dealt under public repair and development department where emphasis is laid on construction of missing road links, road widening schemes and building flyovers (CRISIL, 2014). Comprehensive mobility plan of Rajkot defined short and long term projects. Some of the projects advised in the plan are development of bicycle lanes, improvement of roads in central areas and re-organization of parking spaces. Widening of bridges and construction of flyovers and bus infrastructure were to be completed in a span of 4–5 years (Rajkot Municipal Corporation, 2010). As discussed, except Rajkot, the other two cities have consolidated plans for development of transport infrastructure however do not provide appropriate built environment to retain and cause shift towards NMT and PT in the cities.

Travel pattern

Trip length

ATL in Udaipur is 5.1 km as compared to 3.5 km in Rajkot and 3.3 km in Vizag. Even though, Vizag is spread over larger area (53,000 Ha) than Udaipur (34,791 Ha) and has similar physical constraints for city expansion in all directions, yet ATL in Vizag is less than that of Udaipur.

As shown in Fig. 3 and 40% and 60% of the trips are shorter than 2 km in Rajkot and Vizag, respectively. Only 20% of the total trips are longer than 5 km in both the cities. Acceptable trip length for walk and bicycle is 0.7 km and 2.5 km, respectively (Advani and Tiwari, 2006). Trip length frequency distribution of both the cities therefore implies that there is a larger share of potential walk and bicycle trips in these cities.

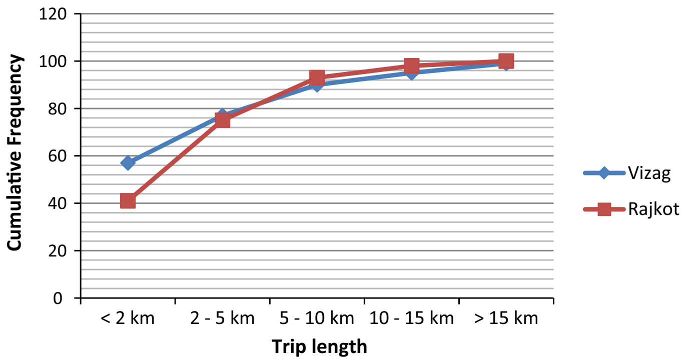

Fig. 3. Trip length frequency distribution. *Source:* UMTC (2014), Munshi et al. (2014), Arora et al. (2014).

Travel mode share

Table 4 presents travel mode share and ATL by modes for the three cities. Travel mode share of walking is 53% in Vizag and 38% in Rajkot. In Rajkot people walk longer (trip length = 1.68 km) as compared to Vizag (trip length = 0.64 km). Bicycling is comparatively low in Vizag because of land terrain. High share of walk trips is associated with short trip lengths. In Vizag 60% of the trips are shorter than 2 km as compared to 40% in Rajkot. Vizag has good public transport service in the city while Rajkot lacks the system. This is reflected in the modal split of both the cities.

Energy consumption and emissions

Methodology

Energy consumption and equivalent CO_2 emissions are estimated for Rajkot and Vizag using ASIF approach (Schipper et al., 2000). The approach takes into account

- A – travel activity measured in terms of passenger-km.
- *S* – modal split of travel in the city.
- *I* – energy intensity or energy consumed per passenger-km or vehicle-km by every mode type.
- *F* – emission factor of the fuel used.

Thus emissions can be calculated as

$$E = \text{Population} \times \text{Trip rate} \times \sum_{i=0,j=0}^{n} [Si \times (\text{average trip length})i \times Ii \times Fj] \tag{1}$$

where *i* and *j* are the modes and fuel used, respectively. Fuel consumption intensity and fuel mix is determined using petrol pump survey conducted in both Rajkot and Vizag (Mohan et al., 2014). This method accounts for fuel mix, average speed on city roads and vehicle age into account.

Vehicle fleet characteristics

Vehicle fleet characteristics is determined from sample data collected at petrol pump for both Rajkot and Vizag (Mohan et al., 2014). Fig. 4 shows the share of vehicles on road by fuel used and proportion of kilometers travelled by vehicle type. There are negligible Compressed Natural Gas (CNG) fuelled vehicles in both the cities. Buses in both the cities are fuelled by diesel. In Rajkot, 66% of the distance travelled by three-wheelers is by CNG.

Fuel efficiency for different types of vehicles in Rajkot and Vizag is estimated based on petrol pump data (Table 5). Average fuel efficiency is comparatively higher in Rajkot. Average age of cars and MTW in Rajkot is approximately 4 years, as compared to 7 years for MTW and for cars it is 4 years in Vizag. The difference in vehicle age along with other factors like traffic conditions is the reason for the difference in vehicle fuel efficiency of the two cities.

Fuel consumption and CO_2 emissions

Table 6 shows total fuel consumption by urban transport in the two cities. In Vizag, nearly 23% of the total fuel is consumed by bus as compared to only 11% in Rajkot. This is attributed to the smaller share of trips being catered by bus in Rajkot as compared to Vizag. Since, in Rajkot 35% of total trips are by MTW as compared to only 15% in Vizag; fuel consumption by MTW is approximately 51% as compared to 39% in Vizag.

Table 7 shows the resulting contribution of each mode to the total equivalent CO_2 emissions by urban passenger transport in both the cities. Although there is difference in total CO_2 emissions by urban passenger transport in the two cities, however per capita emission is same in both the cities.

Table 4
Travel mode share and mode wise average trip length. *Source:* UMTC (2014), Munshi et al. (2014), Arora et al. (2014).

	Udaipur		Rajkot		Vizag	
	Modal share (%)	ATL (km)	Modal share (%)	ATL (km)	Modal share (%)	ATL (km)
Walk	48	2.5	38	1.7	53	0.6
Bicycle	2	5.0	10	3.4	4	2.5
MTW	34	5.2	35	4.2	15	5.0
Car	3	6.0	2	11.7	2	6.6
Ipt	11	4.5	11	4.3	9	4.2
Buses	2	8.5	3	8.5	17	9.0
Others			1			

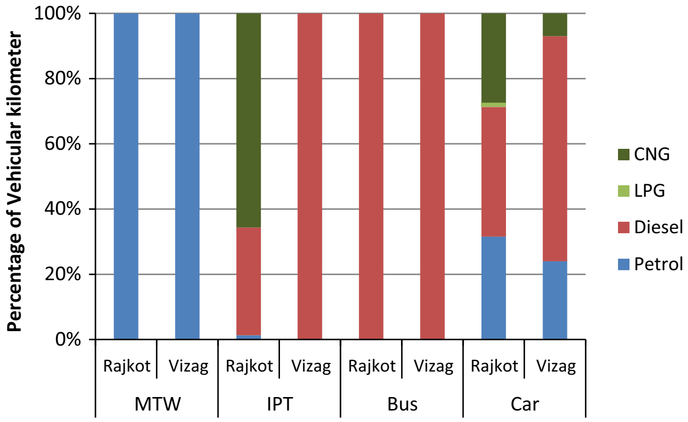

Fig. 4. Fleet composition in Rajkot and Vizag. *Source:* Mohan et al. (2014).

Table 5
Fuel efficiency (km/l) for Rajkot and Vizag using petrol pump survey. *Source:* Mohan et al. (2014).

		Petrol	Diesel	LPG	CNG
Rajkot	MTW	53	NA	NA	NA
	IPT	20	27	NA	32
	Bus	NA	4	NA	NA
	Car	16	17	20	19
Vizag	MTW	49	NA	NA	NA
	IPT	NA	29	NA	NA
	Bus	NA	4	NA	NA
	Car	14	16		14

Table 6
Total and mode wise fuel consumption (1000 l) in Rajkot and Vizag.

	Rajkot					Vizag				
	Petrol	Diesel	CNG	Total		Petrol	Diesel	CNG	Total	
MTW	48	0	0	48	51%	39	0	0	39	39%
IPT	0	6	10	17	18%	0	20	0	20	20%
Bus	8	2	0	10	11%	0	23	0	23	23%
Car	6	7	5	19	20%	4	11	1	17	17%
Total	95					98				

Table 7
Equivalent CO_2 emissions – Rajkot and Vizag.

	Rajkot		Vizag	
	Equivalent CO_2 emissions (1000 kg)	Percentage (%)	Equivalent CO_2 emissions (1000 kg)	Percentage (%)
MTW	112	59	89	37
IPT	17	9	53	22
Bus	25	13	61	25
Car	35	18	40	17
Total	189		243	
Per capita emissions (kg/pp)	0.13		0.14	

Safety

Risk of getting involved in road traffic crash is an important aspect in determining travel mode choice. Two indicators are used to analyze safety i.e. risk associated with different travel modes and risk imposed by different travel modes (Tiwari and Jain, 2012). The indicators help in determining targeted intervention to reduce risk faced by specific road users. This analysis requires detailed accident profile data including details of the victim and impacting vehicle involved in traffic crash. Detailed fatal crash data for 2010–2012 from Vizag have been used to estimate the safety indicators. Table 8 shows that highest risk is

Table 8
Mode wise risk exposure and risk imposed – Vizag.

	Percentage of total fatalities (%)	Risk exposure (fatalities per 100,000 users)	Risk imposed by (fatalities per 100,000 users)
Pedestrian	49	0.029	Nil
Bicycle	6	0.045	Nil
MTW	34	0.073	0.005
Car	1	0.021	0.005
Ipt	6	0.022	0.003
Buses	2	0.003	0.004
Trucks	2	0.048	0.011

faced by MTW users followed by trucks and bicyclists. Pedestrians are involved in maximum fatal crashes however because of relatively large number of walk trips effective risk rate to pedestrians is less than other modes.

Fig. 5 represents the percentage of total road fatalities by victim and impacting vehicle. Based on the analysis, it can be said that conflict between pedestrians & trucks; and MTW & trucks needs to be reduced to increase road safety in Vizag. Pedestrians face major risk from bus and car followed by MTW and IPT. Pedestrian infrastructure with provision of safe crossings at regular intervals can help in increasing road safety in the city.

Impact of built environment on mode choice

Impact of built environment on travel patterns

Cervero et al. (2013) found strong correlation between built environment features and choice of access mode to public transit stops. Landuse patterns and population densities have been found to have a major impact on trip lengths and choice of travel modes (Cervero, 2002; Meurs and Haaijer, 2001). Other factors attributed to individual like age, sex, income and vehicle ownership (Zhou, 2012; Palma and Rochat, 2000) combined with trip length and infrastructure quality having influence on safety, comfort, travel time and travel cost of modes (Jain et al., 2010; Palma and Rochat, 2000) has impact on the choice of travel modes (Limtanakool et al., 2006).

As per Cervero (2003) increase in demand for motorized transport is often attributed to the improvement in infrastructure for cars. These empirical studies results support the fundamental thesis suggested by Manheim (1979) that as service level of transport system improves, travel demand increases.

Impact of built environment on bicycle use

Bicycle besides walking is one of the dominant modes of NMT in the urban environment. With the ever increasing emissions due to motorized modes, bicycling can be positioned as the low carbon mode of transportation. Besides, it is a vital access mode for both bus and metro system.

Noland and Kunreuther (1995) showed that perceived costs, risks, comfort and convenience along with travel time and parking availability are some of the factors that influence the use of bicycles. Major results of their study imply two possible courses of action-providing bicycle infrastructure and decreasing the automobile convenience. This has proven to increase the level of bicycle commuting while simultaneously reducing automobile commuting; the premise being to provide urban form that allows people to have bicycle as a choice of mode.

Stinson and Bhat (2003) found that the link-level and route-level factors, along with many social variables, seemed to play a definitive role that affect cyclists' route choice. The link-level factors influencing route choice may include bicycle facility presence and motor vehicle traffic characteristics (Howard and Burns, 2001; Moritz, 1997; Beck and Immers, 1994; Hope,

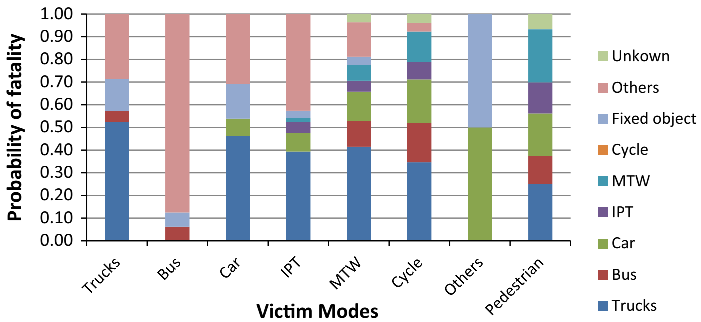

Fig. 5. Probability of being hit in a fatal accident by different modes.

1994), parking characteristics (Dixon, 1996; Sorton and Walsh, 1994; Epperson, 1994), riding surface quality (Harkey et al., 1998; Ashley and Banister, 1989; Bovy and Bradley, 1985) and hilliness (Landis et al., 1997).

Discussions with cyclists about route choice have revealed a number of criteria for the use of the bicycle as the preferred travel mode, such as the possibility of using the secondary road network (21.3%), shortest path (14.9%), and existence of cycle facilities (12.5%). Utilitarian cyclists of this group tend to look for the shortest and most cycle-suitable path (19.6%) (Noel and Lee-Gosselin, 2002). Another survey revealed that cyclists may travel up to 20 min more to switch from an unmarked on-road facility with side parking to an off-road bicycle trail, with smaller changes associated with less dramatic improvements (Tilahun et al., 2007). Bike trips in Vancouver were, on an average, 360 m longer than the shortest possible route; car trips were 540 m longer showing a minor detour of less than 5% of total trip length. Differences in the built environment measures suggest reasons to detour: the chosen routes had significantly more bicycle facilities (traffic-calming features, bike stencils, and signage) than did the shortest path routes (Winters et al., 2010; Su et al., 2010).

Thus, it is evident from the studies that the share of bicycling trips can be increased by improved infrastructure design and appropriate urban form.

Built environment and PT use

The demand for PT is dependent on both the physical and socio economic characteristics of an urban area. Availability of road infrastructure, geographical spread of the city, landuse patterns, population density, and income distribution are some of the important characteristics that influence public transport demand. Since these characteristics change with time, the PT demand also changes. Apart from the most commonly used variables of total time and total cost; users consider comfort, number of transfers, age, urgency of making the trip, reliability of different modes, safety, which again differs with time of travel (day and night) for different type of users (gender, age), etc.

Earlier studies show that along with many other variables of distance, time, and cost, ratios of access and egress trips with total and main line haul trips are also important (Krygsman and Dijst, 2001). Much of the effort associated with public transport trips is performed to simply reach the system and the final destination. Access and egress stages (together with wait and transfer times) are the weakest part of a multimodal PT chain and their contribution to the total travel disutility is often substantial (Bovy and Jansen, 1979). TRL report (2004) finding shows that weighing for walking times to and from stops and stations range between 1.4 and 2 units of in-vehicle time.

Vehicle ownership has a significant impact on the mode choice behavior especially motorcycle seems to be a very attractive mode for Asian people due to its low cost. Tuan and Shimizu (2005), Hsu et al. (2007), and Leong and Mohd Sadullah (2007) have stated that the cost is the greatest advantage of using a motorcycle, particularly for the lower income group. Additionally, Leong and Mohd Sadullah (2007), Chang and Wu (2008) and Minh (2007) supported that the usage performance is the other major advantage of the motorcycle. In several situations, a motorcycle can provide greater comfort and convenience to the travelers than a private car and public transit.

Discussion

There is strong evidence from previous studies that amongst other factors built environment and infrastructure design impacts the choice of PT and NMT use (walking and bicycling). NMT has minimum impact on environment and cater to maximum travel demand in Indian cities. Given the existing trip length distribution of Indian cities, improving bus infrastructure is likely to have a substantial impact on the bus trips. Thus improvement in infrastructure for bus service and NMT has a large potential to reduce fuel consumption and CO_2 emissions from transport sector.

Improvement in bus infrastructure includes improving operation of bus service by optimizing routes and scheduling and infrastructural improvements like reserving lanes for bus on congested parts of the routes and improving location and design of bus stops. NMT infrastructure includes provision of dedicated infrastructure for NMT on arterial roads, creating a city wide NMT network and developing urban environment for safe, secure and comfortable movement of both bicycles and pedestrians.

Mobility, environment and safety indicators can be estimated in three scenarios – existing conditions, improving bus infrastructure and improving NMT infrastructure. Change in travel modes in the alternate scenarios can be assumed on the basis of studied impact of improving infrastructure in other cities.

The three scenarios

Three scenarios are proposed to estimate the impact of change in built environment and infrastructure improvement on travel patterns and resulting change in energy, environment and safety indicators. Scenario 1 includes improving NMT facilities with exclusive lanes on arterial roads and safe crossing facilities at intersections. Scenario 2 includes prioritizing bus operations, exclusive bus lanes along arterial roads along with improved bus stop location and design and scenario 3 includes both facilities for NMT and for buses.

The impact of improving NMT and bus infrastructure on modal shifts is determined in two steps. Firstly willingness of people to shift from motorized vehicles to NMT and PT determined based on the literature review of stated preference studies conducted in seven Indian cities. Finally, the respective shifts are estimated based on the trip length frequency distribution of each mode from which the shift is expected. It is assumed that improving NMT infrastructure shall cause a share of trips to shift from MTW, three-wheelers, and public transport having trip length less than 5 km to NMT. Similarly, improving bus infrastructure shall cause a share of trips to shift from MTW and three-wheelers having trip length more than 5 km to bus.

Various studies have estimated the influence of improving transport infrastructure on modal shares of NMT and bus for Indian cities (Table 9). Jain et al. (2010) shows that 35% and 45% of the trips shorter than 5 km made by MTW and bus are likely to shift to bicycle, when bicycle infrastructure is improved in Pune. Rastogi (2010) with the help of stated preference survey shows that more shift to NMT is expected from short trip lengths for access trips to Mumbai railway station. In a similar study conducted by Vedagiri and Arasan (2009) in Mumbai 53% of the MTW users are likely to shift to bus in Mumbai, if bus priority measures are adopted resulting in same travel time by both the modes.

Similar studies conducted in Indian cities have used stated preference surveys to determine the modal shift to NMT and bus from other motorized modes when NMT/bus infrastructure is improved (Fatima and Kumar, 2014; PV et al., 2014; Grover et al., 2013; Thamiz Arasan and Vedagiri, 2011; Jain et al., 2010; Rastogi, 2010; Vedagiri and Arasan, 2009; Bajracharya, 2008). Modal shifts from carbon intensive modes to low carbon modes are estimated for each of the proposed scenarios based on the empirical studies.

Kroes and Sheldon (1988) emphasizes that people do not necessarily do what they say in stated preference surveys. Therefore, for each of the scenarios maximum shift scenario (MSS) and least shift scenario (LSS) are developed to understand the possible range of impacts of improving NMT and PT infrastructure. LSS scenarios are developed in order to understand the impact of minor improvements in NMT and bus infrastructure on energy consumption, emissions and safety parameters.

MSS scenario is based on the mean value of the modal shifts determined from the stated published studies, while, modal shifts in LSS scenario is based on the lowest value of the modal shift expected in these studies. On an average 34% of the short trips are expected to shift from all motorized modes (excluding cars) to NMT while 50% of the shift is expected from all modes (excluding cars) to bus when infrastructure for NMT and bus are improved. Lowest range of modal shift from motorized modes to NMT is 8–12% and to bus is 20–22%. Based on these values the three scenarios are developed that are explained below (Table 10).

Scenario 1. Improving NMT infrastructure

MSS: This scenario includes 30% of the trips shorter than 5 km by MTW, three-wheelers and bus shift to NMT and the modal share of the trips longer than 5 km are retained.

Table 9
Probability of shifting to NMT and bus using stated preference surveys.

Modes to which shift is estimated, location	Type of trips considered	Variables considered for determining shifts		Percentage shift from modes			
				Cars	MTW	IPT	Bus
To bicycle, Pune[a]	Trip shorter than 5 km	Change in average travel time by motorized modes		14	35		45
To NMT, Mumbai[b]	Access trips to railway station	Access trip length	<1250 m	8	8	69	15
			>1250 m	4	2	16	78
To bus, Mumbai[c]	All trips	Difference in travel time between PMV and PT	0%	13	53		
			10%	22	68		
			20%	35	80		

[a] Jain et al. (2010).
[b] Rastogi (2010).
[c] Arasan and Vedagiri (2011), Vedagiri and Arasan (2009).

Table 10
Scenarios.

	Description		Share of trip shorter than 5 km shifting to NMT	Share of trips longer than 5 km shifting to bus
Scenario 1	Improving NMT infrastructure	MSS	30% from MTW, three-wheelers and bus	0%
		LSS	10% from MTW, three-wheelers and bus	0%
Scenario 2	Improving bus infrastructure	MSS	0%	50% from MTW and three-wheelers
		LSS	0%	20% from MTW and 5% from three-wheelers
Scenario 3	Improving both NMT and bus infrastructure	MSS	30% from MTW, three-wheelers and bus	50% from MTW and three-wheelers
		LSS	10% from MTW, three-wheelers and bus	20% from MTW and 5% from three-wheelers

LSS: This scenario includes only 10% of the trips shorter than 5 km by MTW, three-wheelers and bus shift to NMT and the modal share of the trips longer than 5 km are retained.

Scenario 2. Improving bus infrastructure

MSS: Improving bus infrastructure does not have impact on trips shorter than 5 km. However improving infrastructure for buses results in 50% of the trips longer than 5 km made by MTW and three-wheelers to shift to bus.

LSS: In this scenario, it is assumed that 20% of the trips longer than 5 km made by MTW and 5% of the trips longer than 5 km from three-wheelers shift to bus.

Scenario 3. Improving both NMT and bus infrastructure

MSS: In this scenario both NMT and bus infrastructure is improved resulting in shift from short trips and long trips to NMT and bus, respectively. This scenario includes 30% of the trips shorter than 5 km using MTW, three-wheelers and bus shift to NMT. In addition to this, 50% of the trips longer than 5 km shift from MTW and three-wheelers to bus.

LSS: In this scenario 10% of the trips shorter than 5 km using MTW, three-wheelers and bus shift to NMT. Moreover, 20% of the trips longer than 5 km from MTW and 5% of the trips longer than 5 km from three-wheelers shift to bus.

In Indian cities motor vehicle ownership is 58 per 1000 person which is likely to increase with increasing income and aspirations. Hence net modal shift from cars to environmental friendly modes is assumed to be negligible in all the scenarios. Also, it is assumed that improvement in bus infrastructure does not result in shift from NMT to bus. This is because existing long distance NMT users may have monetary constraints for shifting to bus. However a percentage of short distance bus users are likely to shift to NMT when NMT infrastructure is improved.

In each scenario shifts from different travel modes have been assumed based on city specific trip length distributions. In a city where 70% of the trips are less than 5 km, the impact of improving bus infrastructure will be on 30% trips only. This results in different proportion of trips shifting to NMT or PT.

Travel mode shares in the three scenarios

Rajkot and Vizag are different in terms of availability of transport infrastructure and travel mode shares while trip length frequency distribution is similar in both the cities. In Rajkot 3% of the total trips are made by bus as compared to 17% in Vizag. Rajkot does not have an organized bus system. In Vizag only 4% of the total trips are by NMT as compared to 10% in Rajkot. This has resulted in difference in impacts of improving NMT and bus infrastructure on travel mode shares in the two cities. Improving NMT infrastructure is likely to result in increasing modal share of NMT by 146% in Vizag as compared to 95% in Rajkot. Improving bus infrastructure is likely to result in increasing modal share of bus by 262% in Rajkot as compared to only 28% in Vizag (Table 11). Maximum shift to NMT in Rajkot is likely to take place from MTW and from IPT to bus. In Vizag maximum shift to NMT is estimated from MTW and IPT.

There is no change in share of walking trips and car trips. Most pedestrians are captive pedestrians therefore improvement in NMT and PT infrastructure will not result in shift from walking to NMT or PT.

Energy consumption and emissions in the three scenarios

Figs. 6 and 7 show percentage change in energy consumption and emissions in the three scenarios for Rajkot and Vizag. Diesel consumption may increase in both cities in PT scenarios because of increase in bus trips. Percentage increase in diesel consumption in Rajkot will be more as compared to Vizag because Rajkot has very few bus trips as compared to Vizag in the existing condition. Under PT scenario Rajkot may have major savings in CNG because trips on three wheelers running on CNG shift to bus system. Under NMT scenario savings in petrol and diesel is similar in both cities. Largest savings in petrol consumption is in third scenario when infrastructure for NMT and PT both are improved.

Fig. 7 shows change in equivalent CO_2 emissions in Rajkot and Vizag in three scenarios. Largest reduction in CO_2 emissions occurs in scenario 3 (NMT and PT combined) in both the cities, however percentage reduction is more in Rajkot as compared to Vizag. In Rajkot reduction in emissions in PT scenario is more as compared to NMT scenario, whereas in Vizag NMT scenario results in higher reduction as compared to PT scenario.

Table 11
Estimated share of travel modes (percentage change) Rajkot and Vizag under different scenarios.

		NMT		MTW		IPT		Bus	
		MSS	LSS	MSS	LSS	MSS	LSS	MSS	LSS
Rajkot	Only NMT	20 (95%)	13 (32%)	28 (−20%)	33 (−7%)	9 (−19%)	10 (−6%)	3 (−15%)[a]	3 (−5%)[a]
	Only PT	10 (0%)	10 (0%)	29 (−17%)	33 (−7%)	9 (−19%)	11 (−2%)	11 (262%)	6 (84%)
	Both NMT & PT	20 (95%)	13 (32%)	22 (−37%)	30 (−13%)	7 (−38%)	10 (−8%)	10 (247%)	5 (79%)
Vizag	Only NMT	10 (146%)	6 (49%)	12 (−18%)	14 (−6%)	7 (−18%)	8 (−6%)	15 (−9%)	16 (−3%)
	Only PT	4 (0%)	4 (0%)	12 (−20%)	14 (−8%)	7 (−20%)	9 (−2%)	22 (28%)	18 (8%)
	Both NMT & PT	10 (146%)	6 (49%)	9 (−38%)	13 (−14%)	6 (−38%)	8 (−8%)	20 (19%)	18 (5%)

[a] Existing modal share of bus in Rajkot is only 3% and the resulting modal share of bus in scenario 1 – MSS and LSS are 2.6% and 2.9%, respectively.

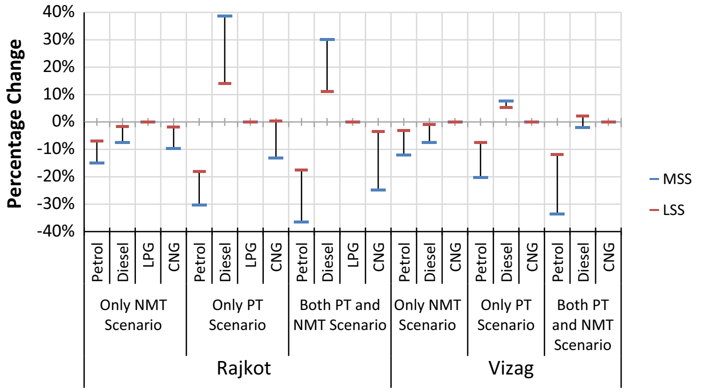

Fig. 6. Percentage change in energy consumption in Rajkot and Vizag under three scenarios.

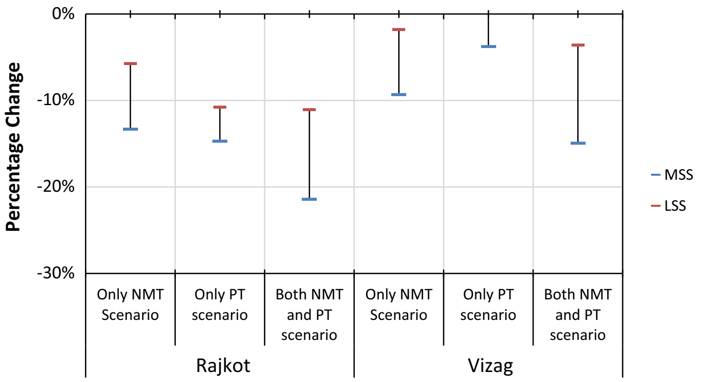

Fig. 7. Percentage change in emissions (CO_2 equivalent) in Rajkot and Vizag under three scenarios.

Safety indicators

Total fatality due to road crashes depends on the level of interaction between different road users. As per Bhalla et al. (2007), probability of a fatal crash is a product of the probability that a crash occurs between the road users and the probability that the crash is fatal. Therefore;

$$\mathrm{fatal}_{\mathrm{victim}}^{\mathrm{threat}} = c_{\mathrm{victim}}^{\mathrm{threat}} \times r_{\mathrm{victim}}^{\mathrm{threat}} \tag{2}$$

where $\mathrm{fatal}_{\mathrm{victim}}^{\mathrm{threat}}$ is the probability that the victim is killed; $c_{\mathrm{victim}}^{\mathrm{threat}}$ is the probability that a road user (victim) is struck by a vehicle (threat); $r_{\mathrm{victim}}^{\mathrm{threat}}$ is the case fatality ratio (CFR) for the victim of the crash. In the case of single vehicle crash, victim mode is replaced by environment, for example, probability of single vehicle scooter crash is given as $r_{\mathrm{scooter}}^{\mathrm{enviourment}}$. For each pair of threat and victim mode, probability of a crash depends on

1. The population of road users that belong to the victim's travel mode, U_{victim}, and the number of "at-risk" kilometers travelled (i.e., distance over which the victim is exposed to the threat) by each of these road users, d_{victim}.
2. The total number of threat vehicles, M_{threat}, and the number of km travelled by each of these vehicles, d_{threat}.
3. Vehicle attributes (e.g., antilock brakes, visibility, stability).
4. Driver attributes (e.g., socio-demographic characteristics, license status, alcohol use, driver training).
5. Roadway infrastructure (pedestrian walkways, lane separating medians).
6. Broader systemic attributes (legal and insurance systems).

that is,

$$c_{\mathrm{victim}}^{\mathrm{threat}} = f\quad(U_{\mathrm{victim}},\ d_{\mathrm{victim}},\ M_{\mathrm{threat}},\ d_{\mathrm{threat}},\ \text{vehicle attributes},\ \text{driver attributes},\ \text{roadway attributes},\ \text{systemic attributes})$$

Bhalla et al. (2007) proposed the following form for this relationship

$$c_{\mathrm{victim}}^{\mathrm{threat}} = K_{\mathrm{victim}}^{\mathrm{threat}} \times U_{\mathrm{victim}} \times d_{\mathrm{victim}} \times M_{\mathrm{threat}} \times d_{\mathrm{threat}} \tag{3}$$

Table 12
Percentage change in number of fatalities in three scenarios – Vizag.

	Only NMT scenario	Only PT scenario	Both NMT and PT scenario
Pedestrians	444 (−6%)	455 (−3%)	420 (−11%)
Bicyclist	54 (0%)	49 (−9%)	51 (−5%)
MTW	288 (−13%)	248 (−25%)	208 (−37%)
IPT	57 (−6%)	55 (−10%)	48 (−21%)
Bus	16 (0%)	17 (6%)	17 (6%)
Car	13 (0%)	13 (0%)	13 (0%)
Trucks	21 (0%)	21 (0%)	21 (0%)

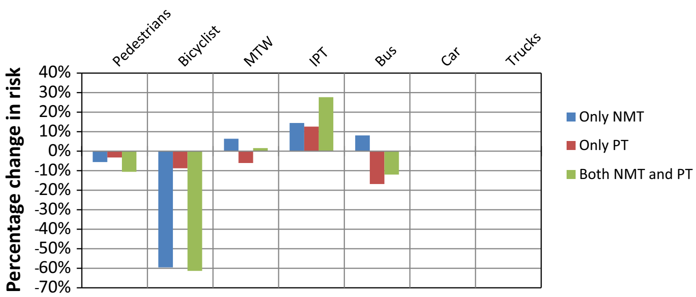

Fig. 8. Percentage change in risk to different road users under three scenarios – Vizag.

So,

$$\text{fatal}_{\text{victim}}^{\text{threat}} = K_{\text{victim}}^{\text{threat}} \times U_{\text{victim}} \times d_{\text{victim}} \times M_{\text{threat}} \times d_{\text{threat}} \times r_{\text{victim}}^{\text{threat}} \quad (4)$$

Therefore, the probability of a specific threat–victim crash is proportional to the product of the total "at-risk" kilometers travelled by road users in the victim's travel mode ($U_{\text{victim}} \times d_{\text{victim}}$) and the total distance travelled by the vehicles that pose the threat ($M_{\text{threat}} \times d_{\text{threat}}$). The proportionality constant, $K_{\text{victim}}^{\text{threat}}$, accounts for all the other variables listed in items 3–6 above and captures the relationship between road use and the probability of a crash.

Estimates of safety indicators for Vizag under three scenarios

Total number of fatalities for different road users has been estimated under the three scenarios (MSS) based on the estimated change in modal shares and trip length as discussed in Section 'Energy consumption and emissions in the three scenarios' for Vizag.

Introducing bicycle lanes along with provision of safe crossing facilities is likely to reduce fatalities drastically on those roads where bicycle infrastructure is planned. Similarly provision of bus infrastructure may reduce conflict between bus and other road users like bicycles, MTW and cars. As per the LCMP submitted for Vizag, bicycle and BRT infrastructure is planned on the roads having width more than 30 m. For the purpose of analysis it is assumed that fatalities for all road users except for pedestrians caused by bus will be negligible on those roads where BRT infrastructure is proposed since buses have dedicated reserved lanes in BRT corridors. Similarly, bicycle fatalities are assumed to be negligible on the roads where dedicated bicycle infrastructure is planned. To increase safety of pedestrians from buses additional interventions may be required along with dedicated bus and NMT infrastructure for controlling speed of buses on BRT lanes.

Table 12 shows total number of fatalities and percentage change from existing situation for different road users under the three scenarios. As per the estimates, there is a significant decrease in the total number of fatalities for all road users except for bus, cars and trucks. Provision of dedicated bus infrastructure is likely to result in increase in passenger-km travelled by bus and the existing fatal cases of bus users are not on the roads where bus infrastructure is planned. Therefore, total number of fatalities has increased by one for bus users when dedicated bus infrastructure is provided.

Fig. 8 shows percentage change in risk to different road users in the three scenarios. There is a significant increase in bicyclist's safety on roads when bicycle infrastructure is provided. Similarly there is total reduction in risk to bus users when dedicated bus infrastructure is provided.

Pedestrians also benefit from provision of both NMT and PT infrastructure as distance travelled by other modes has reduced. Risk to MTW users decreases by 6% when bus infrastructure is improved as conflict between buses and MTW has reduced. However, risk to IPT users has increased in all scenarios even though total number of fatalities has reduced. This is attributed to the significant decrease in number of IPT trips (38%).

Conclusion

Walk, bicycles and PT are the most desirable modes of travel for meeting travel demands of city residents with least adverse impacts on environment, energy consumption and traffic safety. Though, existing mode shares in Indian cities is in favor of NMT, PT and walking, however their use has been declining. This is having detrimental impact on environment. Improving NMT and PT infrastructure shall ensure safety and comfort to these users and therefore help in retaining the existing share of NMT and PT. The strategy is also likely to cause potential NMT and PT trips to shift from PMV.

In the study three scenarios are developed to estimate the impact of improving built environment and infrastructure on travel behavior, energy consumption, emissions and safety for medium size cities. The study is conducted on cities of similar size to understand the variation in travel behavior and impacts of improving infrastructure. The three scenarios include – improving NMT infrastructure, improving bus service and infrastructure and improving both.

Detailed analysis of trip characteristics from two cities – Rajkot and Vizag shows that there are potential bicycle and PT trips in these cities. The results of scenario analysis clearly show the benefits of improving NMT facilities. NMT modal share increases in both the cities, at the same time share of IPT users, MTW users and bus users' decreases. This leads to saving in fuel consumption and reduction in equivalent CO_2 emissions. Improved NMT facilities lead to risk reduction to NMT users. The magnitude of the impact of NMT facility improvement on travel mode share, energy consumption, emissions and safety is different in Vizag and Rajkot because the current mode shares of NMT is different in the two cities. Improvement in NMT facility impacts the use of MTW, bus and IPT in both cities. Improving PT facilities results in increased share of bus trips in both the cities; however the percentage increase in Rajkot is more than Vizag.

The analysis shows the importance of NMT infrastructure on safety. Major safety benefits are estimated under NMT improvement scenario. If bus operations are improved without developing safe and exclusive infrastructure for buses, risk to road users including bus users may increase.

The results can be easily extrapolated to other Indian cities also. Improving NMT in all cities will result in CO_2 benefits as well as improved safety. PT improvement in cities will result in increased share of bus trips. Since, most of the trips will shift from MTW, overall CO_2 emissions will reduce. However, risk to bus users and other road users will increase; therefore PT improvement strategy must include development of safe dedicated lanes for buses and safe road crossing facilities for bus commuters.

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